## Instream Flow Standard Assessment Report

# Island of Hawaii
# Hydrologic Units 8161
# Waikoloa

**December 2023** **DRAFT PR-2023-02**



**State of Hawaii**
**Department of Land and Natural Resources**
**Commission on Water Resource Management**

COVER
Satallite image of Waikoloa hydrologic unit with Waikoloa Stream flowing into the Pacific Ocean, Hawaii [Google Earth, 2023].

Note: This report is intended for both print and electronic dissemination and does not include diacritical marks in spelling of Hawaiian words, names, and place names due to problems associated with its use electronically. However, Commission staff has made attempts to include diacritical marks in direct quotations to preserve accuracy.

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# Acronyms and Abbreviations

| | |
|---|---|
| AG | agricultural |
| ALISH | Agricultural Lands of Importance to the State of Hawaii |
| ALUM | agricultural land use maps [prepared by HDOA] |
| BFQ | base flow statistics |
| BLNR | Board of Land and Natural Resources (State of Hawaii) |
| C-CAP | Coastal Change Analysis Program |
| cfs | cubic feet per second |
| Code | State Water Code (State of Hawaii) |
| COM | commercial |
| Commission | Commission on Water Resource Management (DLNR) |
| CPRC | Compilation of Public Review Comments (PR-2008-07, CWRM |
| CWA | Clean Water Act (EPA) |
| CWRM | Commission on Water Resource Management (State of Hawaii) |
| DAR | Division of Aquatic Resources (State of Hawaii) |
| DHHL | Department of Hawaiian Home Lands (State of Hawaii) |
| DLNR | Department of Land and Natural Resources (State of Hawaii) |
| DOH | Department of Health (State of Hawaii) |
| HiDWS | Hawaii Department of Water Supply (County of Hawaii) |
| EA | Environmental Assessment |
| EIS | Environmental Impact Statement |
| EPA | United States Environmental Protection Agency |
| FEMA | Federal Emergency Management Agency (Department of Homeland Security) |
| FILEREF | File Reference [in the Commission's records of registered diversions] |
| ft | feet |
| gad | gallons per acre per day |
| GIS | Geographic Information Systems |
| G.L. | Government Lease |
| GOV | government |
| gpm | gallons per minute |
| Gr. | Grant |
| HAR | Hawaii Administrative Rules |
| HDOA | State Department of Agriculture (State of Hawaii) |
| HI-GAP | Hawaii Gap Analysis Program |
| HOT | hotel |
| HSA | Hawaii Stream Assessment |
| IFS | instream flow standard |
| IFSAR | Instream Flow Standard Assessment Report |
| IND | industry |
| IRR | irrigation requirements |
| IWREDSS | Irrigation Water Requirement Estimation Decision Support System |
| KAA | Kekaha Agriculture Association |
| KIUC | Kauai Island Utility Cooperative |
| LCA | Land Commission Award |
| LUC | Land Use Commission (State of Hawaii) |
| HECO | Hawaiian Electric Company |
| MF | multi-family residential |
| mgd | million gallons per day |
| Mgal/d | million gallons per day |
| mi | mile |
| MOU | Memorandum of Understanding |
| na | not available |
| NAWQA | National Water Quality Assessment (USGS) |

| | |
|---|---|
| NHLC | Native Hawaiian Legal Corporation |
| NIR | net irrigation requirements |
| NPDES | National Pollutant Discharge Elimination System |
| NPV | Net Present Value |
| NRCS | Natural Resource Conservation Service (USDA) |
| NVCS | National Vegetation Classification System |
| por. | Portion |
| REL | religious |
| RMT | R.M. Towill Corporation |
| SCS | Soil Conservation Service (United States Department of Agriculture) |
| | Note: The SCS is now called the Natural Resources Conservation Service (NRCS) |
| SF | single family residential |
| SPI | Standardized Precipitation Index |
| sq mi | square miles |
| TFQ | total flow statistics |
| $TFQ_{50}$ | 50 percent exceedence probability |
| $TFQ_{90}$ | 90 percent exceedence probability |
| TMDL | Total Maximum Daily Load |
| TMK | Tax Map Key |
| UHERO | University of Hawaii's Economic Research Organization |
| USDA | United States Department of Agriculture |
| USFWS | United States Fish and Wildlife Service (Department of the Interior) |
| USGS | United States Geological Survey (Department of the Interior) |
| WQS | Water Quality Standards |
| WRPP | Water Resource Protection Plan (Commission on Water Resource Management) |
| WTF | water treatment facility |

# 1.0 Introduction

## General Overview

The surface water hydrologic unit of Waikoloa, in the district of South Kohala on Hawaiʻi Island, lies primarily on the southwestern flank of the Kohala Volcano but also includes a region of the leeward flank of Mauna Kea (Figure 1-3). The perennially flowing streams in the Waikoloa watershed originate on the Kohala Mountain side of the hydrologic unit at an elevation of about 5320 ft. While a portion of Mauna Kea contributes to the 51.439 square miles surface area of the hydrologic unit, the limited rainfall and high porosity prevents runoff in this region from contributing to the surface water hydrology of Waikoloa. High elevation groundwater is found in small, perched water bodies on Kohala mountain, primarily at the interface between the eroded early phase Pololu and later phase Hāwī volcanics, but also above interbedded soil and ash deposits above the 4,000 feet elevation. Dike structures along rift zones support high elevation water in vertical reservoirs in Kohala Mountain and this contributes to discharge into the eastern streams of Kohala, where erosion or ditch tunnels have exposed these groundwater sources. Between the fault zones radiating southeast from Kohala is another high elevation aquifer confined by dike structures.

There are multiple perennially flowing streams in the Waikoloa hydrologic unit, Waikoloa and Kohakohau/Keanuiamano, which merge at approximately 1430 ft in elevation to form Waiʻulaʻula Stream, before flowing into the Pacific Ocean at Waiʻulaʻula Point (Figure 1-4). Both streams are diverted by Parker Ranch and Hawaiʻi County Department of Water Supply (Hawaiʻi DWS). The Parker Ranch non-potable water system diverts approximately 0.3 mgd of surface water for livestock while Hawaiʻi DWS diverts the remaining streamflow below intake capacity from Waikoloa and Kohakohau Stream at about 3470 ft elevation. At these elevations, Waikoloa Stream is 3.09 miles in length with a drainage area of 1.41 square miles, while Kohakohau Stream is 5.17 miles in length, with a drainage area of 2.42 square miles (Figures 1-5 and 1-6). The Hawaiʻi DWS and Parker Ranch stream diversions on Waikoloa Stream are located on Parker Ranch land, while both system diversions on Kohakohau Stream are located on land owned by the Department of Hawaiian Home Lands (DHHL). 12.6% of the Waikoloa hydrologic unit is managed for conservation by the State of Hawaiʻi Department of Land and Natural Resources (DLNR) in the Kohala Watershed and Mauna Kea forest reserves and the Puu O Umi Natural Area Reserve. Above the Hawaiʻi DWS intakes, 83.9% of the Waikoloa stream catchment and 97.4% of the Kohākōhau Stream catchment are owned by the State of Hawaiʻi and managed by DLNR and/or DHHL. Waikoloa, Kohākōhau/Keanuiomano, and Waiʻulaʻula streams would flow perennially mauka to makai 100% of the time if low flows weren't diverted at upper elevations.

Multiple state highways can be found traversing the unit (Figure 1-7). The Lalamilo agricultural complex along Waikoloa Stream west of present-day Waimea Town Center near the Kawaihae-Waimea Road, supported a large population of Hawaiians who relied on both wetland and dryland agriculture utilizing a complex system of irrigation ditches. Many of the historic auwai, terraces, and home sites are still visible across the landscape. Below the 800 ft elevation, archeological remains document extensive agricultural utilization of the land along Waikoloa Stream. The Waikoloa hydrologic unit includes all or parts of multiple ahupuaʻa including Paauhau-makua, Puukapu, Keoniki, Kauniho, Wa, Lanikepu, Ouli, Momoualoa, Pauahi, Waimea, Waikoloa, Lalamilo, Keanuiomano. There is much interest in restoring recreational and aesthetic access along Waikoloa Stream near Waimea Town, implementing watershed management practices to reduce sediment loading in the near-shore environment, and restoring traditional agricultural practices in the Lalamilo area. The hydrologic unit spans parts of the Waimea-PuuAnahulu, Waimea-Kohala, Waikoloa-South Kohala, and Kawaihae-Anaehoomalu census tracts with a combined population of 21,988. In addition to the two surface water sources, the Hawaiʻi DWS South Kohala public water system includes two high elevation wells, the Waimea Deepwell (well 6240-002) and the

Parker Deepwell (well 6239-002). From 2013 to 2022, the Waimea Deepwell was utilized 23% of the time while the Parker Deepwell was utilized 36% of the time.

## Current Instream Flow Standard

The current interim instream flow standard (IFS) for Waikoloa Stream was established by way of Hawaiʻi Administrative Rules (HAR) §13-169-46, which, in pertinent part, reads as follows:

> Interim instream flow standard for Hawaiʻi. The Interim Instream Flow Standard for all streams on Hawaiʻi, as adopted by the commission on water resource management on June 15, 1988, shall be that amount of water flowing in each stream on the effective date of this standard, and as that flow may naturally vary throughout the year and from year to year without further amounts of water being diverted offstream through new or expanded diversions, and under the stream conditions existing on the effective date of the standard.

The current interim IFS became effective on October 8, 1988. Streamflow was not measured on that date; therefore, the current interim IFS is not a quantifiable value.

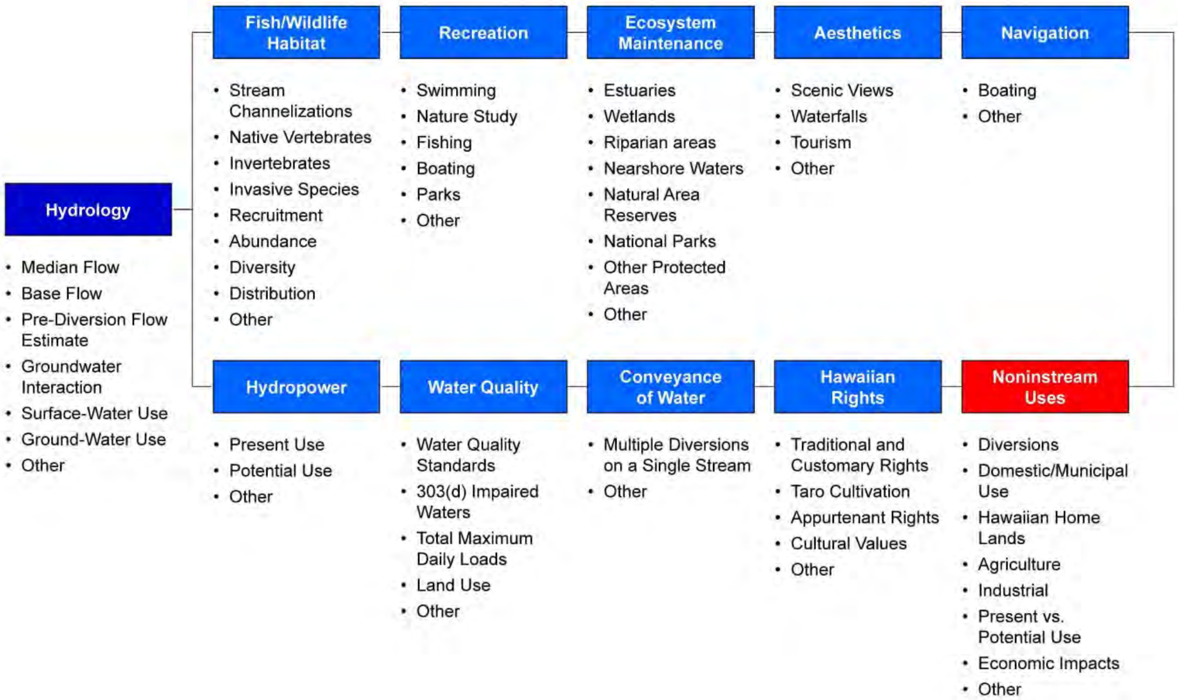
## Instream Flow Standards

Under the State Water Code (Code), Chapter 174C, Hawaii Revised Statutes (HRS), the Commission on Water Resource Management (Commission) has the responsibility of establishing IFS on a stream-by-stream basis whenever necessary to protect the public interest in the waters of the State. Early in its history, the Commission recognized the complexity of establishing IFS for the State's estimated 376 perennial streams and instead set interim IFS at "status quo" levels. These interim IFS were defined as the amount of water flowing in each stream (with consideration for the natural variability in stream flow and conditions) at the time the administrative rules governing them were adopted in 1988 and 1989.

The Hawaiʻi Supreme Court, upon reviewing the Waiahole Ditch Contested Case Decision and Order, held that such "status quo" interim IFS were not adequate to protect streams and required the Commission to take immediate steps to assess stream flow characteristics and develop quantitative interim IFS for affected Windward Oʻahu streams, as well as other streams statewide. The Hawaiʻi Supreme Court also emphasized that "instream flow standards serve as the primary mechanism by which the Commission is to discharge its duty to protect and promote the entire range of public trust purposes dependent upon instream flows."

To the casual observer, IFS may appear relatively simple to establish upon a basic review of the Code provisions. However, the complex nature of IFS becomes apparent upon further review of the individual components that comprise surface water hydrology, instream uses, noninstream uses, and their interrelationships. The Commission has the distinct responsibility of weighing competing uses for a limited resource in a legal realm that is continuing to evolve. The following illustration (Figure 1-1) was developed to illustrate the wide range of information, in relation to hydrology, instream uses, and noninstream uses that should be addressed in conducting a comprehensive IFS assessment.

Figure 1-1. Information to consider in setting measurable instream flow standards.




## Interim Instream Flow Standard Process

The Code provides for a process to amend an interim IFS in order to protect the public interest pending the establishment of a permanent IFS. The Code, at §174C-71(2), describes this process including the role of the Commission to "weigh the importance of the present or potential instream values with the importance of the present or potential uses of water for noninstream purposes, including the economic impact of restricting such uses."

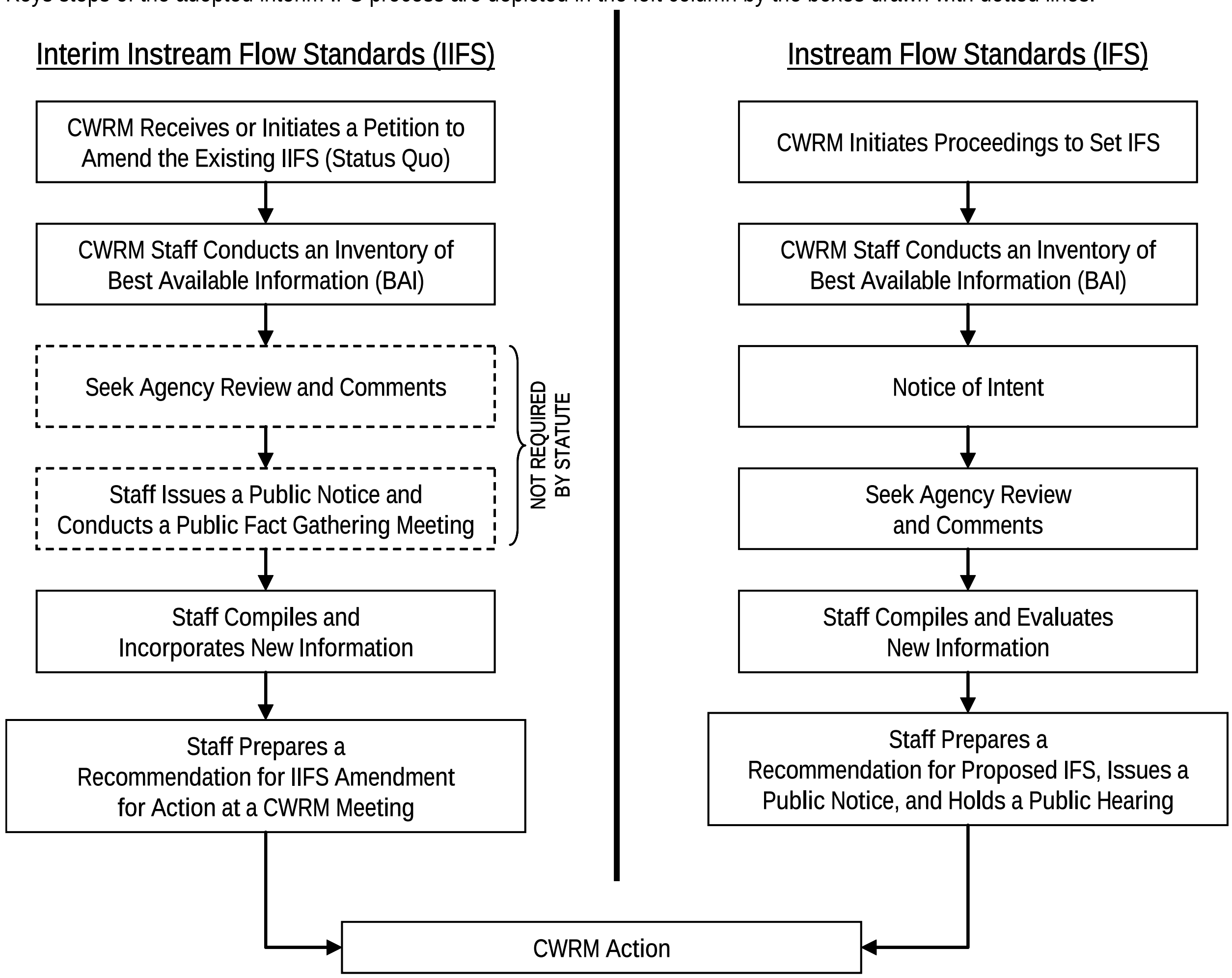
Recognizing the complexity of establishing measurable IFS, while cognizant of the Hawaii Supreme Court's mandate to designate interim IFS based on best available information under the Waiahole Combined Contested Case, the Commission at its December 13, 2006 meeting authorized staff to initiate and conduct public fact gathering. Under this adopted process (reflected in the left column of Figure 1-2), the Commission staff will conduct a preliminary inventory of best available information upon receipt of a petition to amend an existing interim IFS. The Commission staff shall then seek agency review and comments on the compiled information (compiled in an Instream Flow Standard Assessment Report) in conjunction with issuing a public notice for a public fact gathering meeting. Shortly thereafter (generally within 30 days), the Commission staff will conduct a public fact gathering meeting in, or near, the hydrologic unit of interest.

## Instream Flow Standard Assessment Report

The Instream Flow Standard Assessment Report (IFSAR) is a compilation of the hydrology, instream uses, and noninstream uses related to a specific stream and its respective surface water hydrologic unit. The report is organized in much the same way as the elements of IFS are depicted in Figure 1-1. The purpose of the IFSAR is to present the best available information for a given hydrologic unit. This information is used to determine the interim IFS recommendations, which is compiled as a separate report. The IFSAR is intended to act as a living document that should be updated and revised as necessary, thus also serving as a stand-alone document in the event that the Commission receives a subsequent petition solely for the respective hydrologic unit.

Each report begins with an introduction of the subject hydrologic unit and the current IFS status. Section 2.0 is comprised of the various hydrologic unit characteristics that, both directly and indirectly, impact surface water resources. Section 3.0 contains a summary of available hydrologic information, while Sections 4.0 through 12.0 summarize the best available information for the nine instream uses as defined by the Code. Section 13.0 describes public trust uses of water not covered in other sections. Noninstream uses are summarized in Section 14.0. Maps are provided at the end of each section to help illustrate information presented within the section's text or tables. Finally, Section 15.0 provides a comprehensive listing of cited references and is intended to offer readers the opportunity to review IFSAR references in further detail.

Figure 1-2. Simplified representation of the interim instream flow standard and permanent instream flow standard processes. Keys steps of the adopted interim IFS process are depicted in the left column by the boxes drawn with dotted lines.




An important component of the IFSAR and the interim IFS process is the Compilation of Public Review Comments (CPRC). The CPRC serves as a supporting document containing the oral and written comments that are submitted as part of the initial public review process. Comments referred to within the IFSAR will identify both the section and page number where the original comment can be located in the CPRC. For example, a reference to "8.0-3" indicates the third page of comments in Section 8.0 of the CPRC.

Following the preparation of the IFSAR and initial agency and public review, information may be added to the IFSAR at any time. Dates of revision will be reflected as such. Future review of the IFSAR, by agencies and the public, will only be sought when a new petition to amend the interim (or permanent) instream flow standard is pending. Recommendations for IFS amendments are prepared separately as a stand-alone document. Thus, the IFSAR acts solely as a compendium of best available information and may be revised further without the need for subsequent public review following its initial preparation.

## Surface Water Hydrologic Units

Early efforts to update the Commission's Water Resource Protection Plan (WRPP) highlighted the need for surface water hydrologic units to delineate and codify Hawaii's surface water resources. Surface water hydrologic units served as an important first-step towards improving the organization and management of surface water information that the Commission collects and maintains, including diversions, stream channel alterations, and water use.

In developing the surface water hydrologic units, the Commission staff reviewed various reports to arrive at a coding system that could meet the requirements for organizing and managing surface water information in a database environment and could be easily understood by the general public and other agencies. For all intents and purposes, surface water hydrologic units are synonymous with watershed areas. Though Commission staff recognized that while instream uses may generally fall within a true surface drainage area, noninstream uses tend to be land-based and therefore may not always fall within the same drainage area.

In June 2005, the Commission adopted the report on surface water hydrologic units and authorized staff to implement its use in the development of information databases in support of establishing IFS (State of Hawaii, Commission on Water Resource Management, 2005a). The result is a surface water hydrologic unit code that is a unique combination of four digits. This code appears on the cover of each IFSAR above the hydrologic unit name.

## Surface Water Definitions

Listed below are the most commonly referenced surface water terms as defined by the Code.

Agricultural use. The use of water for the growing, processing, and treating of crops, livestock, aquatic plants and animals, and ornamental flowers and similar foliage.

Channel alteration. (1) To obstruct, diminish, destroy, modify, or relocate a stream channel; (2) To change the direction of flow of water in a stream channel; (3) To place any material or structures in a stream channel; and (4) To remove any material or structures from a stream channel.

Continuous flowing water. A sufficient flow of water that could provide for migration and movement of fish, and includes those reaches of streams which, in their natural state, normally go dry seasonally at the location of the proposed alteration.

Domestic use. Any use of water for individual personal needs and for household purposes such as drinking, bathing, heating, cooking, noncommercial gardening, and sanitation.

Ground water. Any water found beneath the surface of the earth, whether in perched supply, dike-confined, flowing, or percolating in underground channels or streams, under artesian pressure or not, or otherwise.

Hydrologic unit. A surface drainage area or a ground water basin or a combination of the two.

Impoundment. Any lake, reservoir, pond, or other containment of surface water occupying a bed or depression in the earth's surface and having a discernible shoreline.

Instream Flow Standard. A quantity of flow of water or depth of water which is required to be present at a specific location in a stream system at certain specified times of the year to protect fishery, wildlife, recreational, aesthetic, scenic, and other beneficial instream uses.

Instream use. Beneficial uses of stream water for significant purposes which are located in the stream and which are achieved by leaving the water in the stream. Instream uses include, but are not limited to:

(1) Maintenance of fish and wildlife habitats;
(2) Outdoor recreational activities;
(3) Maintenance of ecosystems such as estuaries, wetlands, and stream vegetation;
(4) Aesthetic values such as waterfalls and scenic waterways;
(5) Navigation;
(6) Instream hydropower generation;
(7) Maintenance of water quality;
(8) The conveyance of irrigation and domestic water supplies to downstream points of diversion; and
(9) The protection of traditional and customary Hawaiian rights.

Interim instream flow standard. A temporary instream flow standard of immediate applicability, adopted by the Commission without the necessity of a public hearing, and terminating upon the establishment of an instream flow standard.

Municipal use. The domestic, industrial, and commercial use of water through public services available to persons of a county for the promotion and protection of their health, comfort, and safety, for the protection of property from fire, and for the purposes listed under the term "domestic use."

Noninstream use. The use of stream water that is diverted or removed from its stream channel and includes the use of stream water outside of the channel for domestic, agricultural, and industrial purposes.

Reasonable-beneficial use. The use of water in such a quantity as is necessary for economic and efficient utilization, for a purpose, and in a manner which is both reasonable and consistent with the state and county land use plans and the public interest.

Stream. Any river, creek, slough, or natural watercourse in which water usually flows in a defined bed or channel. It is not essential that the flowing be uniform or uninterrupted. The fact that some parts of the bed or channel have been dredged or improved does not prevent the watercourse from being a stream.

Stream channel. A natural or artificial watercourse with a definite bed and banks which periodically or continuously contains flowing water. The channel referred to is that which exists at the present time, regardless of where the channel may have been located at any time in the past.

Stream diversion. The act of removing water from a stream into a channel, pipeline, or other conduit.

Stream reach. A segment of a stream channel having a defined upstream and downstream point.

Stream system. The aggregate of water features comprising or associated with a stream, including the stream itself and its tributaries, headwaters, ponds, wetlands, and estuary.

Surface water. Both contained surface water--that is, water upon the surface of the earth in bounds created naturally or artificially including, but not limited to, streams, other watercourses, lakes, reservoirs, and coastal waters subject to state jurisdiction--and diffused surface water--that is, water occurring upon the surface of the ground other than in contained water bodies. Water from natural springs is surface water when it exits from the spring onto the earth's surface.

Sustainable yield. The maximum rate at which water may be withdrawn from a water source without impairing the utility or quality of the water source as determined by the Commission.

Time of withdrawal or diversion. In view of the nature, manner, and purposes of a reasonable and beneficial use of water, the most accurate method of describing the time when the water is withdrawn or diverted, including description in terms of hours, days, weeks, months, or physical, operational, or other conditions.

Watercourse. A stream and any canal, ditch, or other artificial watercourse in which water usually flows in a defined bed or channel. It is not essential that the flowing be uniform or uninterrupted.

Figure 1-3. Satellite imagery of the Waikoloa hydrologic unit and streams in South Kohala, Hawai'i.

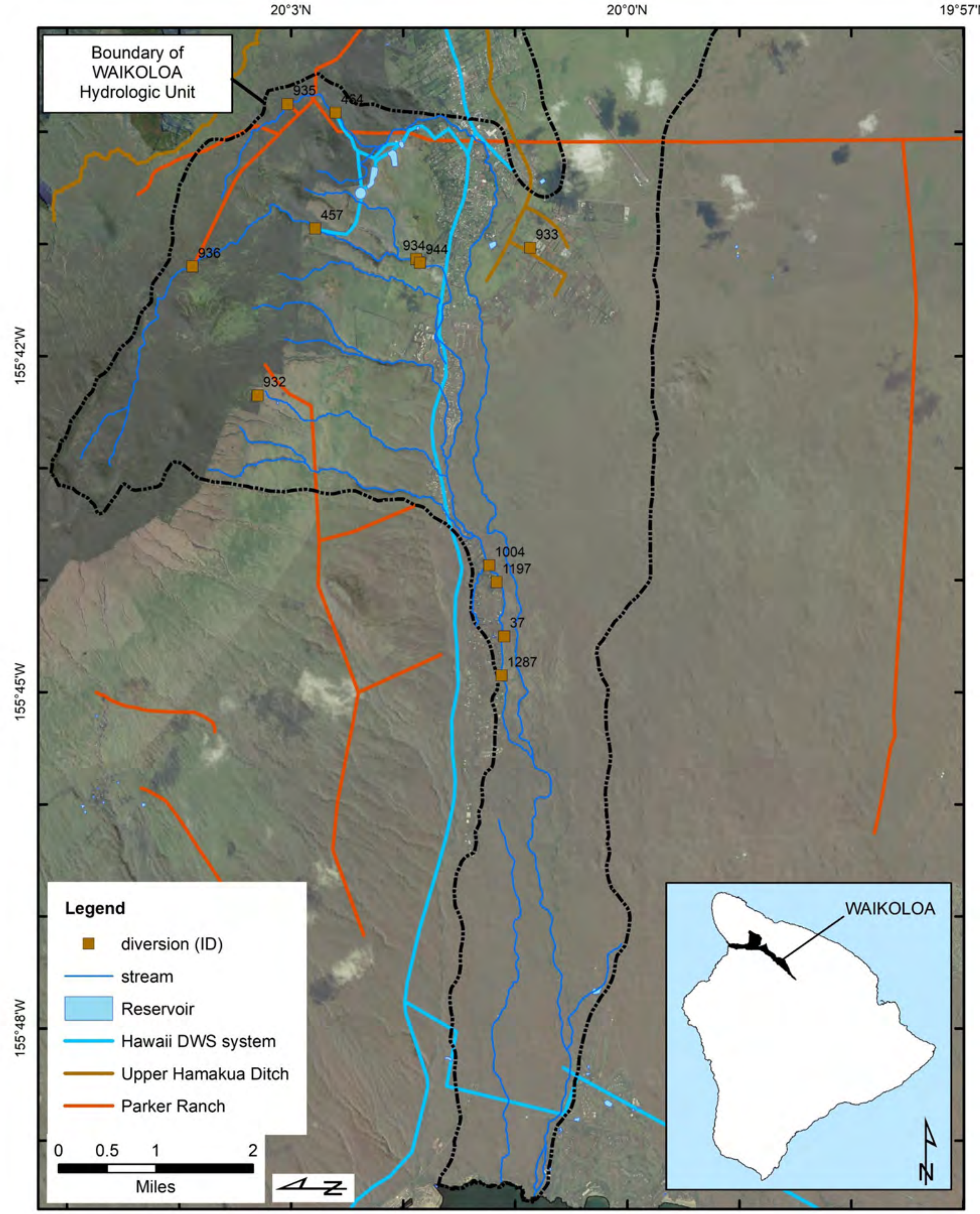


Figure 1-4. Elevation range of the Waikoloa hydrologic unit, Hawaiʻi. (U.S. Geological Survey, 2001)

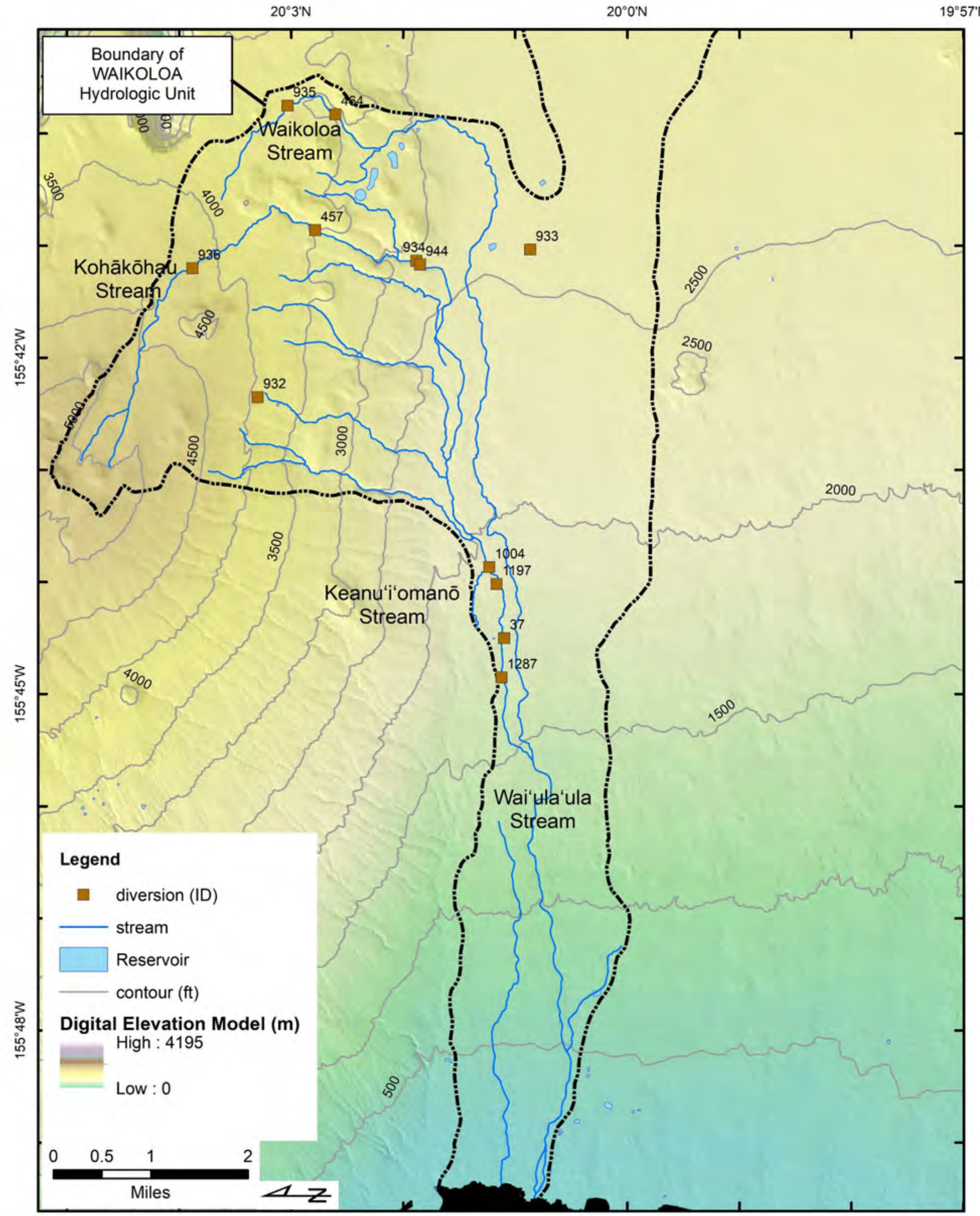


Figure 1-5. USGS topographic map of Waikoloa hydrologic unit, Hawai'i. (Source: U.S. Geological Survey, 1996)

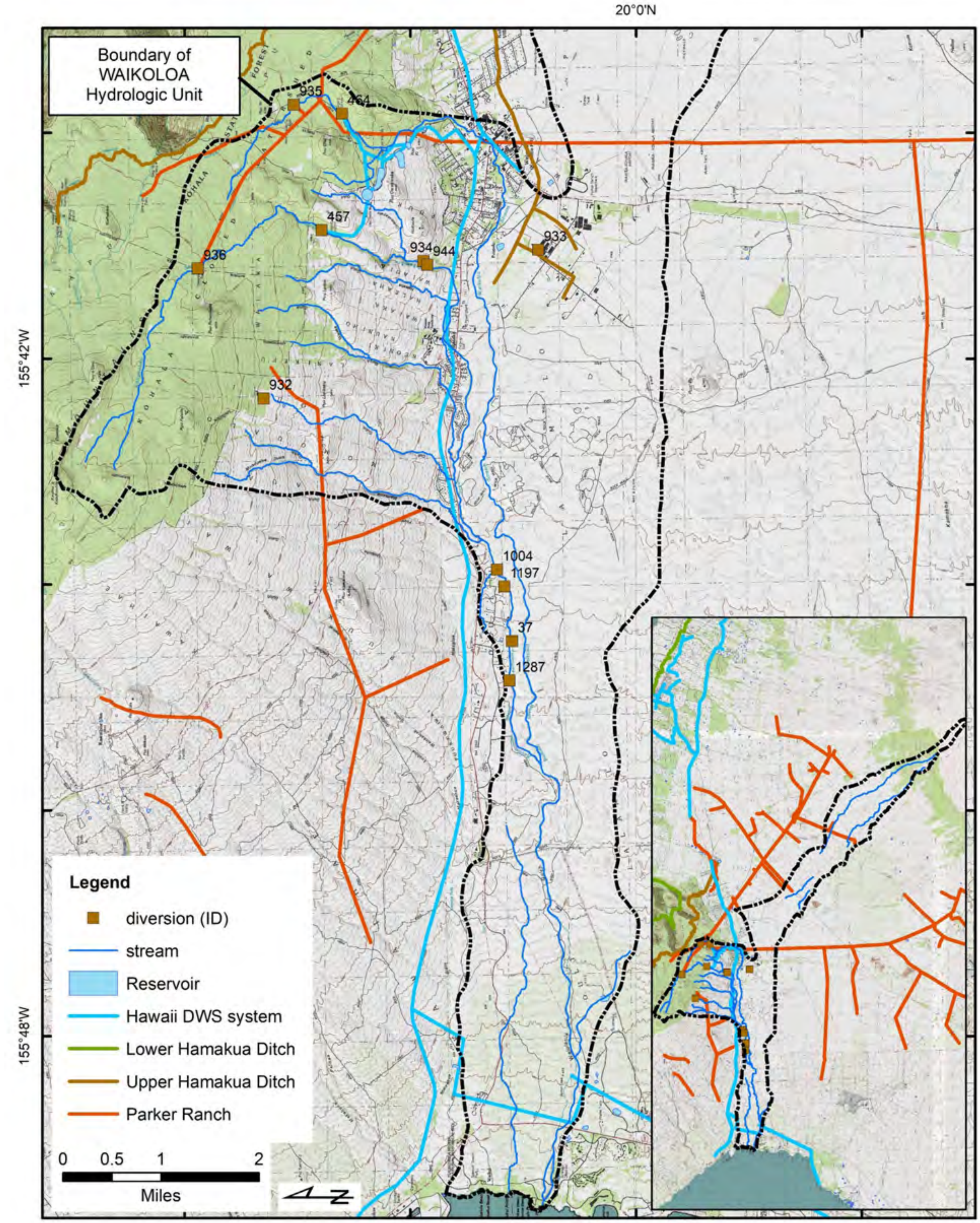


Figure 1-6. Sub-catchments of the Waikoloa hydrologic unit, Hawai'i. (Source: U.S. Geological Survey, 1996)

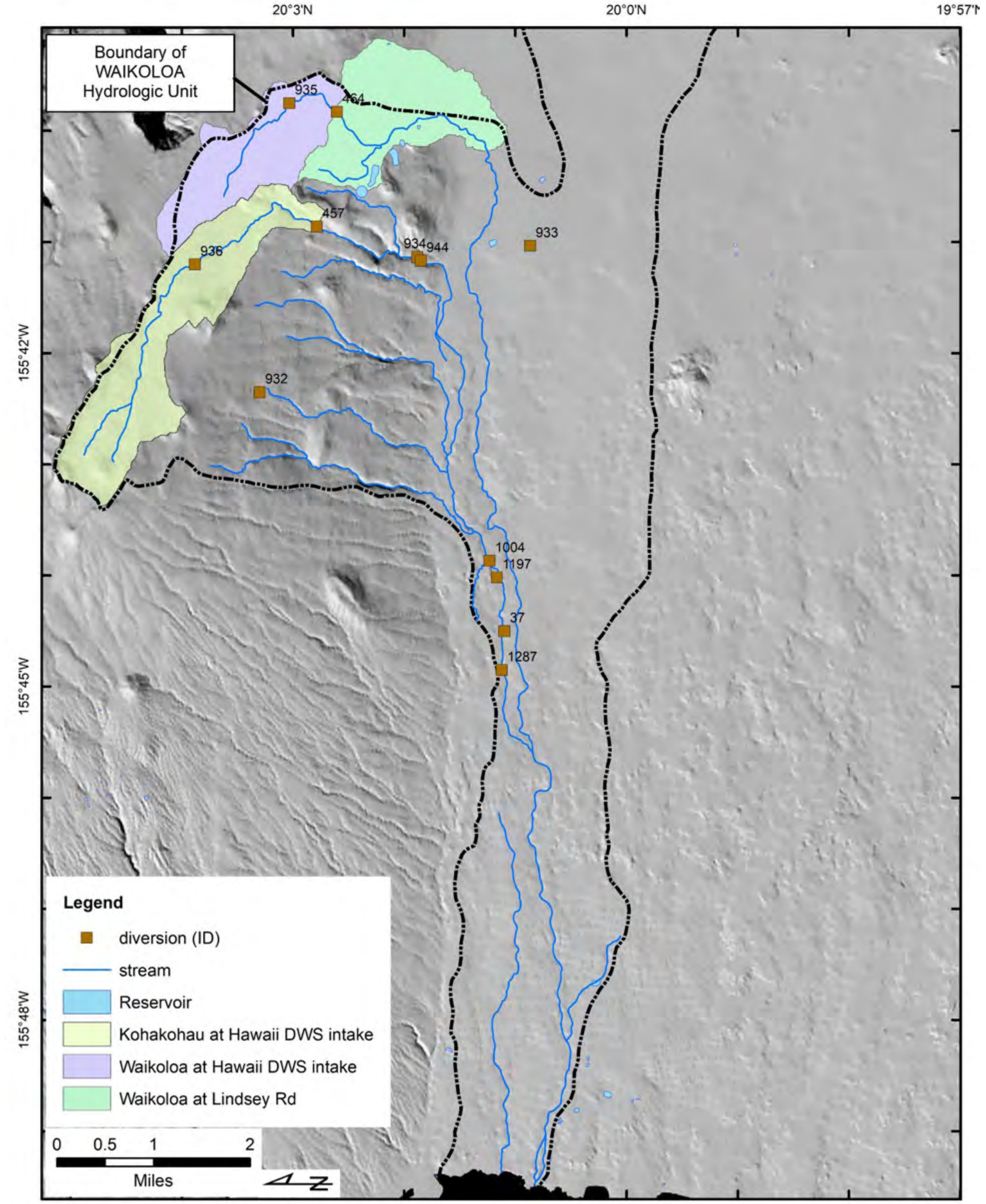
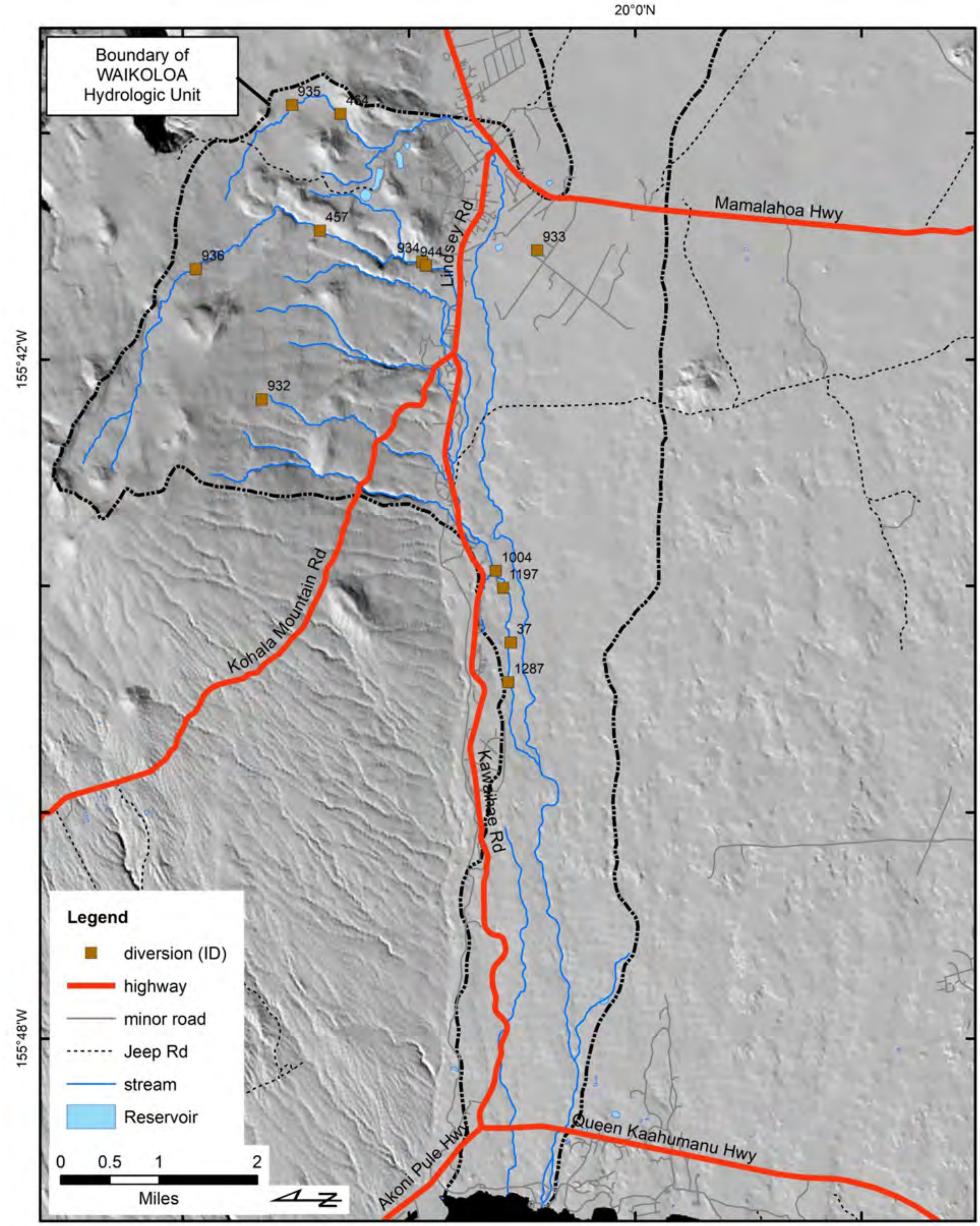


Figure 1-7. Major and minor roads for the Waikoloa hydrologic unit, Hawaiʻi. (Source: State of Hawaii, Office of Planning 2020)



# 2.0 Unit Characteristics

## Geology

The Waikoloa hydrologic unit spans two volcanos, the Kohala and Mauna Kea, and therefore the underlying geology is a complex integration of both. The bulk of Kohala volcano is formed by thin shield-stage basalt lava flows of the Pololū Volcanics. The lava flows on Kohala erupted from two prominent rift zones extending to the northwest and southeast, and possibly from a summit caldera (Izuka et al. 2015). Gravity data show that Kohala volcano has positive anomalies that are consistent with the presence of dense magma-chamber cumulates and zones of dike intrusion associated with calderas (Kauahikaua et al., 2000). The shield-building stage is estimated to have started about 1 million years ago and lasted to about 0.25 million years ago and consists mostly of lava flows of the Pololū Volcanics (Sherrod et al., 2007). Overlying the Pololū Volcanics is the Hāwī Volcanics, which consists of postshield alkalic rocks ranging from basanite to trachyte (Sherrod et al., 2007). The postshield stage produced thicker lava flows and tephra cones that partly covered the Pololū Volcanics. The Pololū Volcanics and the Hāwī Volcanics are separated by an erosional unconformity that formed during a hiatus in volcanism (Stearns and Macdonald, 1946).

The lowermost volcanic rocks exposed above sea level on Mauna Kea are known as the Hāmākua Volcanics (Stearns and Macdonald, 1946) and Izuka et al. (2015) uses the term in the broader sense, inclusive of both shield- and postshield-stage basalts since the distinction is of geochemistry and does not impact hydrogeology. The Laupāhoehoe Volcanics are part of the post-shield stage that forms a thin (relatively speaking) layer 10s of feet to less than a few hundred feet thick. In some places there is an unconformity separating the Laupāhoehoe Volcanics from the underlying Hāmākua Volcanics (Stearns and Macdonald, 1946). Lava flows of the Laupāhoehoe Volcanics are generally thicker than those of the Hāmākua Volcanics, and some form small hills or domes, consistent with the more viscous nature of postshield-stage lava (Izuka et al., 2015). Discontinuous layers of ash and soil occur on top of the lava flows as well as interbedded between some lava flows. The generalized surface geology of the Waikoloa hydrologic unit is depicted in Figure 2-1 and summarized in Table 2-1.

A prominent feature of the Waimea region is the Waimea Plataeu; a large flat region of land formed as fast moving lava from Mauna Kea slowed down and colled upon encountering the older Kohala Mountain. While most of the unit is composed of the Hāmākua and Laupāhoehoe volcanics, the perennial streams originating on Kohala Mountain derived from Hāwī and Pololū Volcanics.

Table 2-1. Area and percentage of surface geologic features for Waikoloa hydrologic unit. (Source: Sherrod et al, 2007)

| Name | Rock Type | Lithology | Age Range (kya) | Area (mi$^2$) | Percent of Unit |
|---|---|---|---|---|---|
| Hāmākua Volcanics | Lave flows, scoria cones | Coarse near-vent fallout | 64-300 | 24.058 | 46.8% |
| Laupāhoehoe Volcanics | Lava flows, tephra deposits, scoria cones | Coarse near-vent cinder | 11-64 | 15.622 | 30.4% |
| Hāwī Volcanics | Lava flows, scoria cones | Generally blocky lava, coarse near-vent cinder | 120-260 | 9.779 | 19.0% |
| Pololū Volcanics | Lava flows | Pahoehoe and aʻa | 260-500 | 1.876 | 3.6% |
| Alluvium | Sand and gravel | | | 0.104 | 0.2% |

## Soils

The U.S. Department of Agriculture's Natural Resources Conservation Service (formerly known as the Soil Conservation Service) divides soils into hydrologic soil groups (A, B, C, and D) according to the rate at which infiltration (intake of water) occurs when the soil is wet. The higher the infiltration rate, the faster the water is absorbed into the ground and the less there is to flow as surface runoff. Group A soils have the highest infiltration rates; group D soils have the lowest. In the Waikoloa hydrologic unit, soils are dominated by the Kemole, Puu Pa, and Waimea series, with many other series contributing less than 7% of the hydrologic unit (Table 2-2). Soils in the hydrologic unit are primarily distributed withing Group B and Group D, although a number of soils are not identified within specific soil hydrologic groups. The soil orders for the Waikoloa hydrologic unit are identified in Figure 2-2.

Waikoloa consists largely of soils that are permeable, except for parts of the mauka section of the hydrologic unit. In that section, some areas are poorly drained, meaning that water does not move quickly through the soil and the soil remains wet for long periods. Along the streams, the soils are mixed. Much of the remainder of the hydrologic unit consists of well-drained soils; thus allowing rainwater to feed both streams and groundwater. In the lower gradient regions, the soils transition to well-drained pu‘u pa, rock outcrop and Waikaloa soils.

Table 2-2. Area and percentage of soil types for the Waikoloa hydrologic unit, Hawaii. (Source: Soil Survey Saff, 2020)

| Soil Series Unit | Hydrologic Soil Group | Area (mi$^2$) | Percent (%) |
|---|---|---|---|
| Kemole | B | 12.002 | 23.3% |
| Pu‘u Pa | B | 8.212 | 16.0% |
| Waimea | B | 7.679 | 14.9% |
| Hapuna | | 5.081 | 9.9% |
| Kahua | D | 3.483 | 6.8% |
| Kahaumanu | | 3.113 | 6.1% |
| Amalu | D | 2.892 | 5.6% |
| Palapalai | B | 2.158 | 4.2% |
| Rock outcrop | | 2.034 | 4.0% |
| Pohakulehu | | 2.016 | 3.9% |
| Kikoni | B | 1.126 | 2.2% |
| Lava flows | | 1.088 | 2.1% |
| Rubble land | | 0.204 | 0.4% |
| Waikaloa | | 0.109 | 0.2% |
| Huikau | A | 0.105 | 0.2% |
| Waikui | | 0.069 | 0.1% |
| Water | | 0.033 | 0.1% |
| Kamakoa | A | 0.032 | 0.1% |
| Puako | | 0.001 | 0.0% |
| Hanipoe | B | 0.000 | 0.0% |

Figure 2-1. Generalized geology of the Waikoloa hydrologic unit, Hawaiʻi. (Source: Sherrod et al., 2007)

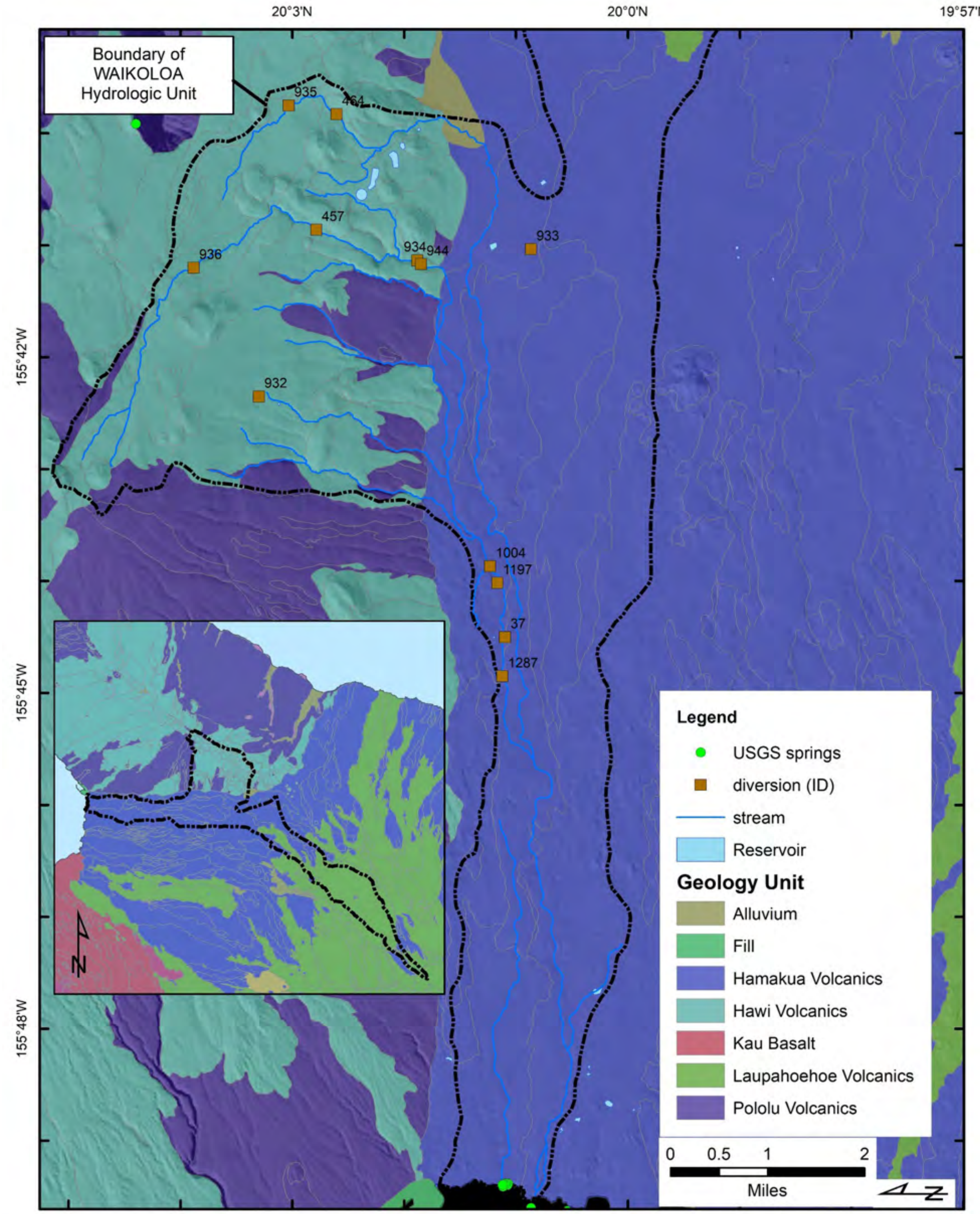
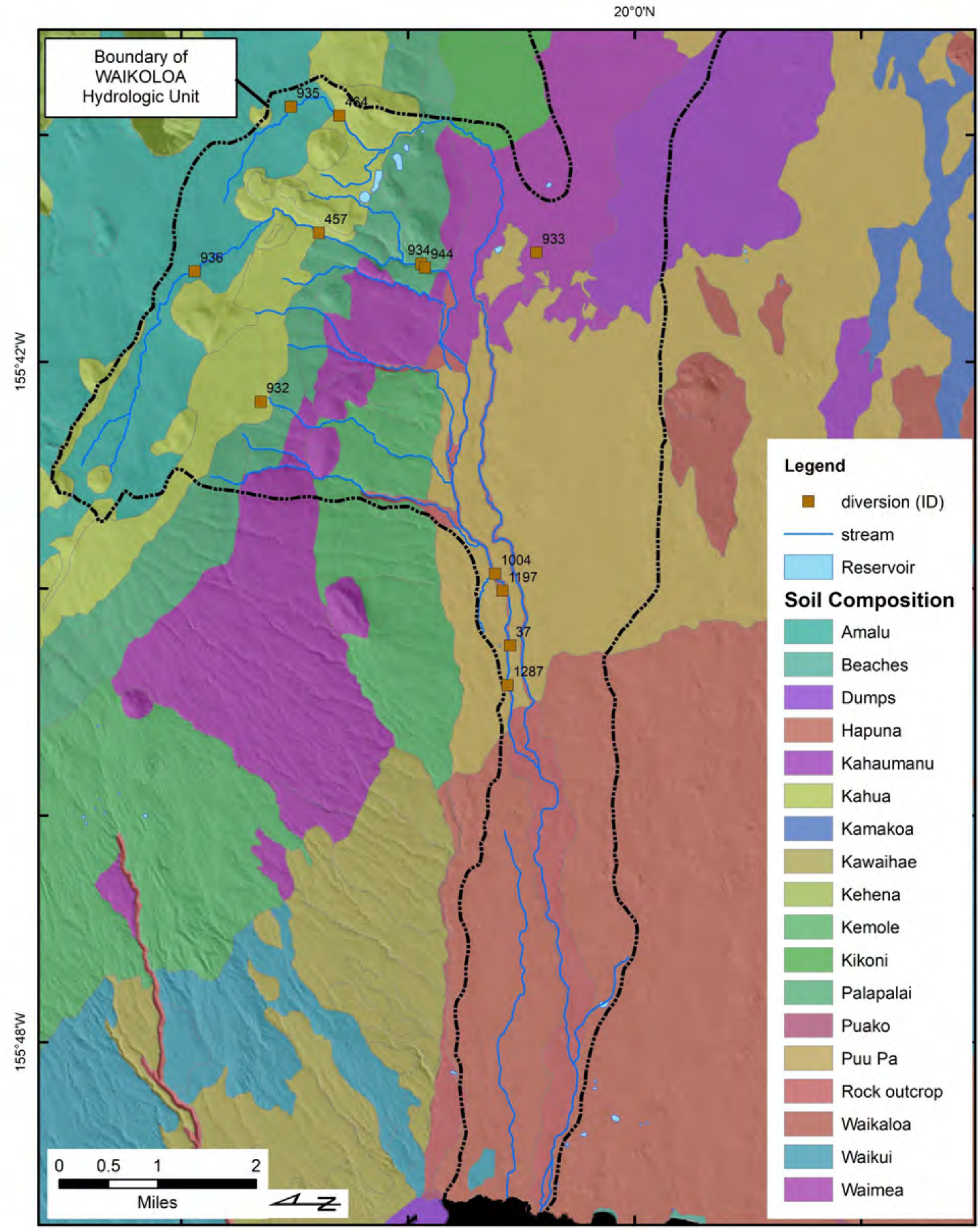


Figure 2-2. Soil order classification of the Waikoloa hydrologic unit, Hawaii. (Source: State of Hawaii, Office of Planning, 2015m)



## Rainfall

Mauna Kea, Mauna Loa, and Kohala are the driving forces affecting the distribution of rainfall on Hawai‘i, with rainfall affected by the orographic[1] effect and the rainshadow effect (Figure 2-3). Orographic precipitation occurs when the prevailing northeasterly trade winds lift warm air up the windward side of the mountains into higher elevations where cooler temperatures persist. As moist air cools, water condenses and the air mass releases precipitation. As a result, frequent and heavy rainfall is observed on the windward mountain slopes. The temperature inversion zone, the range of elevations where temperature increases with elevation, typically extends from 6,560 feet to 7,874 feet. This region is identified by a layer of moist air below and dry air above (Giambelluca and Nullet, 1992).

The fog drip zone on the windward side of islands extends from the cloud base level at about 2,000 feet to the lower limit of the most frequent temperature inversion base height at 6,560 feet (Giambelluca and Nullet, 1992). This zone occurs below the elevation where cloud height is restricted by the temperature inversion (Sholl et al., 2002). Fog drip is a result of cloud-water droplets impacting vegetation (Scholl et al., 2002) and can contribute significantly to groundwater recharge. Above the inversion zone, the air is dry and the sky is frequently clear (absence of clouds) with high solar radiation, creating an arid atmosphere with little rainfall. This region is found in the higher elevations of the largest volcanoes (e.g., Mauna Kea, Haleakala). A majority of the mountains in Hawai‘i, including Kohala Mountain, peak in the fog drip zone, where cloud-water is intercepted by vegetation. In such cases, air passes over the mountains, warming and drying while descending on the leeward mountain slopes. Mauna Kea, as the tallest peak (13,803 feet a.s.l) on Hawai‘i, influences the elevational distribution of moisture around the island. The steep gradient around the island forces moisture-laden air to rapidly rise in elevation (over 3,000 feet) in a short distance, resulting in a rapid release of rainfall. This results in a rain shadow effect on much of the Waikoloa hydrologic unit. However, the Kohala Mountain portions of the hydrologic unit receive relatively more annual rainfall annually than the rest of the unit.

The Waikoloa hydrologic unit is situated on the saddle between the leeward and windward sides of Mauna Kea and Kohala. Much of the upper elevation reaches on Kohala Mountain receives substantial orographic rainfall and fog drip, contributing to higher rainfall in the upper elevations (Figure 2-4). The lower reaches towards the west coast are much drier. The high spatial variability in rainfall is evident by the large variation in mean annual rainfall across the hydrologic unit. Above 2000 ft, rainfall is highest during the months of December, January, March, and April, where the mean monthly rainfall is approximately 48 inches (Table 2-3). Mean annual rainfall at Wamiea Parker Ranch Center (station 192, elevation 2750 feet, active 1891-1950) was 40.8 inches while just a few miles away, mean annual rainfall measured at Laulamilo Field Office (station 191.1; elevation 2620 feet; active from 1965-present) is 17.4 inches. The large differences in rainfall are apparent between the high elevations and the coastline by comparing the currently active Kamuela Upper station (station 192.7; 3112 feet; active from 1992-present) with a mean annual rainfall of 49.5 inches to the Pu‘ukohola Heiau station (station 98.1; 140 feet; active 1977-present) with a mean annual rainfall of 11.1 inches (Giambelluca et al., 2013).

Shade (1999) used the monthly fog drip to rainfall ratios for the windward slopes of Mauna Loa on the Island of Hawai‘i (Table 2-3) to calculate fog drip contribution to the water-budget in Kohala. The fog drip to rainfall ratios were estimated using: 1) the fog drip zone boundaries for Kohala (Giambelluca and Nullet, 1991); and 2) an illustration that shows the relationship between fog drip and rainfall for the windward slopes of Mauna Loa, Island of Hawai‘i (Juvik and Nullet, 1995). This method was used to determine the contribution of fog drip in the Waikoloa hydrologic unit, which is calculated by multiplying the same ratios to the monthly rainfall values in the fog drip zone based on Giambelluca et al. (2013). Calculations show that approximately 85 percent of Waikoloa (43.65 square miles) lies in the fog drip

[1] Orographic refers to influences of mountains and mountain ranges on airflow, but also used to describe effects on other meteorological quantities such as temperature, humidity, or precipitation distribution.

zone based on elevations greater than 2000 feet. The total contribution from fog drip to the water budget based on percent of fog drig from monthly rainfall is about 24 percent (12.9 inches out of 53.7 inches) of the upper (>2,000 ft) watershed, assuming the same ratios apply here (Table 2-3).

Figure 2-3. Orographic precipitation in the presence of mountains higher than 6,000 feet.

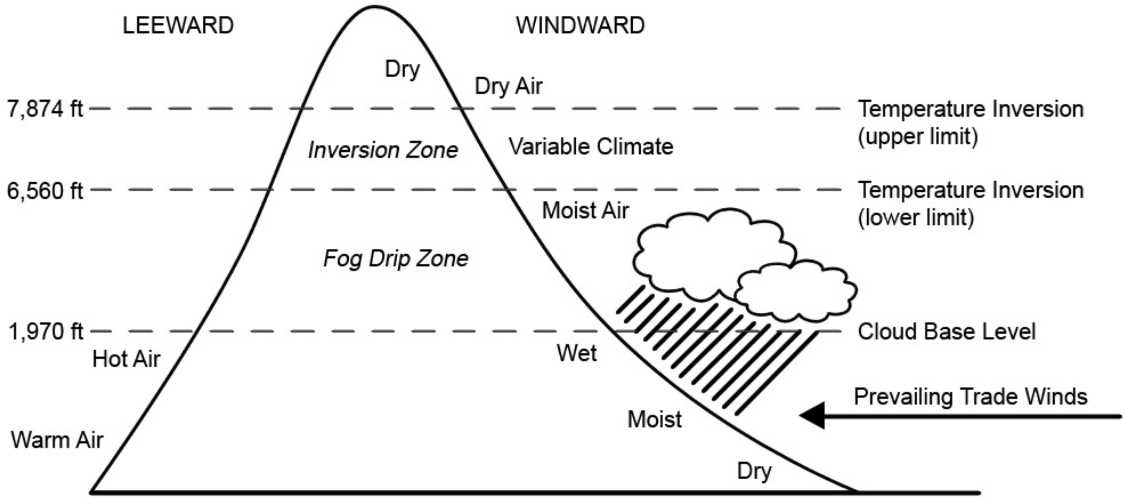



Table 2-3. Fog drip to rainfall ratios for the windward slopes of Mauna Loa on the island of Hawaii and approximate contributions to the Waikoloa hydrologic unit based on an elevation range of 2000-6000 feet and equivalent ratios.

| Month | Ratio (%) | Mean Rainfall (in) | Contribution (in) |
|---|---|---|---|
| January | 13 | 4.76 | 0.62 |
| February | 13 | 3.44 | 0.45 |
| March | 13 | 5.00 | 0.65 |
| April | 27 | 4.60 | 1.24 |
| May | 27 | 3.30 | 0.89 |
| June | 27 | 2.55 | 0.69 |
| July | 67 | 3.32 | 2.22 |
| August | 67 | 2.46 | 1.65 |
| September | 67 | 1.88 | 1.26 |
| October | 40 | 2.06 | 0.82 |
| November | 40 | 3.14 | 1.26 |
| December | 27 | 4.26 | 1.15 |

## Solar Radiation

Solar radiation is the sun's energy that arrives at the Earth's surface after considerable amounts have been absorbed by water vapor and gases in the Earth's atmosphere. The amount of solar radiation to reach the surface in a given area is dependent in part upon latitude and the sun's declination angle (angle from the sun to the equator), which is a function of the time of year. Hawaii's trade winds and the temperature inversion layer greatly affect solar radiation levels, the primary heat source for evaporation. High mountain ranges block moist trade-wind air flow and keep moisture beneath the inversion layer (Lau and Mink, 2006). As a result, windward slopes tend to be shaded by clouds and protected from solar radiation, while dry leeward areas receive a greater amount of solar radiation and thus have higher levels of evaporation.

## Evaporation

Evaporation is the loss of water to the atmosphere from soil surfaces and open water bodies (e.g. streams and lakes). Evaporation from plant surfaces (e.g. leaves, stems, flowers) is termed transpiration. Together, these two processes are commonly referred to as evapotranspiration, and it can significantly affect water yield because it determines the amount of rainfall lost to the atmosphere. On a global scale, the amount of water that evaporates is about the same as the amount of water that falls on Earth as precipitation. However, more water evaporates from the ocean whereas on land, rainfall often exceeds evaporation. The rate of evaporation is dependent on many climatic factors including solar radiation, albedo[2], rainfall, humidity, wind speed, surface temperature, and sensible heat advection[3]. Higher evaporation rates are generally associated with greater net radiation, high wind speed and surface temperature, and lower humidity.

A common approach to estimating evaporation is to employ a relationship between potential evaporation and the available water in the watershed. Potential evaporation is the maximum rate of evaporation if water is not a limiting factor, and it is often measured with evaporation pans. In Hawaii, pan evaporation measurements were generally made in the lower elevations of the drier leeward slopes where sugarcane was grown. These data have been compiled and mapped by Ekern and Chang (1985). Most of the drainage basins in Hawaiʻi are characterized by a relatively large portion of the rainfall leaving the basin as evaporation and the rest as streamflow (Ekern and Chang, 1985). Based on the available pan evaporation data for Hawaiʻi, evaporation generally decreases with increasing elevation below the temperature inversion[4] and the cloud layer (Figure 2-5). At low elevations near the coast, pan evaporation rates are influenced by sensible heat advection from the ocean (Nullet, 1987). Pan evaporation rates are enhanced in the winter by positive heat advection from the ocean, and the opposite occurs in the summer when pan evaporation rates are diminished by negative heat advection (Giambelluca and Nullet, 1992). With increasing distance from the windward coasts, positive heat advection from dry land surfaces becomes an important factor in determining the evaporative demand on the landscape (Nullet, 1987). Shade (1999, Fig. 9) estimated pan evaporation rates of 30 inches per year below 2,000 feet elevation to 90 inches per year near the coast. Within the cloud layer, evaporation rates are particularly low due to the low radiation and high humidity caused by fog drip. Pan evaporation rates dropped below 30 inches per year in this area as reported in Shade (1999, Fig. 9). Near the average height of the temperature inversion, evaporation rates are highly variable as they are mainly influenced by the movement of dry air from above and moist air from below (Nullet and Giambelluca, 1990). Above the inversion, clear sky and high solar radiation at the summit causes increased evaporation, with pan evaporation rates of about 50 to 70 inches per year (Shade, 1999, Fig. 9). For example, Ekern and Chang (1985) reported evaporation increased to 50 percent more than surface oceanic rates near the Mauna Kea crest on the island of Hawaiʻi. A common approach to estimating evaporation is to employ a relationship between potential evaporation and the available water in the watershed, estimated as potential evapotranspiration. Mean annual potential evapotranspiration in the Waikoloa hydrologic unit (Figure 2-6) averages 78.2 inches per year and ranges from 53.0 to 145.0 inches (Giambelluca et al. 2014). Annual actual evapotranspiration for the Waikoloa hydrologic unit ranges from 3.06 inches to 48.3 inches per year, with an average of 48.3 inches per year.

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[2] Albedo is the proportion of solar radiation that is reflected from the Earth, clouds, and atmosphere without heating the receiving surface.
[3] Sensible heat advection refers to the transfer of heat energy that causes the rise and fall in the air temperature.
[4] Temperature inversion is when temperature increases with elevation.

Figure 2-4. Mean annual rainfall in the Waikoloa hydrologic unit, Hawai'i. (Source: Giambelluca et al., 2013)

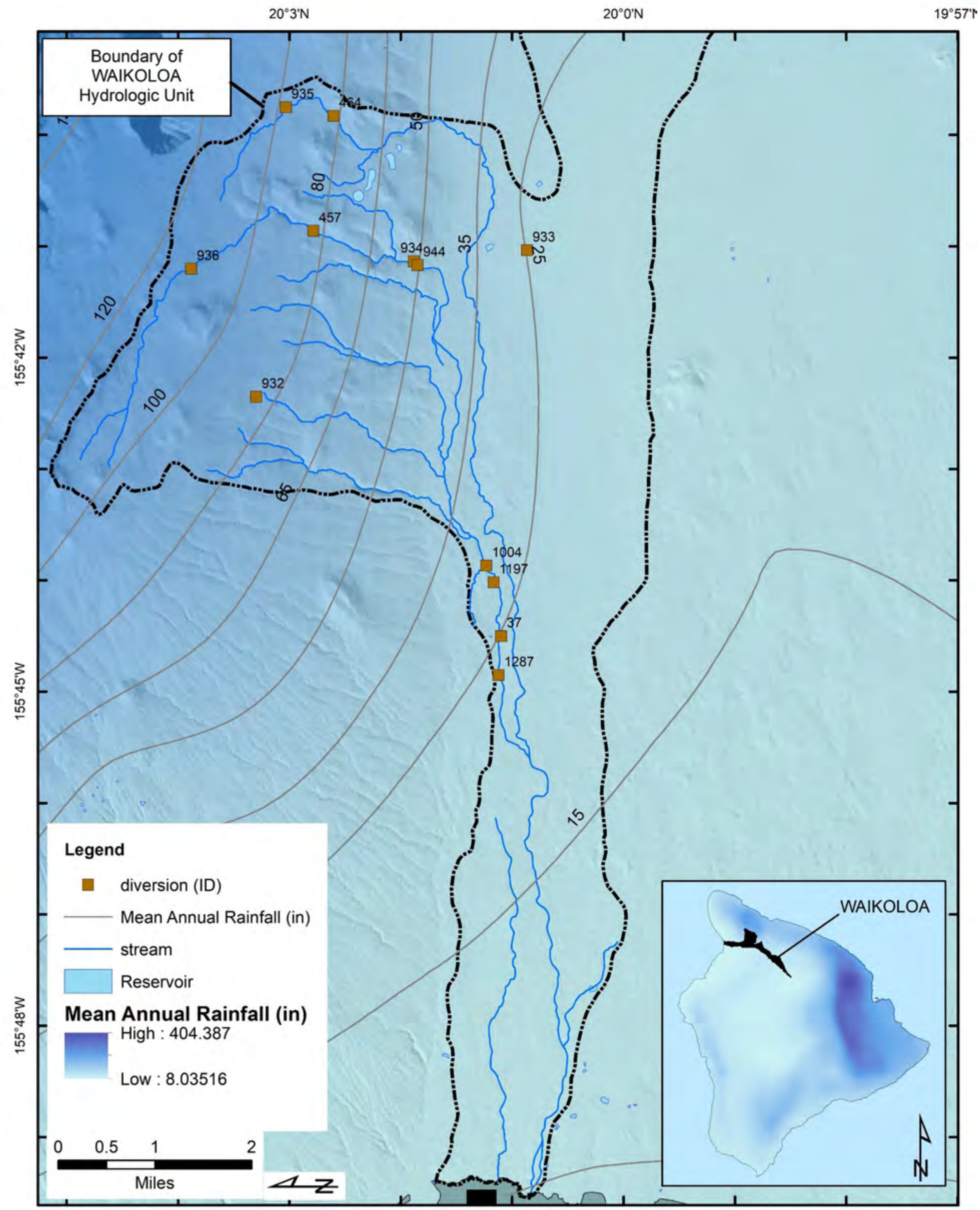
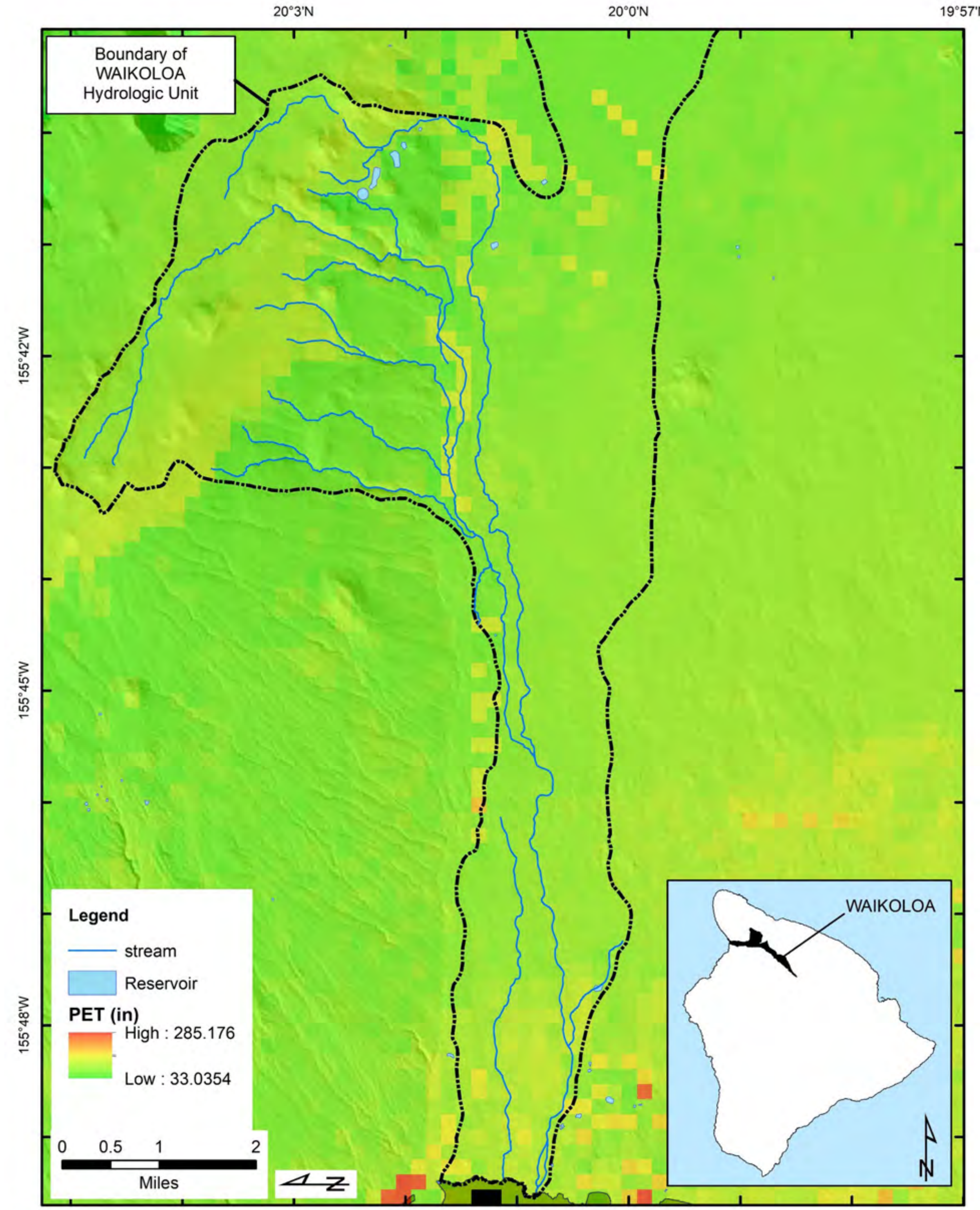


Figure 2-5. Mean annual potential evapotranspiration (Penman-Monteith method) of the Waikoloa hydrologic unit, Hawaiʻi. (Source: Giambelluca et al., 2014)



## Land Use

The Hawaii Land Use Commission (LUC) was established under the State Land Use Law (Chapter 205, Hawaii Revised Statutes) enacted in 1961. Prior to the LUC, the development of scattered subdivisions resulted in the loss of prime agricultural land that was being converted for residential use, while creating problems for public services trying to meet the demands of dispersed communities. The purpose of the law and the LUC is to preserve and protect Hawaii's lands while ensuring that lands are used for the purposes they are best suited. Land use is classified into four broad categories: 1) agricultural; 2) conservation; 3) rural; and 4) urban.

Land use classification is an important component of examining the benefits of protecting instream uses and the appropriateness of surface water use for noninstream uses. While some may argue that land use, in general, should be based upon the availability of surface and groundwater resources, land use classification continues to serve as a valuable tool for long-range planning purposes.

As of 2014, 80.4 percent (41.4 square miles) of the land in Waikoloa is classified as agriculture and 14.6 percent is classified as conservation. The rest of the unit is urban (4.8%) and rural (0.1%). The conservation region is in the upper elevation sections of the hydrologic unit on Kohala Mountain (Figure 2-6).

## Land Cover

Land cover for the hydrologic units of Waikoloa is represented by two separate 30-meter Landsat satellite datasets. One of the datasets, developed by the Coastal Change Analysis Program (C-CAP), provides a general overview of the land cover types in Waikoloa, e.g., forest, grassland, shrub land, with minor developed areas, cultivated areas, and bare land (Table 2-4, Figure 2-7). The second is developed by the Hawaii Gap Analysis Program (HI-GAP), which mapped the National Vegetation Classification System (NVCS) associations for each type of vegetation, creating a more comprehensive land cover dataset (Table 2-5, Figure 2-8).

Based on the two land cover classification systems, the land cover of Waikoloa consists mainly of alien grassland, sparse vegetation and developed landscape, with some areas of open and closed native ohia forest. About three-quarters of the hydrologic unit is made up of alien grassland. Native wet vegetation, open ohia forest or closed ohia forest make up about 10% of the unit in the uppermost elevations. The land cover maps (Figures 2-8, 2-9) provide a general representation of the land cover types in Waikoloa hydrologic unit. At the middle to lower elevations, vegetation is generally dominated by alien grassland, sparese vegetation, and bare land. Given that the scale of the maps is relatively large, they may not capture the smaller cultivated lands or other vegetation occupying smaller parcels of land. Land cover types may also have changed slightly since the year when the maps were published, particularly regarding the use of pasture lands and the extent of native or non-native vegetation.

## Flood

Floods usually occur following prolonged or heavy rainfall associated with tropical storms or hurricanes. The magnitude of a flood depends on topography, ground cover, and soil conditions. Rain falling on areas with steep slopes and soil saturated from previous rainfall events tends to produce severe floods in low-lying areas. Four types of floods exist in Hawaiʻi. Stream or river flooding occurs when the water level in a stream rises into the flood plain. A 100-year flood refers to the probability of a given magnitude flood occuring once in a hundred years, or 1 percent chance of happening in a given year. Flash floods occur within a few hours after a rainfall event, or they can be caused by breaching of a flood safety structure such as a dam. Flash flooding is common in Hawaiʻi because the small drainage basins often have a short response time, typically less than an hour, from peak rainfall to peak streamflow. They are powerful and dangerous in that they can develop quickly and carry rocks, mud, and all the debris in their path down to the coast, causing water quality problems in the near-shore waters.  Some floods can even trigger massive landslides, blocking off the entire stream channel. Sheet flooding occurs when runoff builds up on previously saturated ground, flowing from the high mountain slopes to the sea in a shallow sheet (Pacific Disaster Center, 2007).  Coastal flooding is the inundation of coastal land areas from excessive sea level rise associated with strong winds or a tsunami.

Table 2-4.  C-CAP land cover classes and area distribution in the Waikoloa hydrologic unit, Hawaiʻi.  (Source: National Oceanographic and Atmospheric Agency, 2015)

| Land Cover | Description | Area ($mi^2$) | Percent of Unit |
|---|---|---|---|
| Pasture/Hay | Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled | 36.152 | 70.3% |
| Evergreen Forest | Areas where more than 67% of the trees remain green throughout the year | 5.290 | 10.3% |
| Bare Land | Bare soil, gravel, or other earthen material with little or no vegetation | 2.297 | 4.5% |
| Grassland | Natural and managed herbaceous cover | 1.755 | 3.4% |
| Scrub | Areas dominated by woody vegetation less than 6 meters in height | 1.652 | 3.2% |
| Palustrine Forested Wetland | Included tidal and nontidal wetlands dominated by woody vegetation 5 meters in height or more | 1.523 | 3.0% |
| Low Intensity Developed | Constructed surface with substantial amounts of vegetated surface | 1.040 | 2.0% |
| Developed Open Space | Areas mostly managed grasses or low-lying vegetation planted for recreation, erosion control, or aesthetic purposes | 0.617 | 1.2% |
| Cultivated | | 0.463 | 0.9% |
| Medium Intensity Developed | Areas with a mixture of constructed materials and substantial amounts of vegetation | 0.309 | 0.6% |
| High Intensity Developed | Land area and is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies less than 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover | 0.177 | 0.3% |
| Water | | 0.077 | 0.1% |
| Palustrine Scrub/Shrub Wetland | Tidal and nontidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity is below 0.5%. Total vegetation cover is greater than 20 percent | 0.046 | 0.1% |
| Palustrine Emergent Wetland | Tidal and nontidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.05 percent (0.5 ppt). Total vegetation cover is greater than 80 percent | 0.032 | 0.1% |

Table 2-5. HI-GAP land cover classes and area distribution Waikoloa hydrologic unit, Hawai'i. (Source: USGS, 2005)

| Land Cover | Area ($mi^2$) | Percent of Unit |
|---|---|---|
| Alien Grassland | 39.169 | 76.15% |
| Closed Ohia Forest | 2.944 | 5.72% |
| Open Ohia Forest | 2.142 | 4.16% |
| Very Sparse Vegetation to Unvegetated | 1.579 | 3.07% |
| Developed, Low Intensity | 1.368 | 2.66% |
| Alien Forest | 1.030 | 2.00% |
| Native Shrubland / Sparse Ohia (native shrubs) | 0.928 | 1.80% |
| Mamane / Naio / Native Trees | 0.802 | 1.56% |
| Uncharacterized Open-Sparse Vegetation | 0.355 | 0.69% |
| Cultivated Cropland | 0.341 | 0.66% |
| Developed, High Intensity | 0.240 | 0.47% |
| Uncharacterized Forest | 0.199 | 0.39% |
| Uluhe Shrubland | 0.145 | 0.28% |
| Kiawe Forest and Shrubland | 0.107 | 0.21% |
| Alien Shrubland | 0.066 | 0.13% |
| Open Water | 0.016 | 0.03% |
| Undefined | 0.004 | 0.01% |
| Open Koa-Mamane Forest | 0.003 | 0.01% |

Peak floods in the Waikoloa hydrologic unit have been monitored at a few locations (Table 2-6). Using basin characteristics within the USGS Streamstats GIS-based program, it is possible to model the magnitude of floods at the mouth of streams, even if they are not monitored (Rea and Skinner, 2012). The 2-, 5-, 10-, 50-, and 100-year flood magnitudes in the Waikoloa hydrologic unit are provided in Table 2-6. The Federal Emergency Management Agency (FEMA) developed maps that identify the flood-risk areas in an effort to mitigate life and property losses associated with flooding events. Based on these maps, FEMA identified 0.5% (0.265 square miles) of the stream channel as having a high flood-risk zone, 86.3% (44.38 square miles) are moderate to low risk, while 12.8% of the unit has an undetermined flood risk (Figure 2-9).

Table 2-6. The magnitude of peak flows with specific recurrence intervals based on measured peaks flows at select monitoring locations in the Waikoloa hydrologic unit, Hawai'i. (Source: Oki et al., 2010)

| station ID | station name | period of record | peak flood magnitudes (cfs) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 2-year | 5-year | 10-year | 50-year | 100-year |
| 16756000 | Kohakohau Stream near Kamuela | 1957-1966 | 1680 | 3190 | 4330 | 7060 | 8280 |
| 16756100 | Kohakohau Stream above DWS intake | 1998-2008 | 857 | 1250 | 1530 | 2200 | 2500 |
| 16756300 | Kohakohau Stream below DWS intake | 1967-1991 | 968 | 1620 | 2110 | 3360 | 3950 |
| 16756500 | Keanuiomano Stream near Kamuela | 1964-2008 | 932 | 1620 | 2180 | 3690 | 4450 |
| 16757000 | Waikoloa Stream nr Kamuela | 1948-1971 | 520 | 964 | 1310 | 2160 | 2550 |
| 16758000 | Waikoloa Str at Marine Dam | 1948-2008 | 473 | 971 | 1450 | 3090 | 4100 |
| 16759000 | Hauani Gulch near Kamuela | 1956-2004 | 191 | 360 | 508 | 954 | 1200 |

Figure 2-6. State land use district boundaries of the Waikoloa hydrologic unit, Hawai'i. (Source: State of Hawaii, Office of Planning, 2015d).

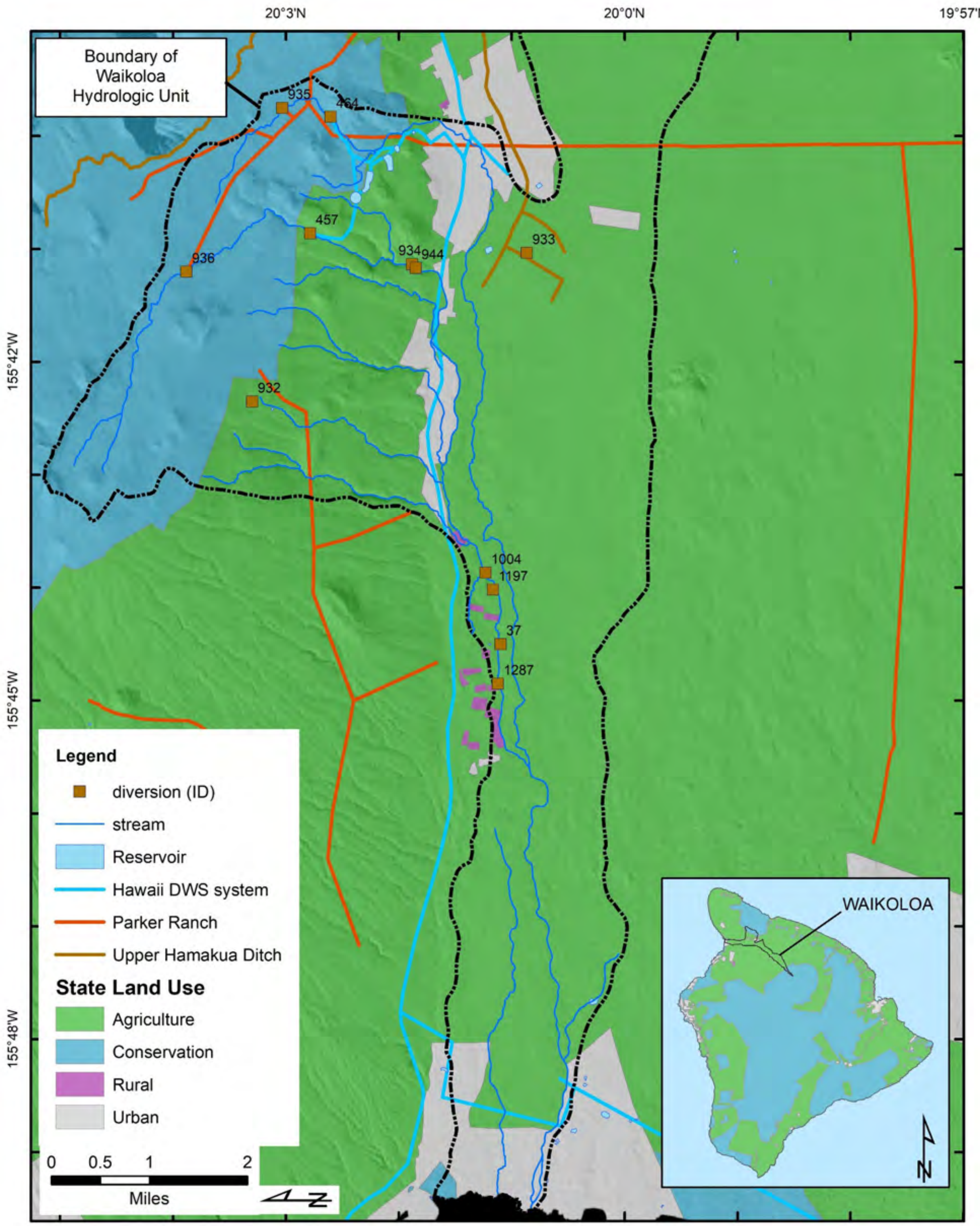


Figure 2-7. C-CAP land cover of the Waikoloa hydrologic unit, Hawai'i. (Source: State of Hawaii, Office of Planning, 2015k).

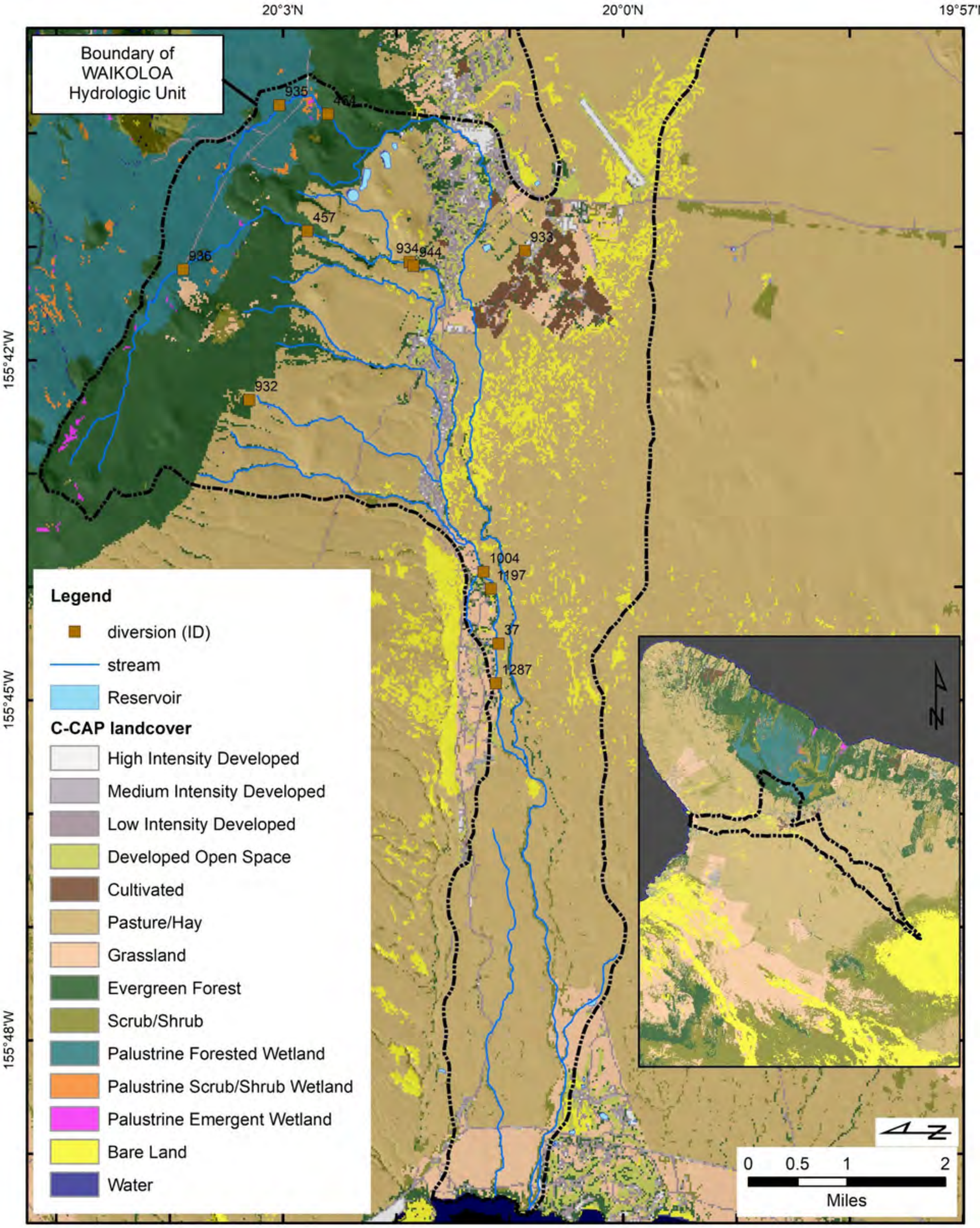


Figure 2-8. Hawaii GAP land cover classes of of the Waikoloa hydrologic unit, Hawai'i. (Source: USGS, 2001).

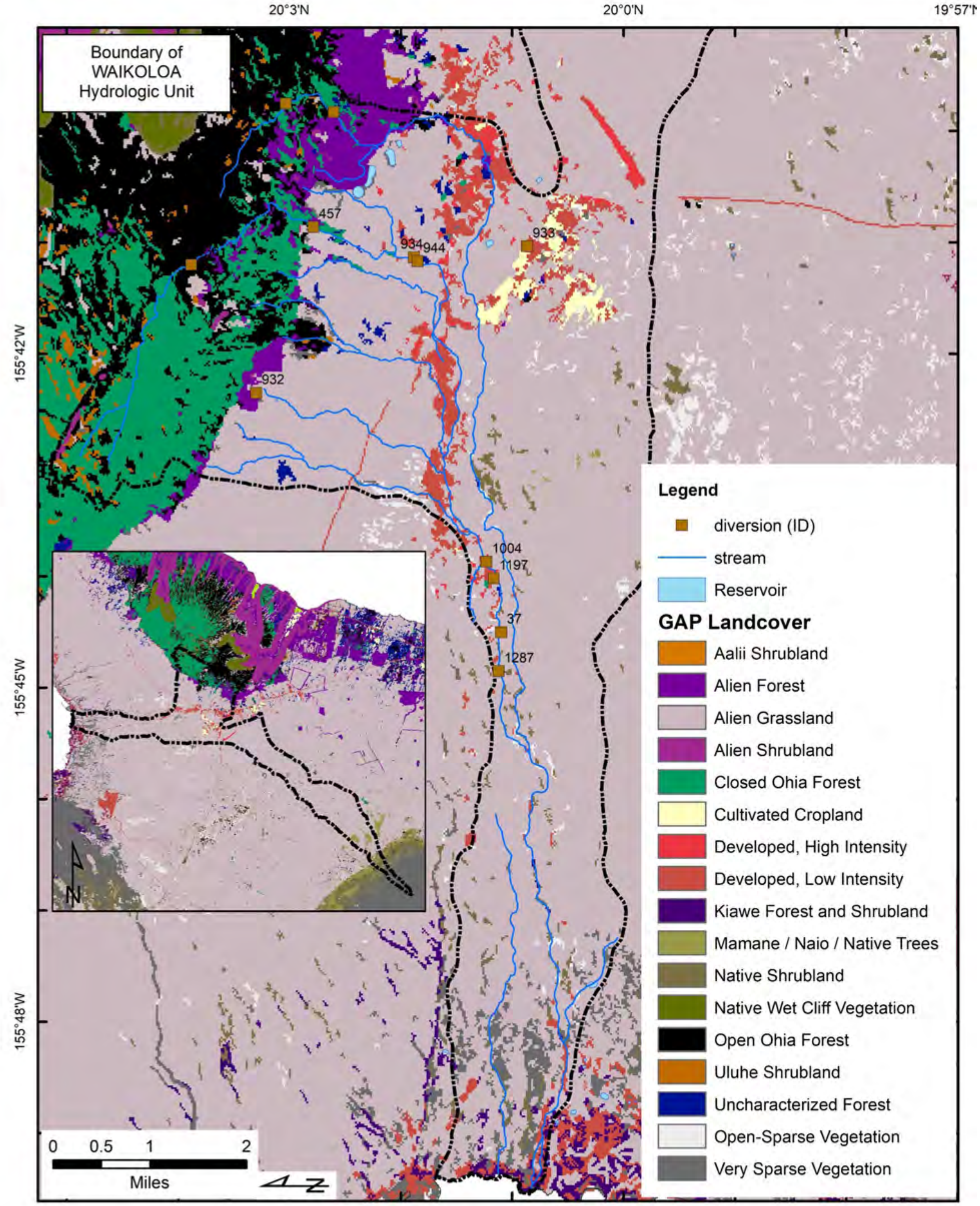
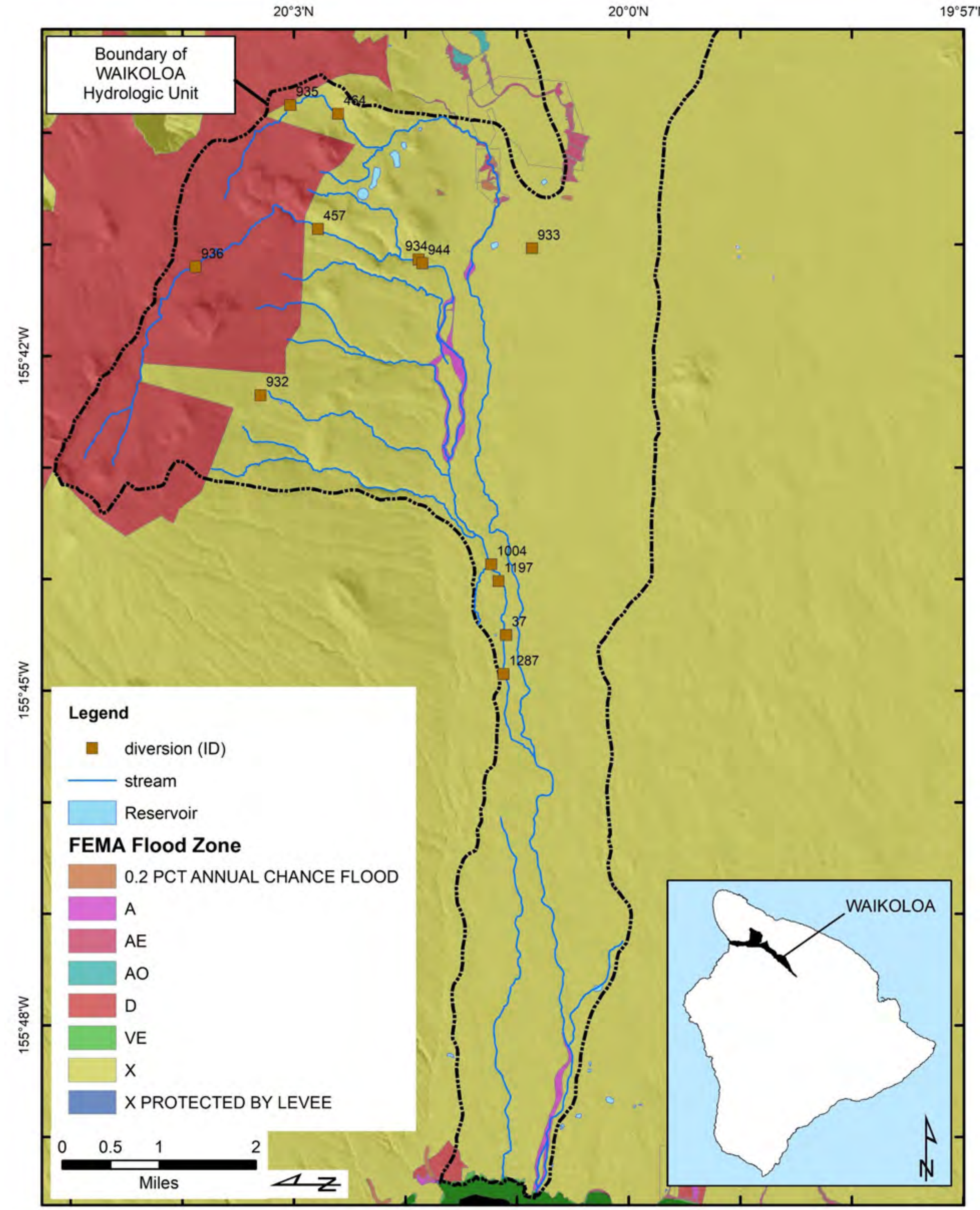


Figure 2-9. FEMA flood zone regions in the Waikoloa hydrologic unit, Hawaii. (Source: Federal Emergency Management Agency, 2014)



## Drought

Drought is generally defined as a shortage of water supply that usually results from lower than normal rainfall over an extended period of time, though it can also result from human activities that increase water demand (Giambelluca et al., 1991). The National Drought Mitigation Center (State of Hawaii, Commission on Water Resource Management, 2005b) uses two types of drought definitions — conceptual and operational. Conceptual definitions help people understand the general concept of drought. Operational definitions describe the onset and severity of a drought, and they are helpful in planning for drought mitigation efforts. The four operational definitions of drought are meteorological, agricultural, hydrological, and socioeconomic. Meteorological drought describes the departure of rainfall from normal based on meteorological measurements and understanding of the regional climatology. Agricultural drought occurs when not enough water is available to meet the water demands of a crop. Hydrological drought refers to declining surface and ground water levels. Lastly, socioeconomic drought occurs when water shortage affects the general public.

Impacts of drought are complex and can be categorized into three sectors: water supply; agriculture and commerce; and environment, public health, and safety sectors (State of Hawaii, Commission on Water Resource Management, 2005b). The water supply sector encompasses urban and rural drinking water systems that are affected when a drought depletes ground water supplies due to reduced recharge from rainfall or surface water due to reduced stream flow. The agriculture and commerce sector includes the reduction of crop yield and livestock sizes due to insufficient water supply for crop irrigation and maintenance of ground cover for grazing. The environmental, public health, and safety sector focuses on wildfires that are both detrimental to the forest ecosystem and hazardous to the public. It also includes the impact of desiccating streams, such as the reduction of instream habitats for native species.

Droughts have affected the islands throughout Hawaii's recorded history. The most severe events of the recent past years are associated with the El Niño phenomenon. In January 1998, the National Weather Service's network of 73 rain gauges throughout the State did not record a single above-normal rainfall, with 36 rain gauges recording less than 25 percent of normal rainfall (State of Hawaii, Commission on Water Resource Management, 2005b). The most recent drought occurred in 2000-2002, affecting all islands, especially the southeastern end of the State. A summary of drought history and its consequences for Hawai‘i is available from Frazier et al. (2022).

With Hawaii's limited water resources and growing water demands, droughts will continue to adversely affect the environment, economy, and the residents of the State. Aggressive planning is necessary to make wise decisions regarding the allocation of water at the present time, and conserving water resources for generations to come. The Hawaii Drought Plan was established in 2000 in an effort to mitigate the long-term effects of drought. One of the projects that supplemented the plan was a drought risk and vulnerability assessment of the State, conducted by researchers at the University of Hawaii (2003). In this project, drought risk areas were determined based on rainfall variation in relation to water source, irrigated area, ground water yield, stream density, land form, drainage condition, and land use. Fifteen years of historical rainfall data were used. The Standardized Precipitation Index (SPI) was used as the drought index because of its ability to assess a range of rainfall conditions in Hawai‘i. It quantifies rainfall deficit for different time periods, i.e. 3 months and 12 months. Results of the study for Hawai‘i are summarized in Table 2-7. Based on the 12-month SPI, the Kona region has the greatest risk to drought impact of the Hawai‘i regions.

Table 2-7. Drought risk areas for Hawaiʻi. (Source: University of Hawaii, 2003)
[Drought classifications of moderate, severe, and extreme have SPI values -1.00 to -1.49, -1.50 to -1.99, and -2.00 or less, respectively]

| Sector | Drought Classification (based on 12-month SPI) | | |
|---|---|---|---|
| | Moderate | Severe | Extreme |
| Water Supply | Kona, South Point | Kona, Kau | Kona, windward slopes of Hāmākua |
| Agriculture and Commerce | Kona, windward slope of Hāmākua | Kona/Western slopes of Mauna Loa near Kealekekua | Kona/Kailua |
| Environment, Public Health and Safety | Waikoloa, Kona | Kona | Kona |

## 3.0 Hydrology

The Commission, under the State Water Code, is tasked with establishing instream flow standards by weighing "the importance of the present or potential instream values with the importance of the present or potential uses of water for noninstream purposes, including the economic impact of restricting such uses." While the Code outlines the instream and offstream uses to be weighed, it assumes that hydrological conditions will also be weighed as part of this equation. The complexity lies in the variability of local surface water conditions that are dependent upon a wide range of factors, including rainfall, geology, and human impacts, as well as the availability of such information. The following is a summary of general hydrology and specific hydrologic characteristics for streams in or near the Waikoloa hydrologic unit.

### Streams in Hawai‘i

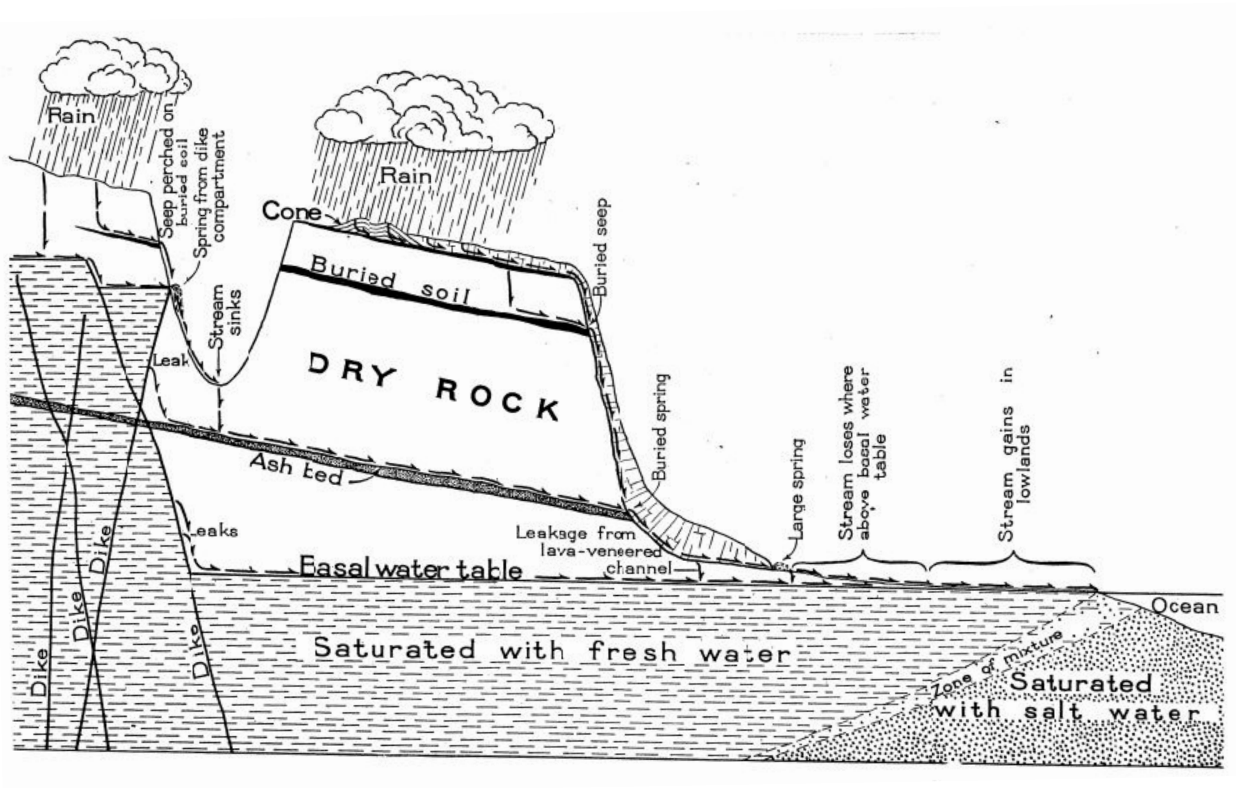
Streamflow consists of: 1) direct surface runoff in the form of overland flow and subsurface flow that rapidly returns infiltrated water to the stream; 2) ground water discharge in the form of base flow; 3) water returned from streambank storage; 4) rain that falls directly on streams; and 5) additional water, including excess irrigation water discharged into streams by humans (Oki, 2003). The amount of runoff and ground water that contribute to total streamflow is dependent on the different components of the hydrologic cycle, as well as man-made structures such as diversions and other stream channel alterations (e.g. channelizations and dams).

Streams in Hawai‘i can either gain or lose water at different locations depending on the geohydrologic conditions. A stream gains water when the ground water table is above the streambed. When the water table is below the streambed, the stream can lose water. Where the streambed is lined with concrete or other low-permeability or impermeable material, interaction between surface water and ground water is unlikely. Another way that ground water influences streamflow is through springs. A spring is formed when a geologic structure (e.g., fault or fracture) or a topographic feature (e.g., side of a hill or a valley) intersects ground water either at or below the water table. It can discharge ground water onto the land surface, directly into the stream, or into the ocean. Figure 3-1 illustrates a valley that has been incised into a high-level water table, resulting in ground water discharges that contribute directly to streamflow and springs that contribute to streamflow. At places where erosion has removed the caprock, ground water discharges either as springs or into the ocean as seeps. The USGS has continuously monitored many streams in the Waikoloa hydrologic unit. Historic data from these stations and nearby stations are available in Table 3-1.

Table 3-1. Selected natural streamflow statistics for the given period of record in or near the Waikoloa hydrologic unit, Hawai‘i. (Source: USGS 2020) [Flows are in cubic feet per second (million gallons per day]

| | | | | | discharge (Q) for a selected percentage ($_{xx}$) discharge was equaled or exceeded | | | |
|---|---|---|---|---|---|---|---|---|
| station ID | station name | period of record | mean daily flow | 14-day low flow | $Q_{50}$ | $Q_{70}$ | $Q_{90}$ | $Q_{95}$ |
| 16756100 | Kohākōhau Stream | 1956-1966 | 8.9 (5.76) | 0.10 | 2.1 (1.36) | 0.93 (0.60) | 0.48 (0.31) | 0.34 (0.22) |
| 16757000 | Waikoloa Stream | 1947-71; 2018-23 | 6.7 (4.32) | 0.25 | 3.8 (2.46) | 2.7 (1.75) | 1.7 (1.12) | 1.5 (0.96) |
| 16579000 | Hauani Stream | 1956-2001 | 1.7 (1.13) | 0.00 | 0.5 (0.35) | 0.28 (0.18) | 0.09 (0.06) | 0.04 (0.026) |
| 16725000 | Alakahi Stream | 1964-2022 | 7.1 (4.58) | 0.00 | 2.7 (1.72) | 1.1 (0.71) | 0.22 (0.14) | 0.04 (0.026) |
| 16720000 | Kawainui Stream | 1964-2022 | 13.9 (8.97) | 0.02 | 4.1 (2.65) | 1.6 (1.01) | 0.50 (0.32) | 0.30 (0.19) |

Figure 3-1. Diagram of the general movement of groundwater on Hawaiʻi Island. (Source: Stearns and Macdonald, 1946)



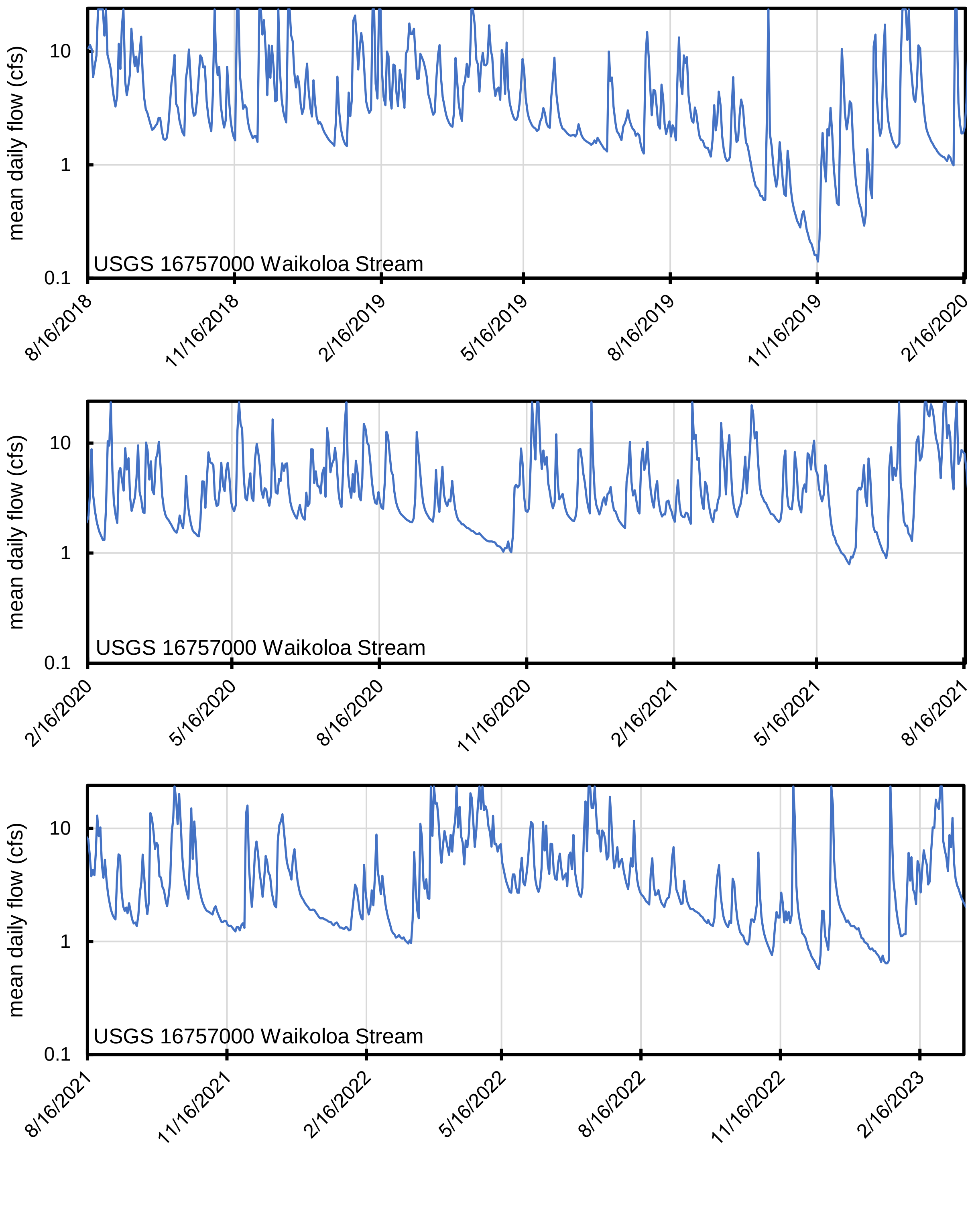

## Groundwater

Groundwater is an important component of streamflow as it constitutes the base flow[5] of Hawaiian streams. Groundwater can also be an alternative source to diverting stream flow. When groundwater is withdrawn from a well, the water level in the surrounding area is lowered. Nearby wetlands or ponds may shrink or even dry up if the pumping rate is sufficiently high (Gingerich and Oki, 2000). The long-term effects of groundwater withdrawal can include the reduction of streamflow, which may cause a decrease in stream habitats for native species and a reduction in the amount of water available for irrigation. The interaction between surface water and groundwater warrants a close look at the groundwater recharge and demand within the State as well as the individual hydrologic units.

In Hawaiʻi, groundwater is replenished by recharge from rainfall, fog drip, and irrigation water that percolate through the plant root zone to the subsurface rock. Recharge can be captured in three major groundwater systems: 1) fresh water-lens system; 2) dike-impounded system; and 3) perched system. The fresh water basal aquifer provides the most important sources of ground water. It includes a lens-shaped layer of fresh water, an intermediate transition zone of brackish water, and underlying salt water. The Ghyben-Herzberg principle describes the displacement of higher density saltwater by lower density fresh water in an aquifer for a condition where two fluids do not mix and the freshwater flow is primarily horizontal. In such a situation, for every one foot above sea level of freshwater, there are approximately 40 feet of freshwater below sea level. Thus, a vertically extensive fresh water-lens system can extend several hundreds of feet below mean sea level.

[5] Base flow is the water that enters a stream from persistent, slowly varying sources (such as the seepage of ground water), and maintains stream flow between water-input events (i.e., it is the flow that remains in a stream in times of little or no rainfall).

Figure 3-2. Natural (unregulated) mean daily flow at USGS 16757000 on Waikoloa Stream from 2018 to 2023. (Source: USGS, 2023)



Most lava on Hawai‘i flows down steep slopes and cools quickly in thicknesses of inches to several feet, often producing more tubes than those on gentle slopes, all yielding a highly porous medium (Stearns and Macdonald, 1946). By contrast, a dike-impounded system is found in rift zones or a caldera where low-permeability dikes compartmentalize areas of permeable volcanic rocks, forming high-level water bodies. On Hawai‘i Island, dikes impound water to as high as 3,300 feet above mean sea level (Figure 3-1). A perched system is found in areas where low-permeability rocks impede the downward movement of percolated water sufficiently to allow a water body to form in the unsaturated zone above the lowest water table (Stearns and Macdonald, 1946). The most significant perched water occurs at the interface between the Hawi and Pololu volcanic series. In Waikoloa, this occurs where ash layers have been deposited or where historic interbedded soil from erosion deposits have been buried by more recent lava flows (Figure 3-3). The water-bearing properties of various rock structures largly depends on their composition, and therefore their permeability. Where a dike complex exists, 100 or more dikes per mile, occupying 5% or more of the rock, is not uncommon and can hold substantial quantities of water in the permeable layers between the dikes.

The hydrogeologic framework of Hawai‘i Island is not as well known as that of the other islands. The island is large, the number of wells per unit area is small and clustered primarily along the coastline. Although a few exploratory and scientific wells and some geophysical studies provide subsurface information in some areas, much of the island—especially the high-altitude interior—has little or no subsurface hydrologic data (Izuka et al. 2015). Also, because Hawai‘i Island is in a youthful stage of erosion, the relation between groundwater occurrence and geologic structures remains more obscured than it is on other islands (Mink and Lau, 1993). Adding to the uncertainty, on Kohala and Mauna Kea, the surface water hydrologic unit of Waikoloa spans both the Mahukona and Waimea aquifer systems.

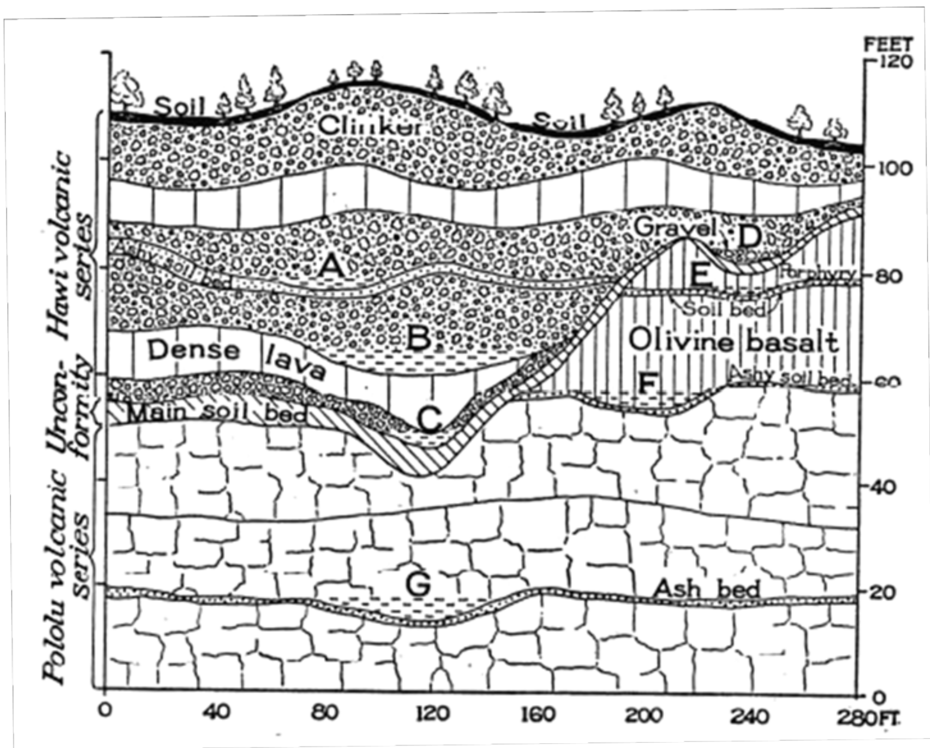
The rate at which water moves underground is important for estimating groundwater availability. Underwood et al. (1995) estimated a hydraulic conductivity of rock formations in Kohala volcano for dike-free lavas at 610–6,400 ft/d, with a median of 1,100 ft/d and arithmetic average of 2,300 ft/d, from aquifer tests of five wells. Rotzoll and El-Kadi (2008) used a specific-capacity/hydraulic conductivity regression analysis to estimate a geometric mean of hydraulic conductivity 1,102 ft/d ranging from 269 to 4,502 ft/d in dike-free lavas. Dike-impounded groundwater is likely to occur in the rift zones of shield volcanoes on Hawai‘i Island (Stearns and Macdonald, 1946). To match water levels in their numerical models, Whittier et al. (2004) used hydraulic conductivity values of 0.7 to 1.6 ft/d for the Kohala dike complex and 0.03 to 3.3 ft/d for the Mauna Kea dike complex.

Perched groundwater is found at high elevations of the Kohala mountain as observed by the development tunnels constructed in the Hāwī Volcanics as well as on ash beds on the underlying Pololū Basalt (Figure 3-3). There are numerous springs and seeps emanating from interstratified ash beds in the Hāwī Volcanic series on Kohala Mountain above Waimea Town which yield small amounts of water (up to 10,000 gallons per day in dry weather) (Stearns and MacDonald, 1946). The soil layer that separates the Pololū from the Hāwī Volcanic series may be relatively thin (~2 inches) or thick (2 feet) and combined with the steep rainfall gradient from windward to leeward, affects the storage and discharge of perched water (Figure 3-3).

Dike structures possibly, from a south or southeast rift zone in the Kohala mountain in the region of Waimea town, form a high elevation water source. These dikes form large reservoirs that discharge eastward into the canyons carved by perennial streams. Stearns and Macdonald (1946) evaluated the capture of dike water by the Lower Hāmākua Ditch and concluded that monthly rainfall measured at the Kawainui rainfall station of less than 3 inches caused a loss of storage due to discharge into streams, and less than 5 inches was mostly lost to evaporation and transpiration, while rainfall of 20 inches or more, often within a few days, largely resulted in runoff that did not increase groundwater storage. Withdrawal from basal lens wells should not affect the high-elevation water table because the thick unsaturated zone will prevent any significant changes in the vertical flow gradient.

The initial survey of gravity density anomalies demonstrated the extent that Kohala Mountain extended beneath the Mauna Kea lava flows (Kinoshita, 1965). While this is not surprising, more recently, Kauahikaua et al. (2000) projected southeasterly trends of the Kohala rift to the offshore Hilo Ridge. Computer projections of Kohala slopes along the theoretical rift zone were used to identify high-level water for a new well (6235-001). Using a water budget approach for regions delineated by known or suspected geologic features (Figure 3-4) which may impound high-level groundwater in the Waimea Plains region, average groundwater recharge values were estimated with and without fog drip contributions as depicted in Figure 3-5 and the average daily recharge in the Waimea Town area is between 8.5 and 10 mgd (Waimea Water Services, 2001).

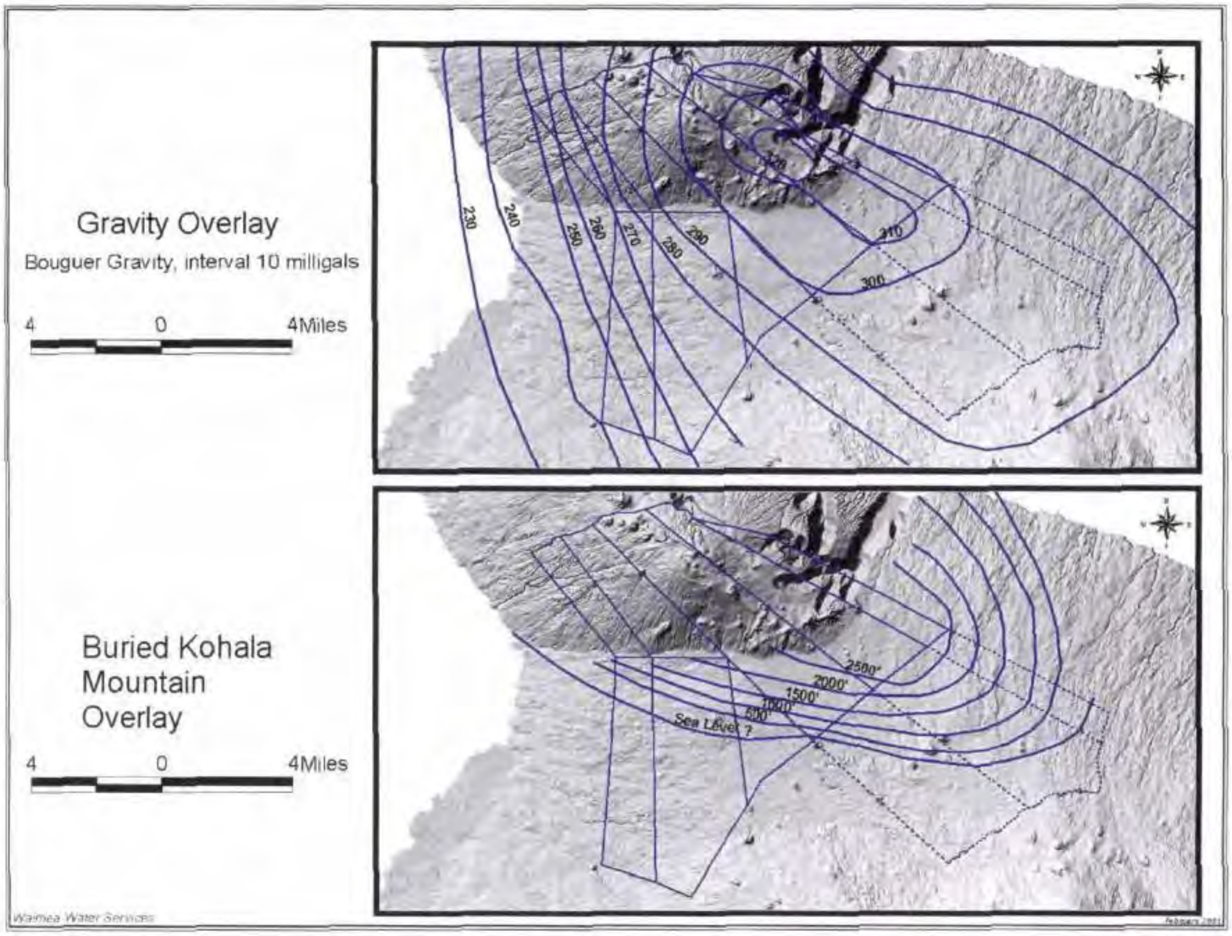
Figure 3-3. Diagram showing the relation of perching structures to the movement of groundwater on the north slope of Kohala Mountain. [ A= ashy soil interbedded with Hawi lava; B = dense lava; C = on soil unconformity; D = boundery conglomerate on uniformity; E,F,G = soil and ash bed interstratified with Pololu lava] (Source: Stearns and Macdonald, 1946)




## Wells in or near the Waikoloa Hydrologic Unit

The Waikoloa surface water hydrologic unit spans the Makuhona and Waimea Aquifer Systems (Figure 3-5). Makuhona is part of the Kohala Aquifer Sector while Waimea is the only system in the West Mauna Kea Aquifer Sector. The 2019 update to the Water Resources Protection Plan revised the sustainable yield of the Waimea Aquifer System from 24 mgd to 16 mgd and the Makuhona Aquifer System from 17 mgd to 10 mgd (State of Hawai‘i, 2019). In the region, there are three principal well types: wells for non-potable irrigation demands operated by private resort communities, potable wells operated by private resort communities, and potable wells operated by Hawai‘i DWS. The location of wells in or near the Waikoloa hydrologic unit and the boundaries to the aquifer systems are depicted in Figure 3-6. The wells located within the Waikoloa hydrologic unit are listed in Table 3-2, with additional wells associated with uses in the hydrologic unit listed in Table 3-3. Water delivery systems extend beyond the boundaries of the Waikoloa hydrologic unit to service various communities, with some sources in the groundwater aquifer systems that are located beyond the surface water hydrologic unit that meet water demands both within and outside of the surface water hydrologic unit. The hydrogeology of these sources do not adhere to the surface topography of the landscape and therefore their usage may impact the availability of groundwater in the Waikoloa hydrologic unit.

Figure 3-4. Gravity Overlay (top) and buried Kohala Mountain Overly indicating high elevation water along the southeast rift zone. (Source: Waimea Water Services, 2001)




## Current groundwater pumpage

The monthly total pumpage (mgd) and chloride levels (ppm) for the Hawai'i DWS well located in the high elevation aquifer at 2970 ft amsl is provided in Figure 3-7 with related statistics provided in Table 3-4. The monthly total pumpage (mgd) and chloride levels (ppm) for eight Hawai'i DWS wells that are part of the Lalamilo water system is provided in Figure 3-8 and four irrigation wells located in the 704-732 ft amsl range are provided in Figure 3-9 with related statistics provided in Table 3-4. The locations of county municipal, private municipal, and irrigation wells for the coastal regions of the Mahukona, Waimea, and Anaehoomalu aquifer systems, along with observation wells, are depicted in Figure 3-11.

Table 3-2. Information associated with wells located in the Waikoloa surface water hydrologic unit. [OBS = observation; IRR = irrigation; MUN = municipal; ABN = abandoned; UNU = unused] (CWRM Well Index, accessed 2023)

| ID | name | owner | Year Drilled | Use | Ground elevation (ft) | Well depth (ft) | Pump elevation (ft) | Initial head (ft) |
|---|---|---|---|---|---|---|---|---|
| 6046-001 | Ouli 1 | Waimea Malama Inc. | 1989 | OBS | 1302 | 1400 | 0 | 13.6 |
| 6047-001 | Ouli C | South Kohala Water Corp. | 1990 | IRR | 724.4 | 764 | -17 | 4.6 |
| 6047-002 | Ouli D | South Kohala Water Corp. | 1991 | IRR | 706 | 758 | -35 | 4.3 |
| 6047-004 | Hapuna 3 | South Kohala Water Corp. | 2003 | IRR | 720 | 765 | -14 | 4.94 |
| 6047-005 | Hapuna 4 | South Kohala Water Corp. | 2006 | IRR | 731 | 765 | -14 | 0 |
| 6049-009 | Mauumae | Mauumae Ventures LLC | 2008 | IRR | -- | 8 | -- | -- |
| 6141-001 | Waiaka Tank | U.S. Geological Survey | 1999 | OBS | 2506 | 1507 | 0 | 1243 |
| 6146-001 | Ouli 2 | Hale Wailani Partners LP | 0 | OBS | 1311.2 | 1371 | 0 | 10.96 |
| 6147-001 | Kawaihae 3 | Queen Emma Foundation | 1963 | OBS | 980.19 | 1046 | 0 | 4.32 |
| 6148-001 | Kawaihae Deepwell #1 [NIU] | Department of Water Supply Hawaii | 1961 | UNU | 579.37 | 620 | 0 | 4.4 |
| 6148-002 | Kawaihae Deepwell #2 [NIU] | Department of Water Supply Hawaii | 1969 | UNU | 583 | 601 | 0 | 4.4 |
| 6148-003 | M Kea Bch | Mauna Kea Beach Hotel Corp. | 0 | IND | 0 | 0 | 0 | 0 |
| 6240-001 | Waimea Obs. | U.S. Geological Survey | 1991 | OBS | 2970 | 2016 | 0 | 0 |
| 6240-002 | Waimea Deepwell | Department of Water Supply Hawaii | 2000 | MUN | 2970 | 2000 | 1194 | 1262.8 |
| 6340-001 | Kohākōhau TH 1 | Land Division Oahu | 1964 | ABN | 3910 | 100 | 0 | 0 |
| 6340-002 | Kohākōhau TH 2 | Land Division Oahu | 1964 | ABN | 3850 | 100 | 0 | 0 |
| 6340-003 | Kohākōhau TH 3 | Land Division Oahu | 1964 | UNU | 3770 | 100 | 0 | 0 |
| 6340-004 | Kohala TH 2 | Land Division Oahu | 1987 | ABN | 0 | 105 | 0 | 0 |
| 6341-001 | Waiaka Gulch TH | Land Division Oahu | 1964 | ABN | 3613 | 924 | 0 | 0 |
| 6341-002 | Kohākōhau TH 4 | Land Division Oahu, | 1964 | ABN | 3790 | 100 | 0 | 0 |
| 6341-003 | Kohākōhau TH 5 | Land Division Oahu | 1964 | ABN | 3850 | 100 | 0 | 0 |

Figure 3-5. Estimated groundwater recharge with (top) and without (bottom) fog drip contributions in the water budget model for regions delineated by known or suspected geologic features that create high-level groundwater. (Source: Waimea Water Services, 2001)

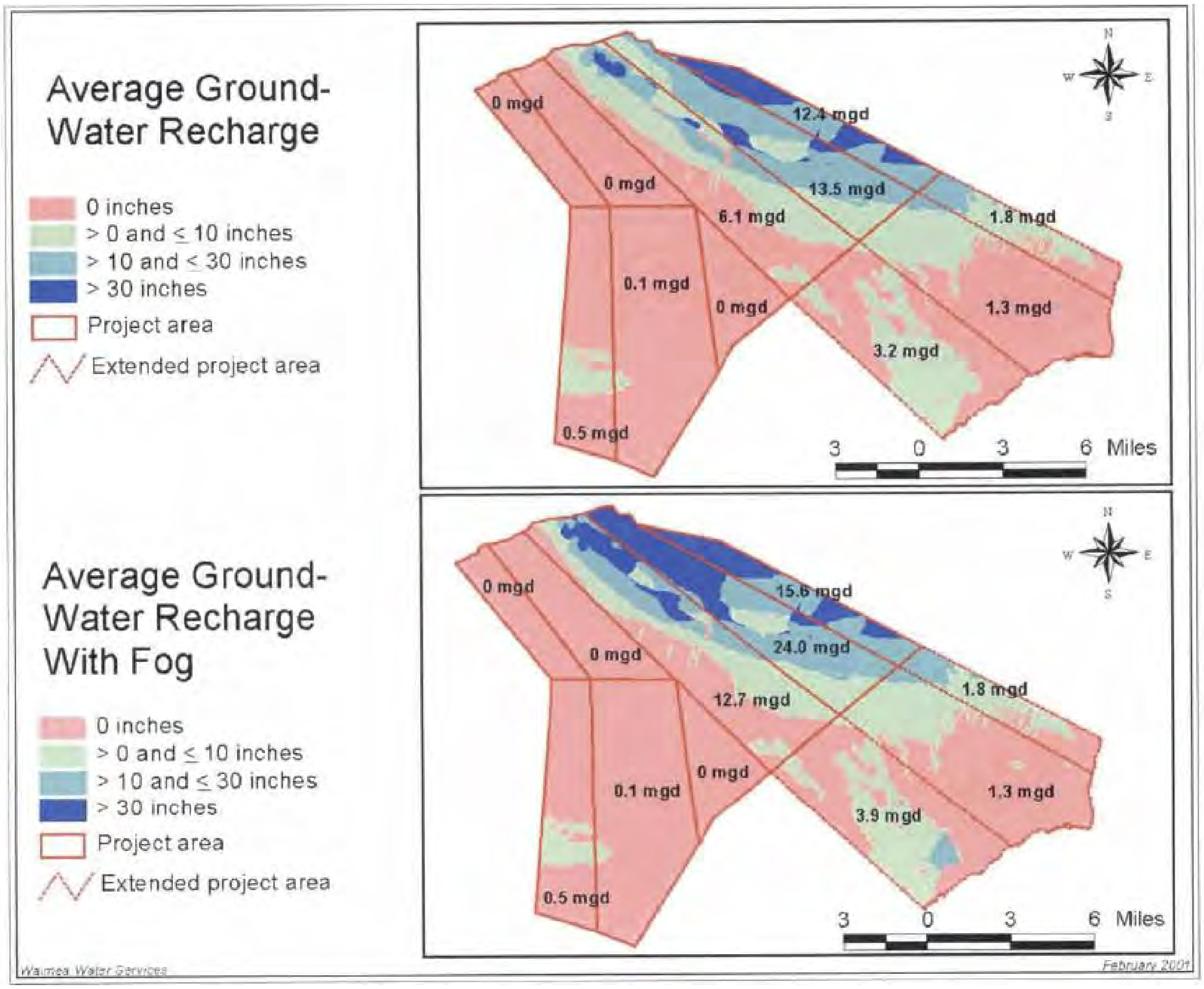


Figure 3-6. Well locations and numbers in and nearby the Waikoloa hydrologic units, Mahukona and Waimea Aquifer Systems, Hawaii. (Source: State of Hawaii, Commission on Water Resource Management, 2020c).

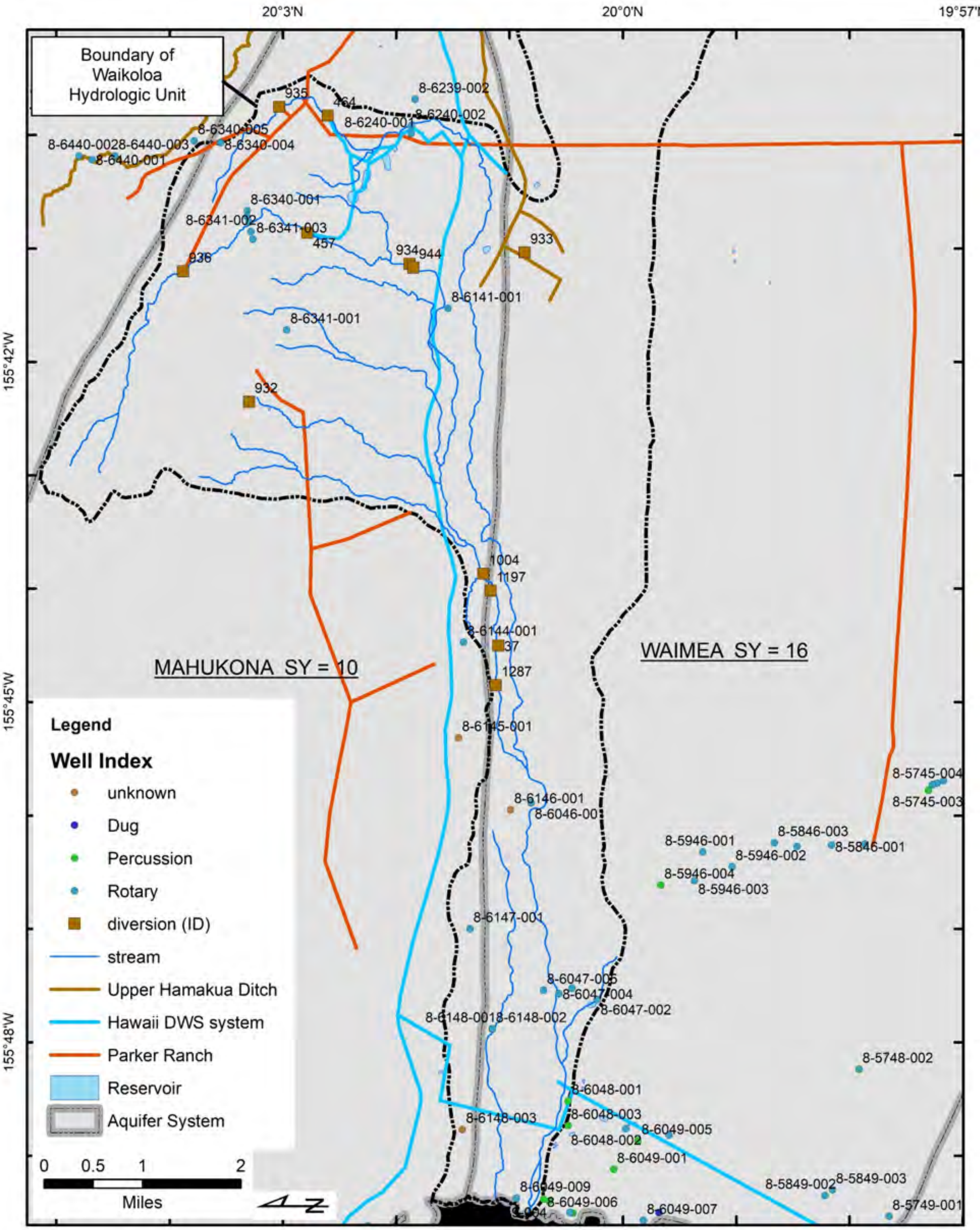


Table 3-3. Information associated with wells located in the vicinity of the Waikoloa surface water hydrologic unit. [OBS = observation; IRR = irrigation; MUN = municipal; OBS = observation; ABN = abandoned; UNU = unused] (CWRM Well Index, accessed 2023)

| ID | name | owner | Year Drilled | Use | Ground elevation (ft) | Well depth (ft) | Pump elevation (ft) | Initial head (ft) |
|---|---|---|---|---|---|---|---|---|
| 5846-001 | Parker #1 Deepwell | Hawai'i DWS | 1992 | MUN | 1146.5 | 1242 | -46.8 | |
| 5846-002 | Parker #2 Deepwell | Hawai'i DWS | 1993 | MUN | 1181.1 | 1275 | -13.9 | 6.3 |
| 5846-003 | Parker #3 Deepwell | Hawai'i DWS | 2005 | MUN | 1178 | 1257 | -31 | 4.81 |
| 5746-001 | Parker #4 Deepwell | Hawai'i DWS | 2005 | MUN | 1111 | 1183 | -31 | 7 |
| 5946-001 | Lalamilo A Deepwell | Hawai'i DWS | 1977 | MUN | 1172 | 1277 | -28.75 | 8.2 |
| 5946-002 | Lalamilo B Deepwell | Hawai'i DWS | 1980 | MUN | 1089 | 1164 | -22 | 6.6 |
| 5946-003 | Lalamilo C Deepwell | Hawai'i DWS | 1980 | MUN | 1088 | 1158 | -20 | 7.6 |
| 5946-004 | Lalamilo D Deepwell | Hawai'i DWS | 1985 | MUN | 1085 | 1144 | -33.36 | 7 |
| 6145-001 | Ouli-Kawamata | Amy K Hara Trust | 1995 | OBS | 1568 | 1602.9 | -- | 9.83 |
| 6239-002 | Parker Ranch Deepwell | Hawai'i DWS | 1994 | MUN | 2822 | 1627 | -- | 1264.4 |
| 6337-001 | Puukapu | DLNR | 1987 | UNU | 3023 | 1744 | 1511 | 1739.6 |
| 6337-002 | Puukapu Shallow | DLNR | 1993 | UNU | 3020 | 355 | -- | -- |

Figure 3-7. Monthly pumpage and chloride measurements for Hawai'i DWS wells in or near the Waikoloa surface water hydrologic unit, Hawai'i.

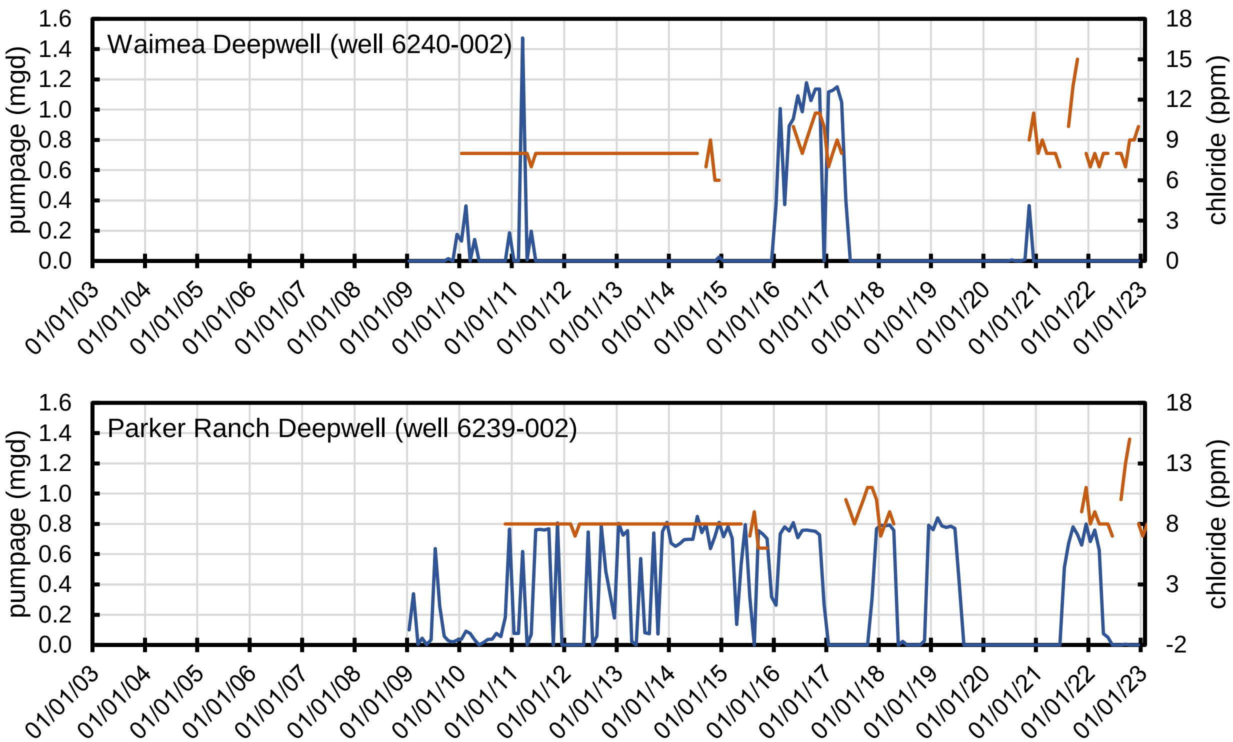


Table 3-4. Reported pumpage for recent periods of record from wells located in or near the Waikoloa surface water hydrologic unit, Hawaii. (CWRM Well Index, accessed 2023)

| ID | name | Use | Period of Record | Mean Monthly pumpage (mgd) | Median Monthly pumpage (mgd) | Maximum Monthly pumpage (mgd) |
|---|---|---|---|---|---|---|
| 6047-001 | Ouli C | Hapuna Golf course | 2003-2022 | 0.356 | 0.370 | 0.664 |
| 6047-002 | Ouli D | Hapuna Golf course | 2003-2022 | 0.348 | 0.381 | 0.674 |
| 6047-004 | Hapuna 3 | Hapuna Golf course | 2005-2022 | 0.411 | 0.420 | 0.777 |
| 6047-005 | Hapuna 4 | Hapuna Golf course | 2009-2022 | 0.336 | 0.320 | 0.724 |
| 6240-002 | Waimea Deepwell | Hawai‘i DWS | 2009-2022 | 0.108 | 0.000 | 1.474 |
| 6239-002 | Parker Ranch Deepwell | Hawai‘i DWS | 2005-2022 | 0.260 | 0.034 | 0.850 |
| 5946-001 | Lalamilo A Deepwell | Hawai‘i DWS | 2003-2022 | 0.308 | 0.104 | 1.152 |
| 5946-002 | Lalamilo B Deepwell | Hawai‘i DWS | 2003-2022 | 0.336 | 0.130 | 1.625 |
| 5946-003 | Lalamilo C Deepwell | Hawai‘i DWS | 2003-2022 | 0.477 | 0.431 | 1.486 |
| 5946-004 | Lalamilo D Deepwell | Hawai‘i DWS | 2003-2022 | 0.679 | 0.761 | 1.677 |
| 5846-001 | Parker #1 Deepwell | Hawai‘i DWS | 2003-2022 | 0.876 | 0.915 | 2.014 |
| 5846-002 | Parker #2 Deepwell | Hawai‘i DWS | 2010-2022 | 0.883 | 0.880 | 2.053 |
| 5846-003 | Parker #3 Deepwell | Hawai‘i DWS | 2010-2022 | 1.158 | 1.441 | 1.989 |
| 5746-001 | Parker #4 Deepwell | Hawai‘i DWS | 2010-2022 | 0.892 | 0.845 | 1.864 |

## Observation wells in or near the Waikoloa Hydrologic Unit

The Commission maintains a number of observation monitoring wells in or near the Waikoloa hydrologic unit to monitor the basal lens height over time. Factors that can affect the height of the water table include seasonal and annual patterns in rainfall-recharge, tidal fluctuations, and pumpage from wells nearby or upgradient of the monitoring well.

From January 2000 to November 2022 at well 6141-001 (2506 ft amsl), the water level of the high-elevation dike-impounded aquifer declined by 14.75 ft, or at a rate of 0.67 ft per year. Over this same time period, the water level of the basal aquifer at well 6046-001 (1202 ft amsl) declined by 0.92 ft, or at a rate of 0.046 ft per year (Figure 3-10). The location of these wells can be found in Figure 3-11.

Figure 3-8. Mean daily total pumpage from the Parker wells and the Lalamilo wells in the Lalamilo water system near the Waikoloa hydrologic unit, Hawai‘i.

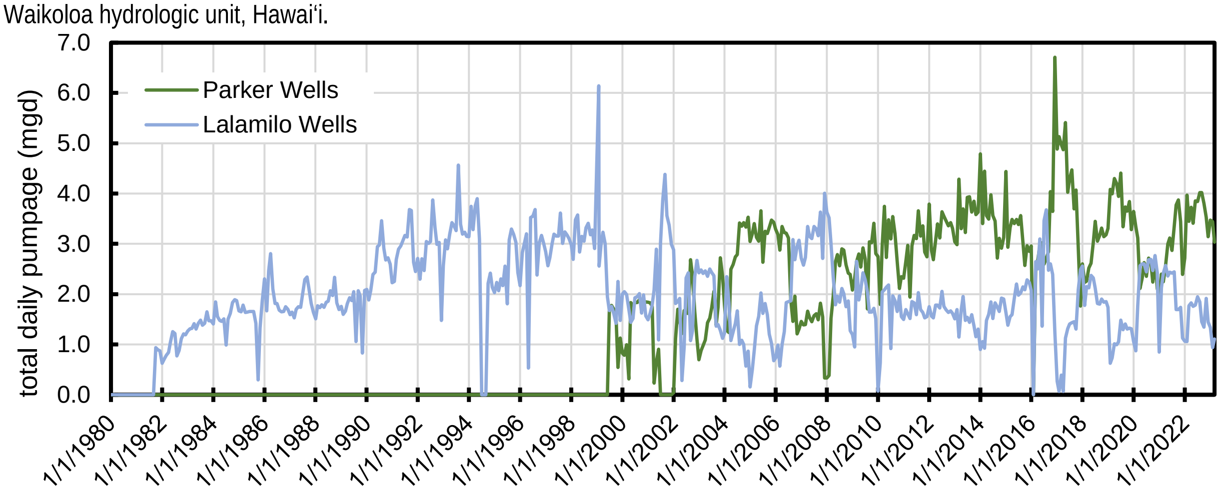


Figure 3-9. Monthly pumpage and chloride measurements for low elevation wells for non-potable irrigation of Mauna Kea Resort in the Waikoloa surface water hydrologic unit, Hawai‘i.

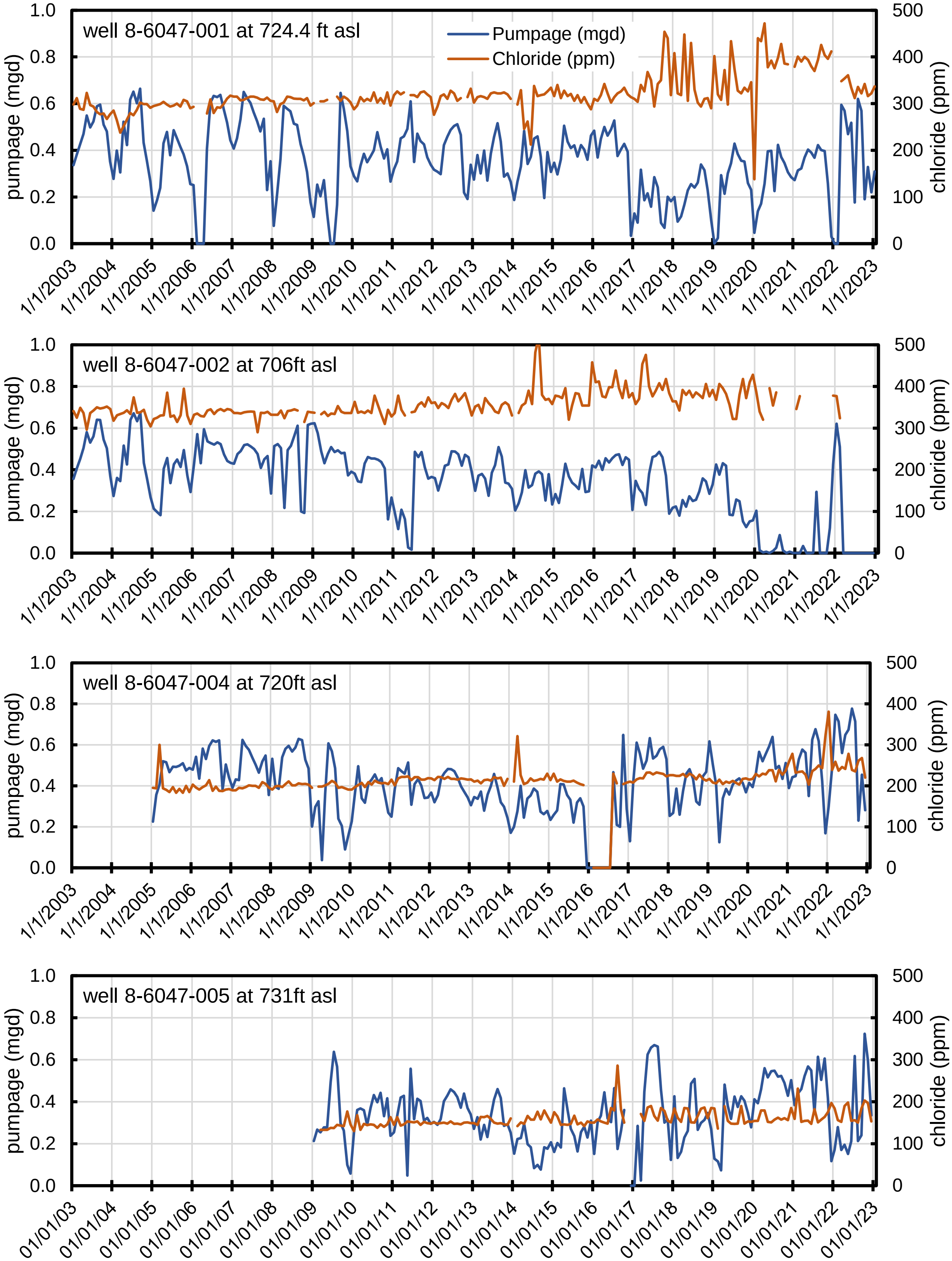


Figure 3-10. Top: Monthly total rainfall (inches, in) with 12-month moving average (blue line) at the Lalamilo Farm Rainfall station. Middle: water level discrete measurements and mean daily water level (feet above mean sea level, ft amsl) for two basal aquifer monitoring wells at differing elevations. Bottom: water level discrete measurements for a high level aquifer monitoring well in the Waikoloa surface water hydrologic unit, Hawaiʻi.

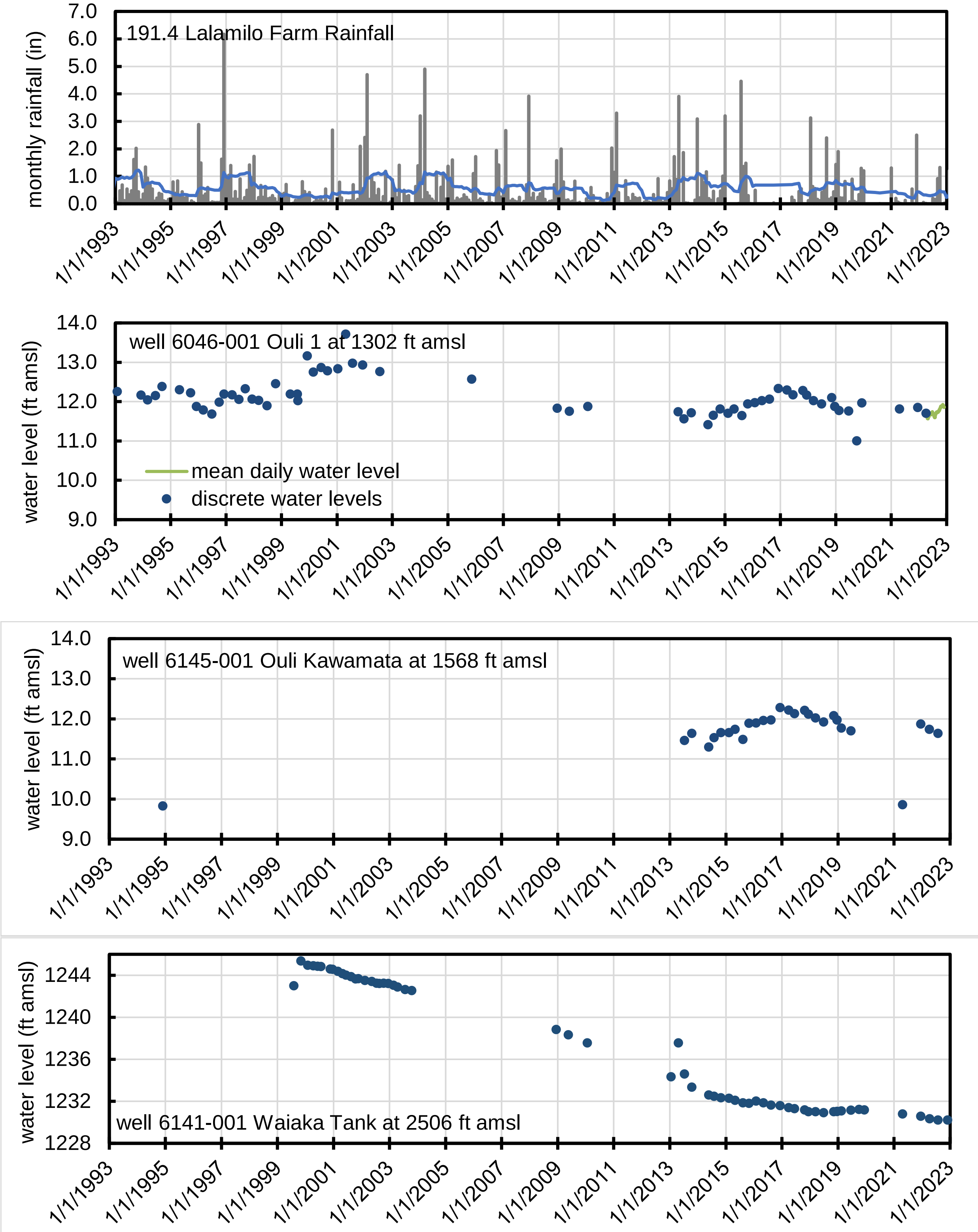
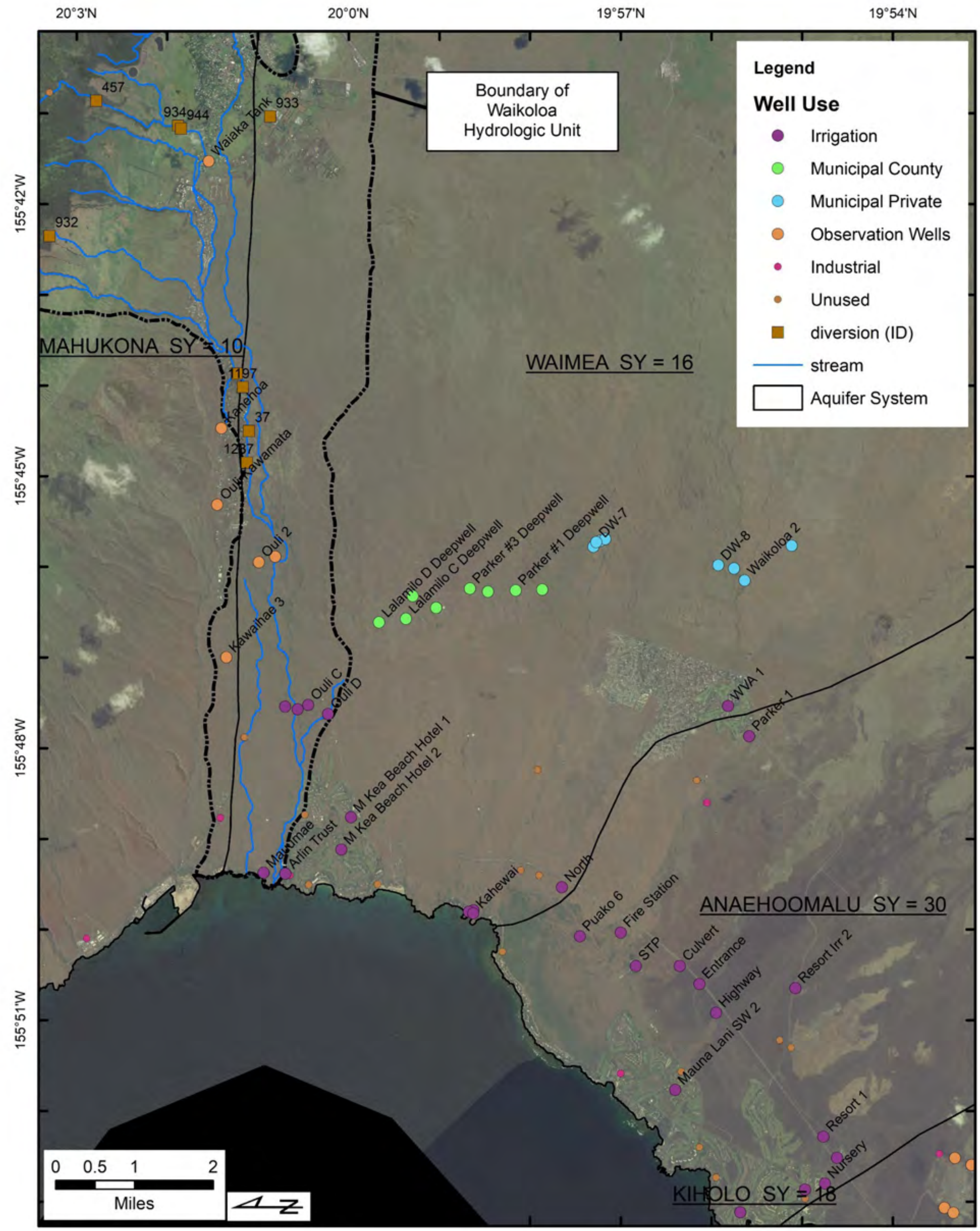


Figure 3-11. County municipal, private municipal, and irrigation wells for the coastal regions of the Mahukona, Waimea, and Anaehoomalu aquifer systems, along with observation wells labeled by well name.



## Streamflow Characteristics in the Waikoloa Hydrologic Unit

Streamflow has been continuously monitored at varying elevations in the Waikoloa and Kohākōhau streams over differing periods of time. One of the most common statistics used to characterize streamflow is the median flow in a particular time period. This statistic is also referred to as the flow at 50 percent exceedence probability, or the total flow that is equaled or exceeded 50 percent of the time ($TFQ_{50}$). The longer the time period that is used to determine the median flow value, the more representative of the flow conditions in the stream. Median flow is typically lower than the mean or average flow because of the bias in higher flows, especially during floods, present when calculating the mean flow. The flow at the 90 percent exceedence probability ($TFQ_{90}$) is commonly used to characterize low flows in a stream. In Hawai‘i, the baseflow is usually exceeded at least 90 percent of the time, and in many cases at least 70 percent of the time (Oki, 2003). Low-flow duration exceedance values measured at USGS stations near the Waikoloa hydrologic unit are provided in Table 3-5. Using index stations and record extension techniques, low-flow duration statistics for the current (1992-2021) climate period were generated for perennial streams in the Waikoloa hydrologic unit (Table 3-6) with associated model evaluation statistics (Table 3-7). The magnitude of specific low-flow duration values at USGS 16758000 was based on the period of overlapping records with USGS 16575000 from 1947 to 1971. Mean annual flow for complete calendar years of data are provided in Figure 3-12. Recent continuous monitoring records for Waikoloa Stream upstream of the Hawai‘i DWS intake at Marine Dam (USGS 16757000) and downstream of the intake (CWRM 8-253) are provided in Figure 3-13.

Table 3-5. Selected natural low-flow duration discharge exceedance values for the current (1992-2021) climate period for index stations near the Waikoloa hydrologic unit, Hawai‘i. [Flows are in cubic feet per second (million gallons per day)]

| station ID | stream name | drainage area (mi$^2$) | elevation (ft) | discharge (Q) for a selected percentage ($_{xx}$) discharge was equaled or exceeded | | | |
|---|---|---|---|---|---|---|---|
| | | | | $Q_{50}$ | $Q_{70}$ | $Q_{90}$ | $Q_{95}$ |
| 16720000 | Kawainui Stream | 1.54 | 4060 | 3.9 (2.49) | 1.42 (0.92) | 0.48 (0.31) | 0.30 (0.19) |
| 16725000 | Alakahi Stream | 0.83 | 3900 | 2.1 (1.34) | 0.77 (0.50) | 0.05 (0.03) | 0.02 (0.013) |

Table 3-6. Selected natural low-flow duration discharge exceedance values for the current (1992-2021) climate period based for Waikoloa hydrologic unit. [Flows are in cubic feet per second (million gallons per day)]

| station ID | stream name | drainage area (mi$^2$) | elevation (ft) | discharge (Q) for a selected percentage ($_{xx}$) discharge was equaled or exceeded | | | |
|---|---|---|---|---|---|---|---|
| | | | | $Q_{50}$ | $Q_{70}$ | $Q_{90}$ | $Q_{95}$ |
| 16757000 | Waikoloa Stream | 0.90 | 3580 | 2.4 (1.56) | 2.13 (1.38) | 1.66 (1.07) | 1.03 (0.67) |
| 16758000 | Waikoloa Stream | 1.40 | 3460 | 3.0 (1.94) | 2.43 (1.57) | 1.76 (1.14) | 1.38 (0.89) |
| 16756100 | Kohākōhau Stream | 2.48 | 3470 | 1.1 (0.71) | 0.70 (0.45) | 0.43 (0.28) | 0.35 (0.22) |

Table 3-7. Nash-Sucliff Efficiency (NSE) index, correlation coefficient, and root mean squared error for low-flow duration discharge exceedance values for the current (1992-2021) climate period in the Waikoloa hydrologic unit.

| station ID | stream name | Index Station | NSE | $R^2$ | RMSE |
|---|---|---|---|---|---|
| 16757000 | Waikoloa Stream | 16725000 | 0.862 | 0.864 | 0.155 |
| 16756100 | Kohākōhau Stream | 16720000 | 0.876 | 0.911 | 0.097 |

Figure 3-12. Mean annual flow in the Waikoloa hydrologic unit at various USGS stations. (Source: USGS, 2023)

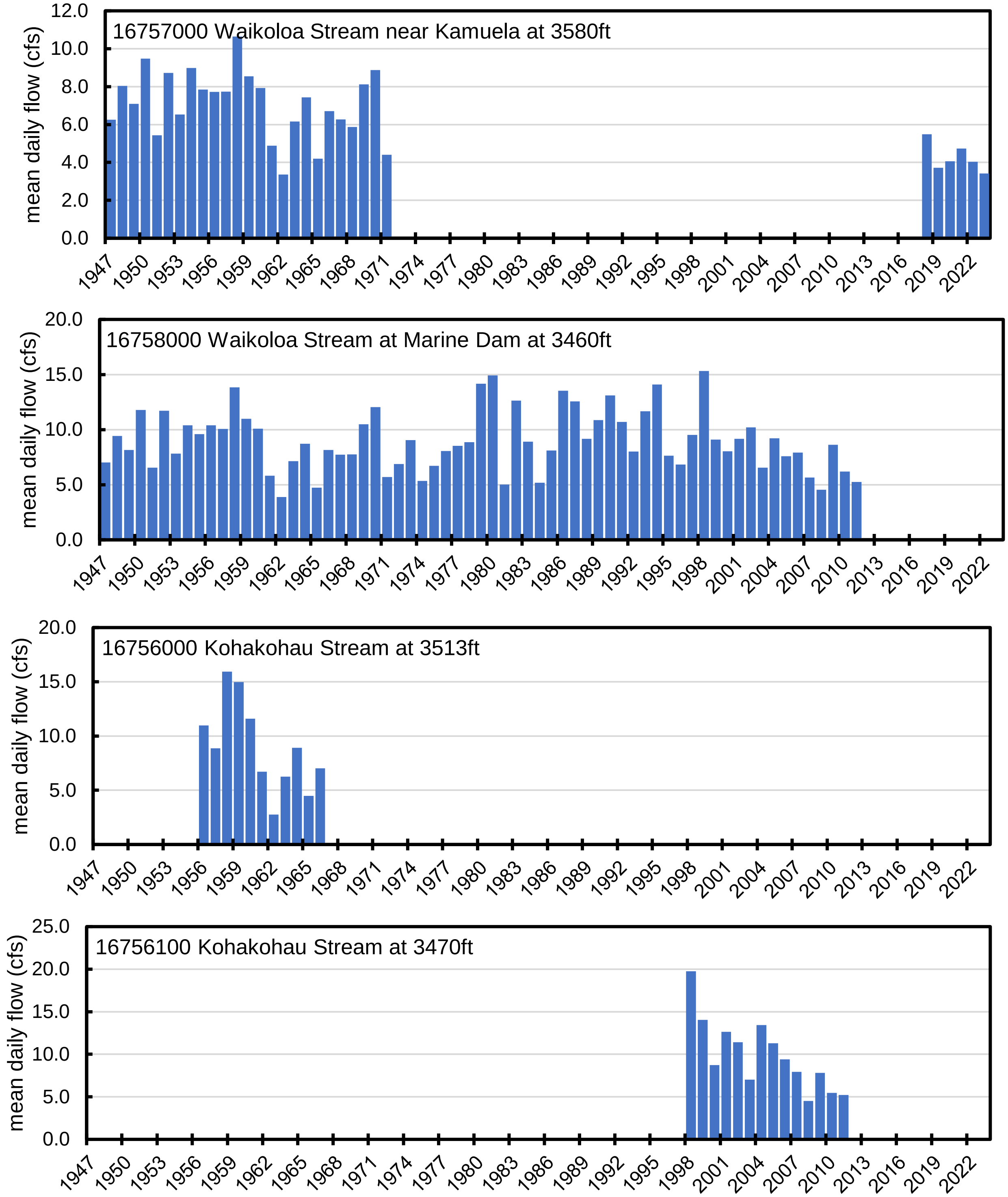
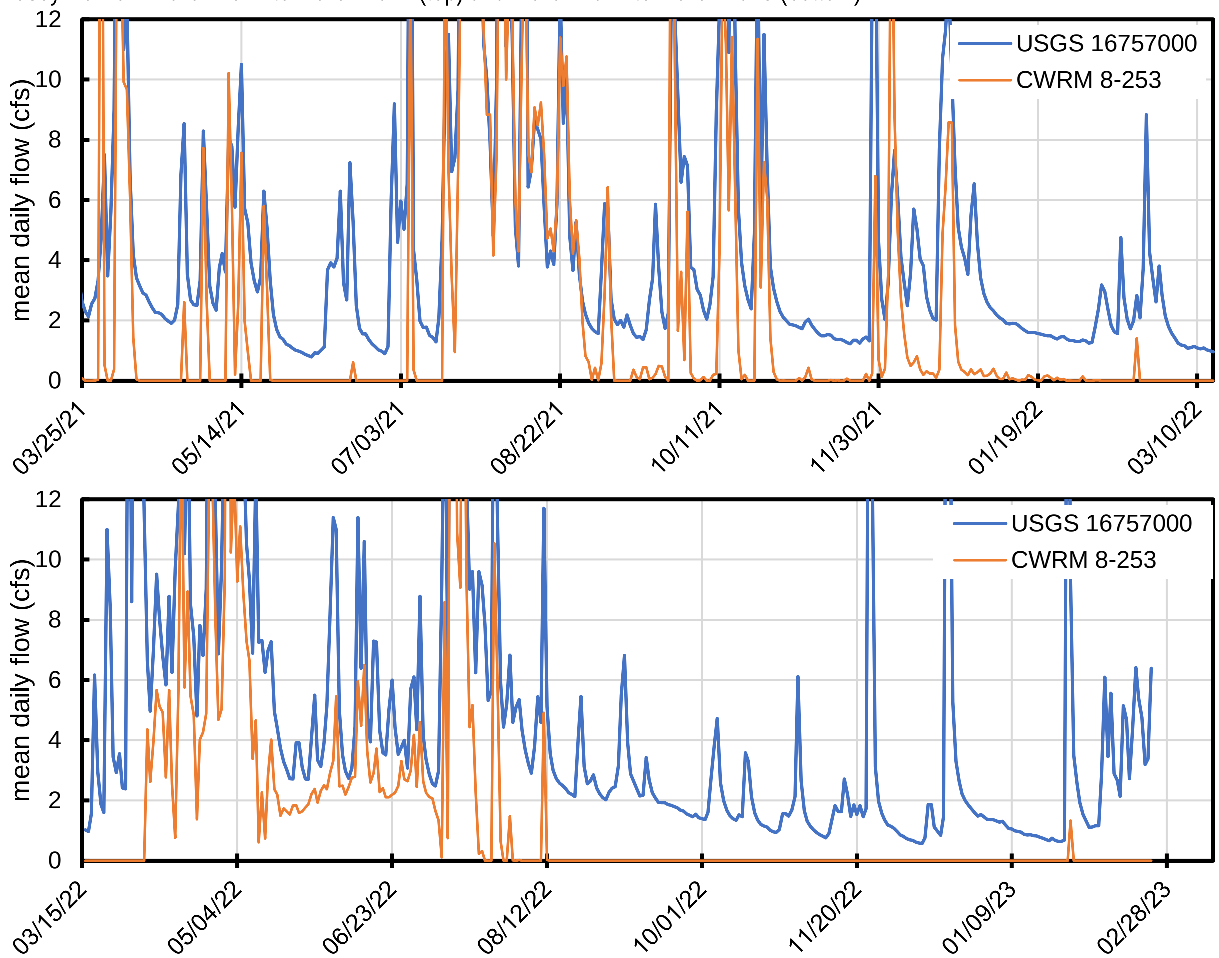


Figure 3-13. Mean daily flow at USGS 16757000 on Waikoloa Stream at 3,580 ft and at CWRM 8-253 on Waikoloa Stream at Lindsey Rd from March 2021 to March 2022 (top) and March 2022 to March 2023 (bottom).




## Continuous monitoring of Waikoloa Stream below DWS intake

From March 15, 2021 to February 23, 2023, Waikoloa Stream at USGS 16757000 had a median daily flow of 2.87 cfs, while Waikoloa Stream at Lindsey Rd had a median daily flow of 0.00 cfs (Figure 3-12). For this nearly two-year period of record, Waikoloa Stream at Lindsey Rd had a mean daily flow of zero (i.e., the stream was dry) for 53% of the time.

As expected, streamflow in Kohala Mountain is dependent on a combination of immediate rainfall conditions and long-term rainfall patterns (Figure 3-13). Using a General Linear Model, there was a significant ($p < 0.01$; NSE = 0.56; $X^2 = 0.69$) linear relationship predicting Waikoloa streamflow at Lindsey Road below the Hawai‘i DWS intake using the previous day’s total rainfall ($\beta = 0.423$, $p = 0.04$) and the previous 14-day total rainfall ($\beta = 0.033$, $p = 0.03$).

## Seepage Run Results on Waikoloa Stream

Discrete discharge measurements were made on October 27, 2021 at sites along selected reaches of Waikoloa Stream, Keanu'i'omanō Stream, and Wai'ula'ula Gulch, Hawai'i (Pagaduan et al. 2023). These discrete discharge measurements form what is commonly referred to as a “seepage run” (Table 3-8). The intent of the seepage run is to quantify the spatial distribution of streamflow along the reach during fair-weather, low-flow conditions, generally characterized by negligible direct runoff within the reach. The measurements can be used to characterize the net seepage of water into (water gain) or out of (water loss) the stream channel between measurement sites provided that the measurements were made during stable, nonchanging flow conditions (or, in some cases, were made simultaneously during transient flow conditions) and external surface inflows (for example, a tributary) or outflows (for example, a diversion) of water to the reach are quantified and accounted for in the computation of net seepage. During the period of data collection for the seepage run, the stage decreased 0.07 feet from 09:36 to 18:52 at site 7 indicated on the map included in this data release. Stage readings made at site 7 indicated that measurements were made during a recession, however the first measurement wasn't made until 12:07 after field personnel hiked to upper reach measurement sites. During the seepage run, approved records at USGS streamflow gaging station 16720000 on Kawainui Stream indicated an average discharge of about 2.83 cubic feet per second (cfs), with a stage decrease of 0.05 occurring between 12:00 to 19:00 hours. Results suggest that Waikoloa Stream is gaining from the 3580 ft elevation at USGS 16757000 downstream to the 3460 ft elevation at USGS 16758000 above the Hawaii DWS intake at Marine Dam. Approximately 2.49 cfs was diverted at Marine Dam and the stream lost approximately 1.58 cfs between 3470 ft elevation and the 2730 ft elevation, with a streamflow gain rate of 0.03 cfs per mile as the stream flows westward for the next 2.85 miles (Figure 3-13).

Figure 3-14. Relationship between the previous day total rainfall (closed circles), previous 5-day total rainfall (grey circles), and previous 14-day total rainfall (open circles) and point measurements on Waikoloa Stream at Lindsey Road by CWRM. Rainfall measured at SKN 197.1 Kamuela Mauka station.

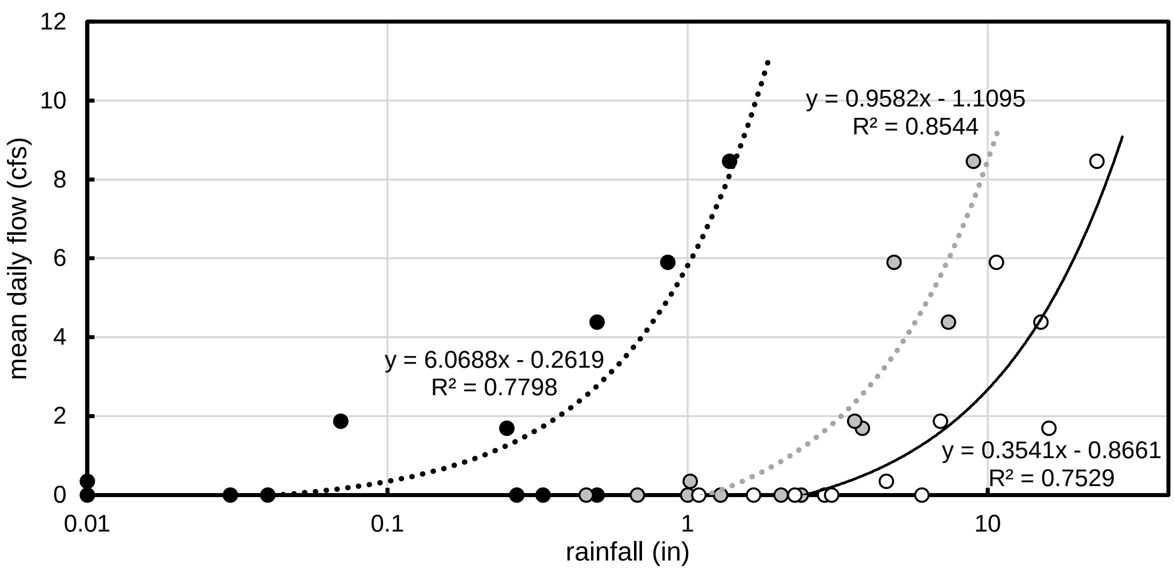
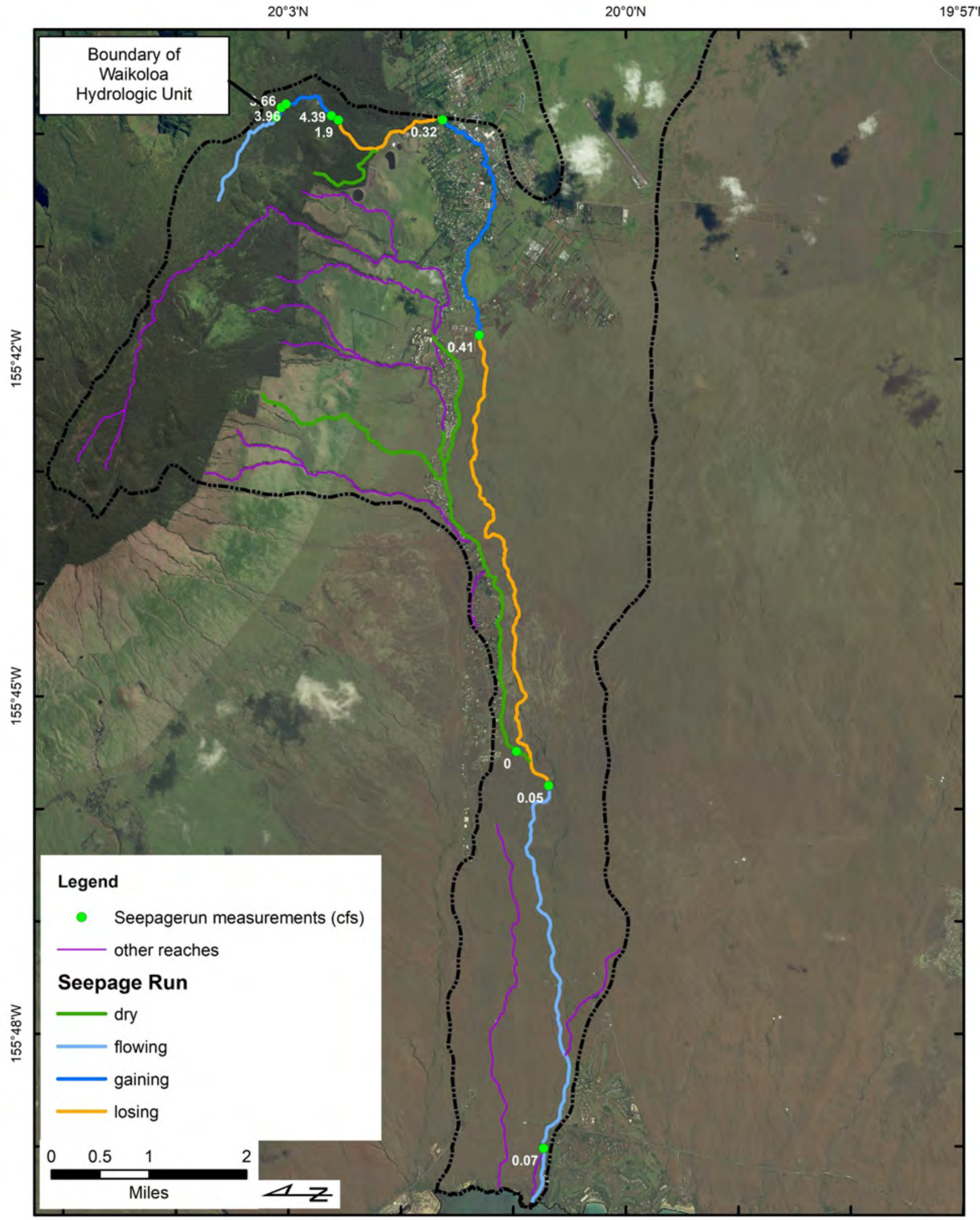



Table 3-8. Seepage run results for October 27, 2021 on Waikoloa Stream, Hawaiʻi. (Source: Pagaduan et al. 2023)

| Station name | USGS ID | Discharge (cfs) | Stream length (mi) | Seepage rate (cfs/mi) |
|---|---|---|---|---|
| Waikoloa Stream | 16757000 | 3.61 | | |
| Waikoloa Str US of diversion dam | 200304155394701 | 3.66 | 0.1 | 0.50 |
| Waikoloa Str DS of diversion dam | 200302155394401 | 3.96 | 0.07 | 4.29 |
| Waikoloa Str US of marine dam | 200241155394601 | 4.39 | 0.65 | 0.66 |
| Waikoloa Str DS of marine dam | 200234155395201 | 1.9 | 0.11 | 2.49 diverted |
| Waikoloa Str nr Kapiolani Rd. | 200138155395201 | 0.32 | 1.41 | -1.12 |
| Waikoloa Str nr transfer station | 200118155414801 | 0.41 | 2.85 | 0.03 |
| Waiulaula Gulch 0.2 mi DS of confluence | 200043155454401 | 0.05 | 5 | -0.07 |
| Waiulaula Gulch 350 ft US of Hwy 19 | 200040155484401 | 0.07 | 3.55 | 0.01 |

Figure 3-15. Seepage run results for Waikoloa Stream on October 27, 2021, Hawai'i. (Source: Pagaduan et al., 2023)



## Long-term trends in rainfall and streamflow

The climate has profound influences on the hydrologic cycle and in the Hawaiian Islands, shifting climate patterns have resulted in an overall decline in rainfall and streamflow. Rainfall trends are driven by large-scale oceanic and atmospheric global circulation patterns including large-scale modes of natural variability such as the El Nino Southern Oscillation and the Pacific Decadal Oscillation, as well as more localized temperature, moisture, and wind patterns (Frazier and Giambelluca, 2017; Frazier et al, 2018). Using monthly rainfall maps, Frazier and Giambelluca (2017) identified regions that have experienced significant ($p<0.05$) long-term decline in annual, dry season, and wet season rainfall from 1920 to 2012 and from 1983 to 2012. On Hawaiʻi, much of the leeward sides of Mauna Loa, Mauna Kea, and Kohala mountains has experienced a significant decline in annual and seasonal rainfall in the from 1920 to 2012, and for most of the island from 1983-2012 (Figure 3-15).

The decline in rainfall on Kohala mountain has contributed to a reduction in the baseflow and runoff that contributes to streamflow in Kawainui and Alakahi streams, as measured at USGS 16720000 and USGS 16725000, respectively (Figure 3-16). Reductions in streamflow is most obvious under low-flow conditions, where flow duration values have declined between 15% amd 90% between $Q_{50}$ and $Q_{99}$ at USGS 16725000 and between 3% and 12% at USGS 16720000. Declines in daily, 5-day, and 14-day total rainfall directly affect the frequency that streamflow overtops the Hawaiʻi DWS intake at Marine Dam on Waikoloa Stream (Figure 3-13).

In a different study, the USGS examined the long-term trends and variations in streamflow on the islands of Hawaiʻi, Maui, Molokaʻi, Oʻahu, and Kauaʻi, where long-term stream gaging stations exist (Oki, 2004). The study analyzed both total flow and estimated base flow at 16 long-term gaging stations. Figure 3-17 illustrates the results of the study for 7 long-term gaging stations around the islands. According to the analyses, low flows generally decreased from 1913 to 2002, which is consistent with the long-term downward trends in rainfall observed throughout the islands during that period. Monthly mean base flows decreased from the early 1940s to 2002, which is consistent with the measured downward trend of low flows from 1913 to 2002. This long-term downward trend in base flow may imply a reduction of groundwater contribution to streams. At a nearby long-term gaging stations on Kawainui Stream (USGS 16720000) and Alakahi Stream (USGS 16725000), which has been active continuously from 1964 to present day, trends in mean annual flow provide some context for the long-term decline in rainfall (Figure 3-18). Changing streamflow characteristics could pose a negative effect on the availability of drinking water for human consumption, habitat for native stream fauna, and traditional and customary practices (Oki, 2004).

Figure 3-16. Annual, wet season (Nov-Apr) and dry season (May-Oct) rainfall trends for the 1920-2012 (A) and 1983-2012 (B) periods, Hawai'i. Hashed line areas represent significant trend over the period.
(with permission from Frazier and Giambelluca, 2017)

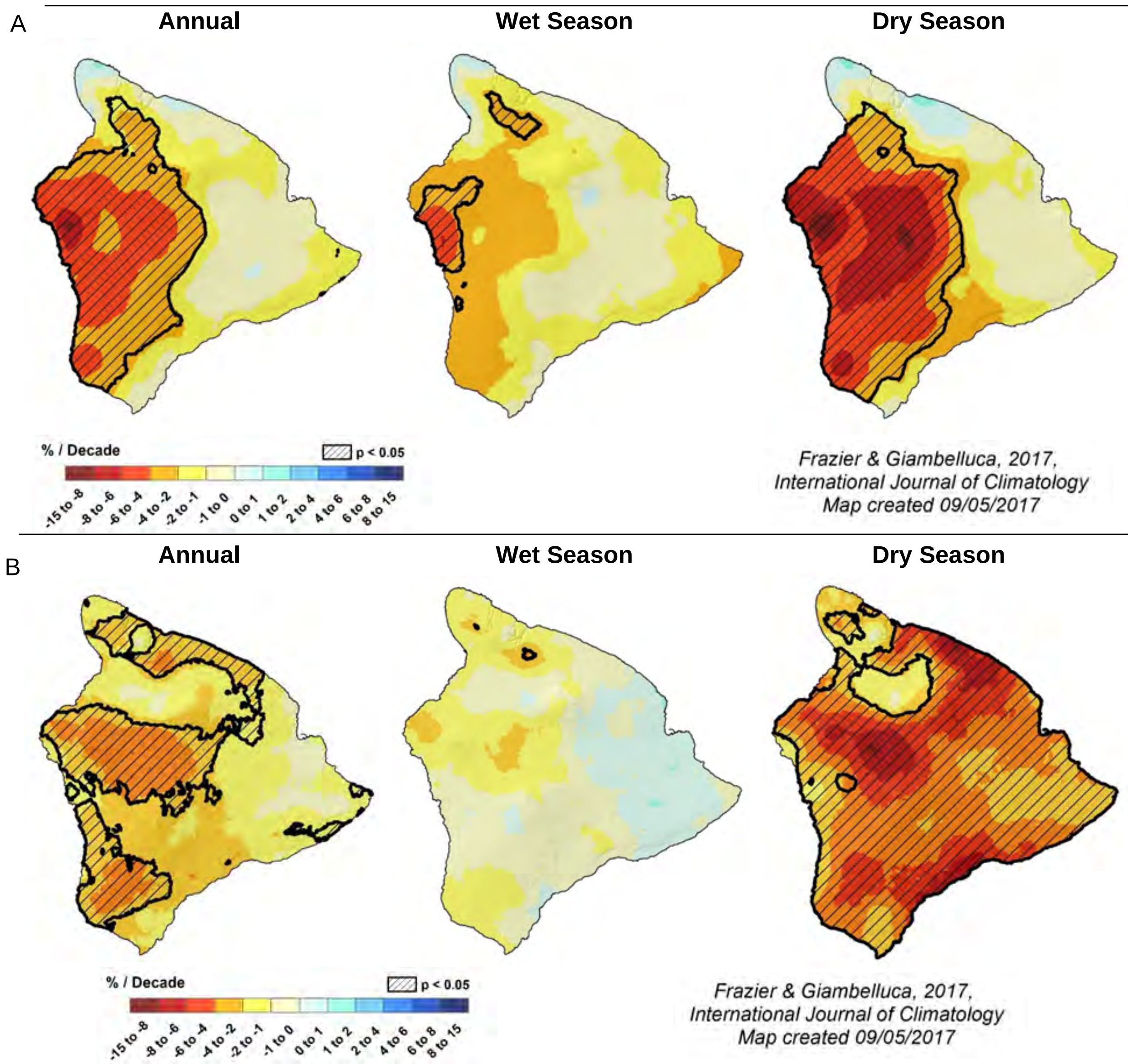


Figure 3-17. Change in flow duration curves for two US Geological Survey (USGS) stream gages on Kohala Mountain between the 1964-1991 and 1992-2021 periods of record.

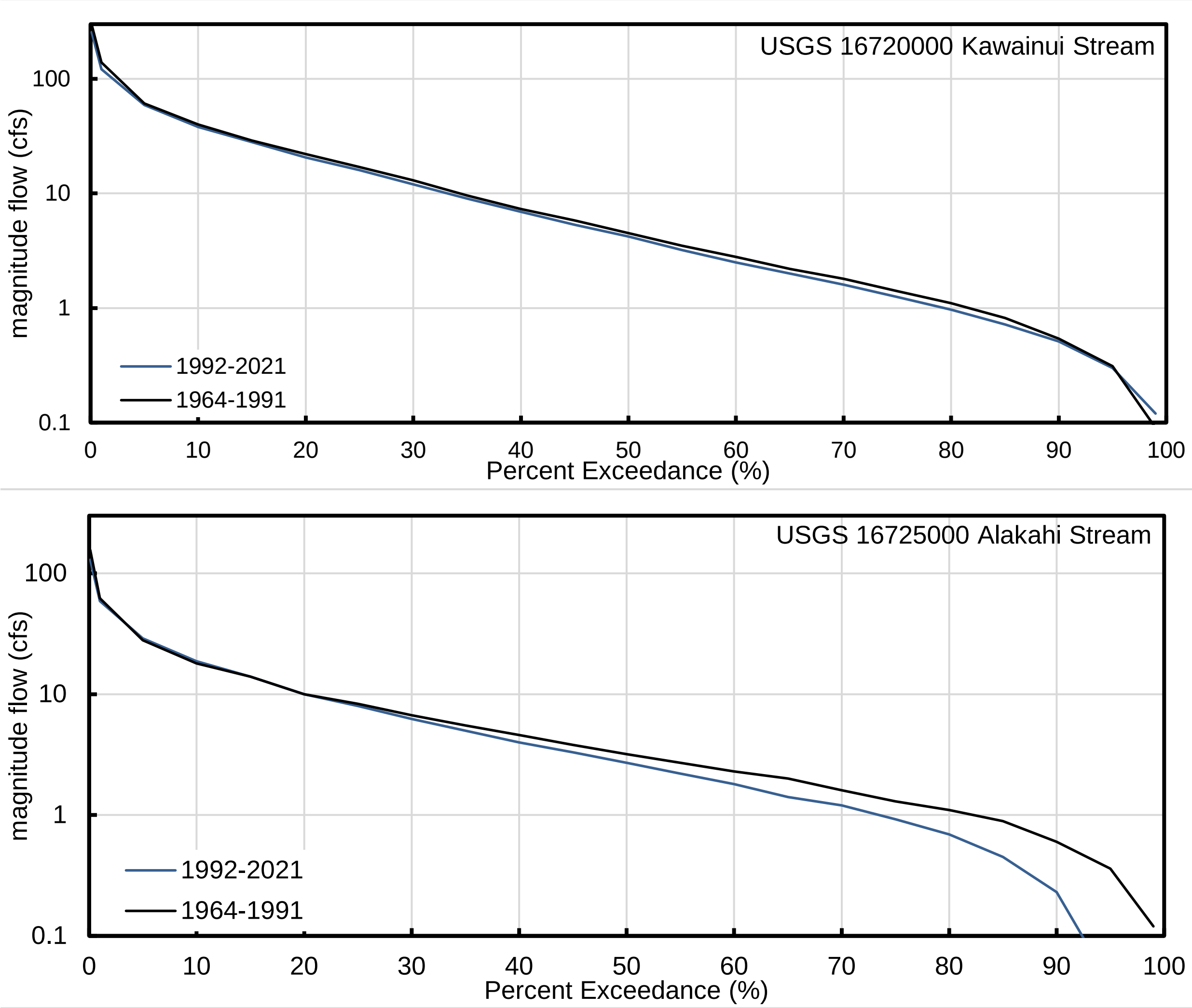


Figure 3-18. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii. This data is based on complete water years from 1913 through 2002. (Oki, 2004, Figure 4)

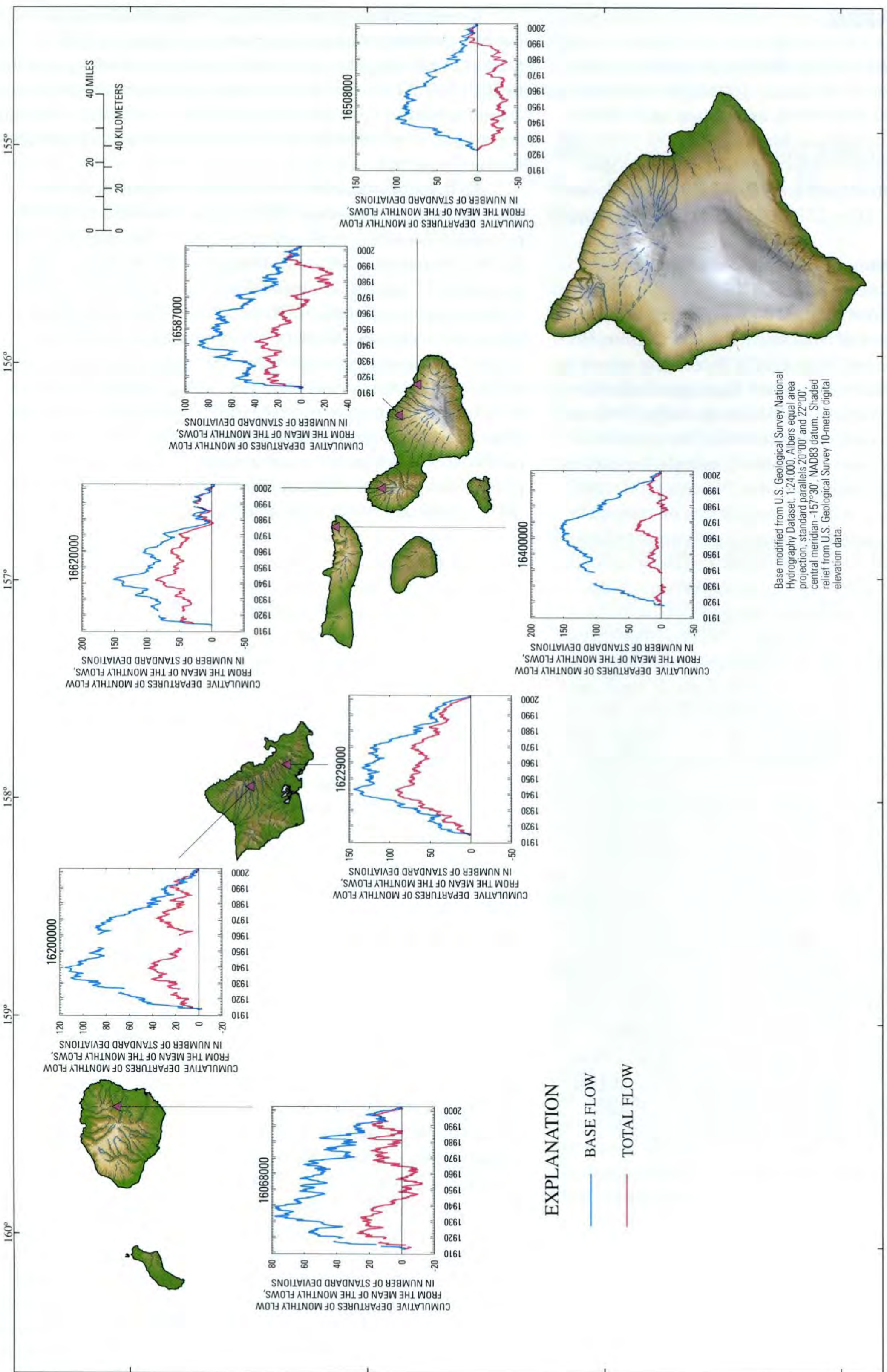
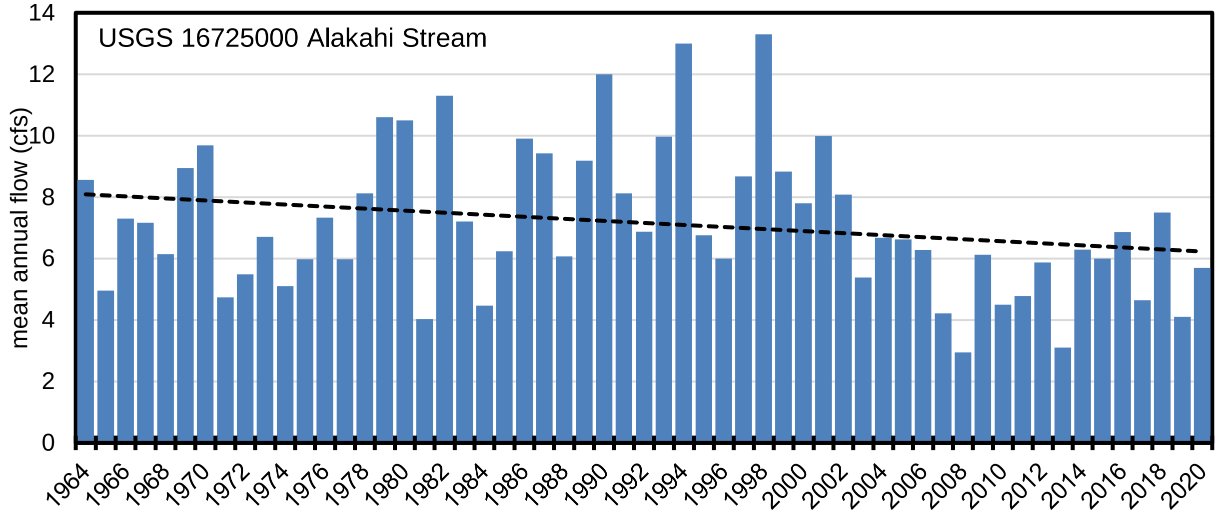
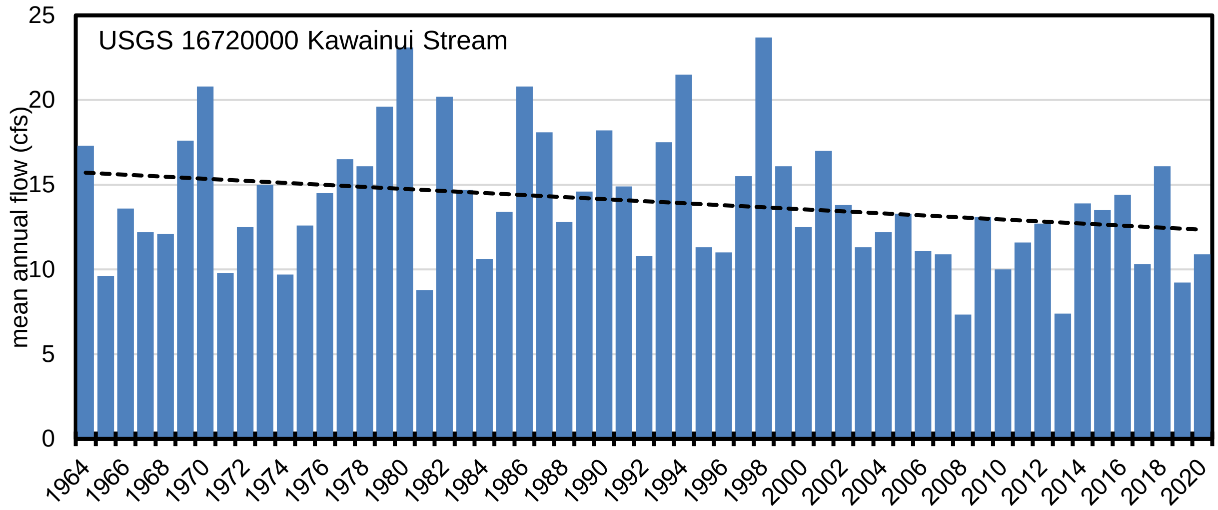


Figure 3-19. Mean annual flow (million gallons per day, mgd) at USGS station 16725000 on Alakahi Stream and at USGS station 16720000 on Kawainui Stream, Hawai'i. Line represents linear regression trend over the period of record. (Source: USGS, 2023)



# 4.0 Maintenance of Fish and Wildlife Habitat

When people in Hawaii consider the protection of instream flows for the maintenance of fish habitat, their thoughts generally focus on just a handful of native species including five native fishes (four gobies and one eleotrid), two snails, one shrimp, and one prawn. Table 4-1 below identifies commonly mentioned native stream animals of Hawaii.

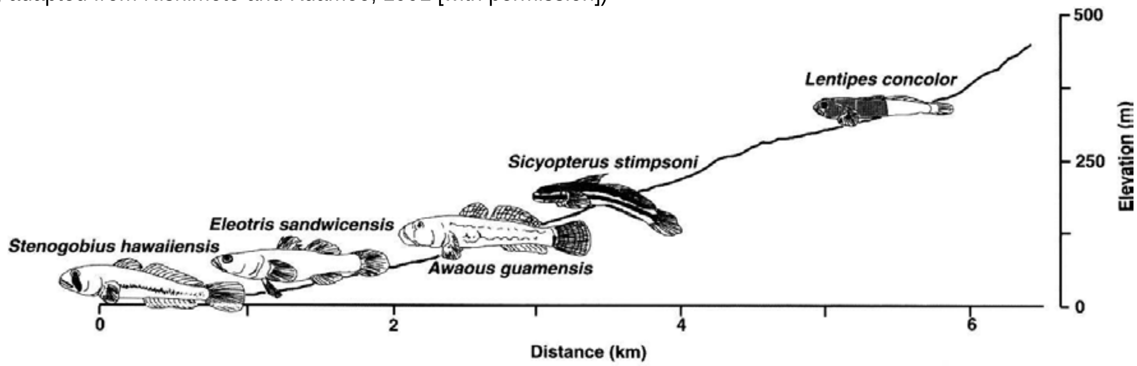
Table 4-1. List of commonly mentioned native stream organisms. (Source: State of Hawaii, Division of Aquatic Resources, 1993)

| Scientific Name | Hawaiian Name | Type |
|---|---|---|
| *Awaous stamineus* | ʻOʻopu nakea | Goby |
| *Lentipes concolor* | ʻOʻopu hiʻukole (alamoʻo) | Goby |
| *Sicyopterus stimpsoni* | ʻOʻopu nopili | Goby |
| *Stenogobius hawaiiensis* | ʻOʻopu naniha | Goby |
| *Eleotris sandwicensis* | ʻOʻopu akupa (okuhe) | Eleotrid |
| *Atyoida bisulcata* | ʻOpae kalaʻole | Shrimp |
| *Macrobrachium grandimanus* | ʻOpae ʻoehaʻa | Prawn |
| *Neritina granosa* | Hihiwai | Snail |
| *Neritina vespertina* | Hapawai | Snail |

Hawaii's native stream animals have amphidromous life cycles (Ego, 1956) meaning that they spend their larval stages in the ocean (salt water), then return to freshwater streams to spend their adult stage and reproduce. Newly hatched fish larvae are carried downstream to the ocean where they become part of the planktonic pool in the open ocean. The larvae remain at sea from a few weeks to a few months, eventually migrating back into a fresh water stream as juvenile *hinana*, or postlarvae (Radtke et al., 1988). Once back in the stream, the distribution of the five native fish species are largely dictated by their climbing ability (Nishimoto and Kuamoo, 1991) along the stream's longitudinal gradient. This ability to climb is made possible by a fused pelvic fin which forms a suction disk. *Eleotris sandwicensis* lacks fused pelvic fins and is mostly found in lower stream reaches. *Stenogobius hawaiiensis* has fused pelvic fins, but lacks the musculature necessary for climbing (Nishimoto and Kuamoo, 1997). *Awaous guamensis* and *Sicyopterus stimpsoni* are able to ascend moderately high waterfalls (less than ~20 meters) (Fitzsimons and Nishimoto, 1990), while *Lentipes concolor* has the greatest climbing ability and has been observed at elevations higher than 3,000 feet (Fitzsimons and Nishimoto, 1990) and above waterfalls more than 900 feet in vertical height (Englund and Filbert, 1997). Figure 4-1 illustrates the elevational profile of these native freshwater fishes.

The maintenance, or restoration, of stream habitat requires an understanding of and the relationships among the various components that impact fish and wildlife habitat, and ultimately, the overall viability of a desired set of species. These components include, but are not limited to, species distribution and diversity, species abundance, predation and competition among native species, similar impacts by alien species, obstacles to migration, water quality, and streamflow. The Commission does not intend to delve into the biological complexities of Hawaiian streams, but rather to present basic evidence that conveys the general health of the subject stream. The biological aspects of Hawaii's streams have an extensive history, and there is a wealth of knowledge, which continues to grow and improve.

Figure 4-1. Elevational profile of a terminal-estuary stream on the Big Island of Hawaii (Hakalau Stream). (Source: McRae, 2007, adapted from Nishimoto and Kuamoo, 1991 [with permission])




## Hawaii Stream Assessment

One of the earliest statewide stream assessments was undertaken by the Commission in cooperation with the National Park Service's Hawaii Cooperative Park Service Unit. The 1990 Hawaii Stream Assessment (HSA) brought together a wide range of stakeholders to research and evaluate numerous stream-related attributes (e.g., hydrology, diversions, gaging, channelizations, hydroelectric uses, special areas, etc.). The HSA specifically focused on the inventory and assessment of four resource categories: 1) aquatic; 2) riparian; 3) cultural; and 4) recreational. Though no field work was conducted in its preparation, the HSA involved considerable research and analysis of existing studies and reports. The data were evaluated according to predefined criteria and each stream received one of five ranks (outstanding, substantial, moderate, limited, and unknown). Based on the stream rankings, the HSA offered six different approaches to identifying candidate streams for protection: streams with outstanding resources (aquatic, riparian, cultural or recreational), streams with diverse or "blue ribbon" resources, streams with high quality natural resources, streams within aquatic resource districts, free flowing streams, or streams within the National Wild and Scenic Rivers database.

Due to the broad scope of the HSA inventory and assessment, it continues to provide a valuable information base for the Commission's Stream Protection and Management Program and will continue to be referred to in various sections throughout this report. The HSA recommend that the Waikoloa stream be listed as a candidate stream for protection based on its outstanding cultural, moderate recreational, and limited aquatic resources. Waikoloa is considered to have "blue ribbon" cultural resources identified by the HSA for protection.

## DAR Atlas of Hawaiian Watersheds

The HSA inventory was general in nature, resulting in major data gaps, especially those related to the distribution and abundance of aquatic organisms – native and introduced – inhabiting the streams. The State of Hawaii Division of Aquatic Resources (DAR) has since continued to expand the knowledge of aquatic biota in Hawaiian streams. Products from their efforts include the compilation and publication of an *Atlas of Hawaiian Watersheds and Their Aquatic Resources* for each of five major islands in the state (Kauai, Hawaii, Oahu, Molokai, and Maui). Each atlas describes watershed and stream features, distribution and abundance of stream animals and insect species, and stream habitat use and availability. Based on these data, a watershed and biological rating is assigned to each stream to allow easy comparison with other streams on the same island and across the state. The data presented in the atlases are collected from various sources, and much of the stream biota data are from stream surveys conducted by DAR. Currently, efforts have been focused on updating the atlases with more recent stream survey data collected statewide, and developing up-to-date reports for Commission use in interim IFS recommendations. A copy of the updated inventory report for Waikoloa is in Appendix A. The following is a summary of the findings.

- **Point Quadrat Survey.** In the Waikoloa watershed, stream surveys were conducted in 1968, 1990, 1992, 1994, 1999, 2000, and 2001 by the Division of Aquatic Resources, USFWS, or the Bishop Museum (Table 4-2 and 4-3). Surveys were conducted on reaches at all elevations.

- **Insect Survey.** The Waikoloa hydrologic unit did not meet the criteria as a biotic stream of importance for native insect diversity (>19 spp), native macrofauna diversity (>5 spp.), or abundance of any native species.

- **Watershed and Biological Rating.** The Waikoloa watershed has a moderate rating for Hawai‘i and statewide for land cover due to the high percentage of conservation land. The lack of wetland and estuarine reaches give the watershed a low rating for shallow waters on Hawai‘i and statewide. The watershed rates poorly for stewardship due to the degree of land and biodiversity protection, pasture land use which is incompatible with native species, and invasive species. Waikoloa Stream has a high rating for stream size, a low rating for wetness, and a high reach diversity rating, resulting in a moderate total watershed rating for Hawai‘i and statewide. The watershed had a moderate rating for number of native species found but a low rating for number of introduced species, resulting in an low score for both all species and a total biological rating for the island and the state. These scores combined gave Waikoloa watershed an slightly below average overall watershed rating.

Table 4-2. Present (P) of native species by stream reach for the Waikoloa Hydrologic unit, Hawaii. (Source: DAR, 2006)

| species | Estuary | Lower | Middle | Upper | Headwaters |
|---|---|---|---|---|---|
| *Atyoida bisulcata* | | | P | P | |
| *Lentipes concolor* | | | | P | |
| *Awaous stamineus* | | P | P | P | |
| *Eleotris sandwicensis* | | | | | |
| *Sicyopterus stimpsoni* | | P | P | P | |
| *Stenogobius hawaiiensis* | | | | | |
| *Macrobrachium grandimanus* | | P | | | |

Table 4-3. Density (# per $m^2$) observed by species and reach elevation in DAR point quadrat surveys in Waikoloa Stream, Hawai‘i.

| species | Estuary | Lower | Middle | Upper | Headwaters |
|---|---|---|---|---|---|
| *Atyoida bisulcata* | | | | | |
| *Lentipes concolor* | | | | 0.736 | |
| *Awaous stamineus* | | 1.104 | 0.343 | 0.619 | |
| *Eleotris sandwicensis* | | | | | |
| *Awaous stamineus* | | 0.159 | 0.050 | | |
| *Stenogobius hawaiiensis* | | | | | |
| *Macrobrachium grandimanus* | | | | | |

The distribution of positive visual detections for *Awaous stamineus, Lentipes concolor, and Awaous stamineus* are provided in Figure 4-2, Figure 4-3, and Figure 4-4.

Figure 4-2. Distribution of positive detections of *Awaous stamineus* (ʻoʻopū nākea) in February or September 1992 from point-quadrant visual surveys conducted by the State of Hawaiʻi Division of Aquatic Resources.

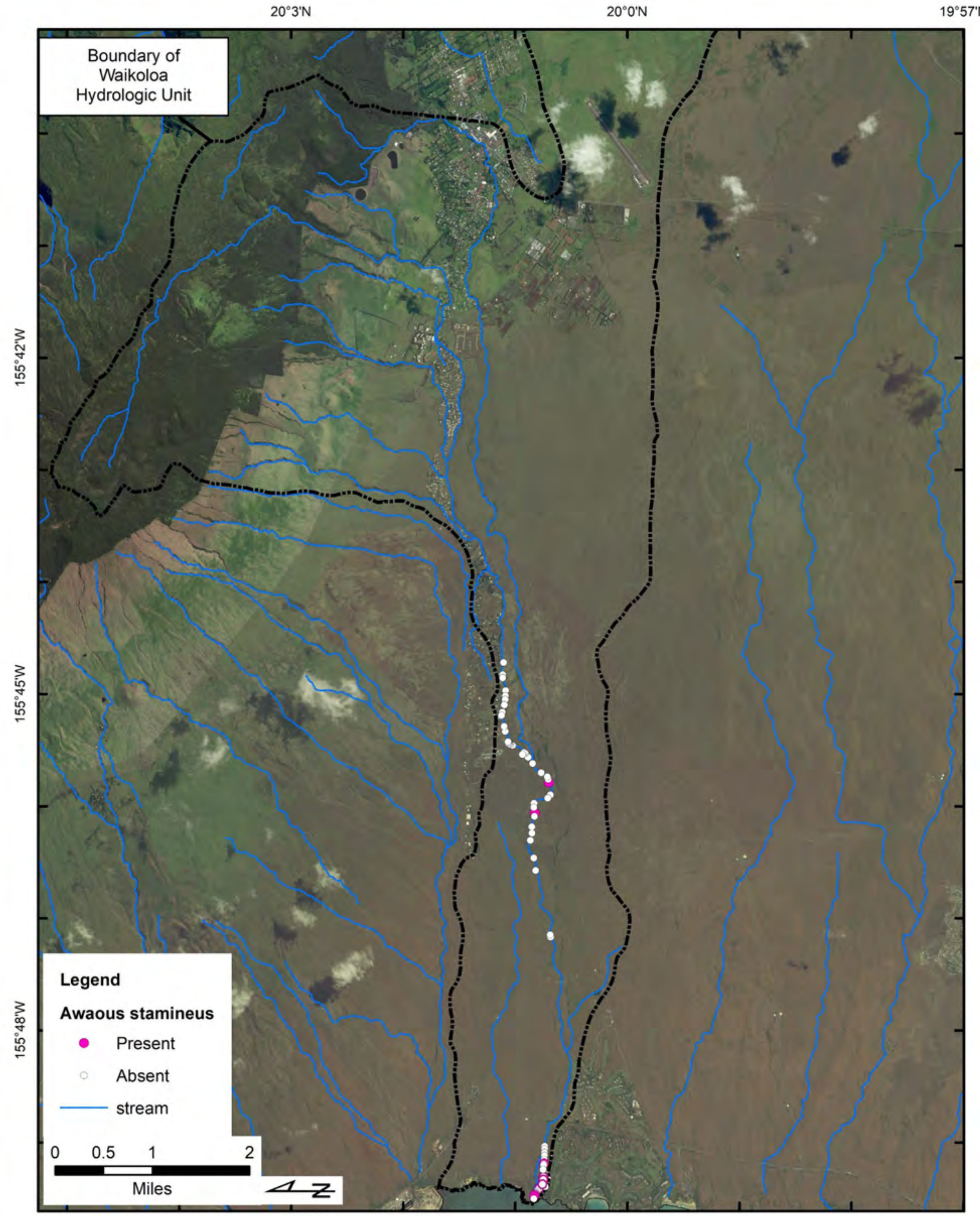


Figure 4-3. Distribution of positive detections of *Lentipes concolor* (‘o‘opū alamo‘o) in February or September 1992 from point-quadrant visual surveys conducted by the State of Hawai‘i Division of Aquatic Resources.

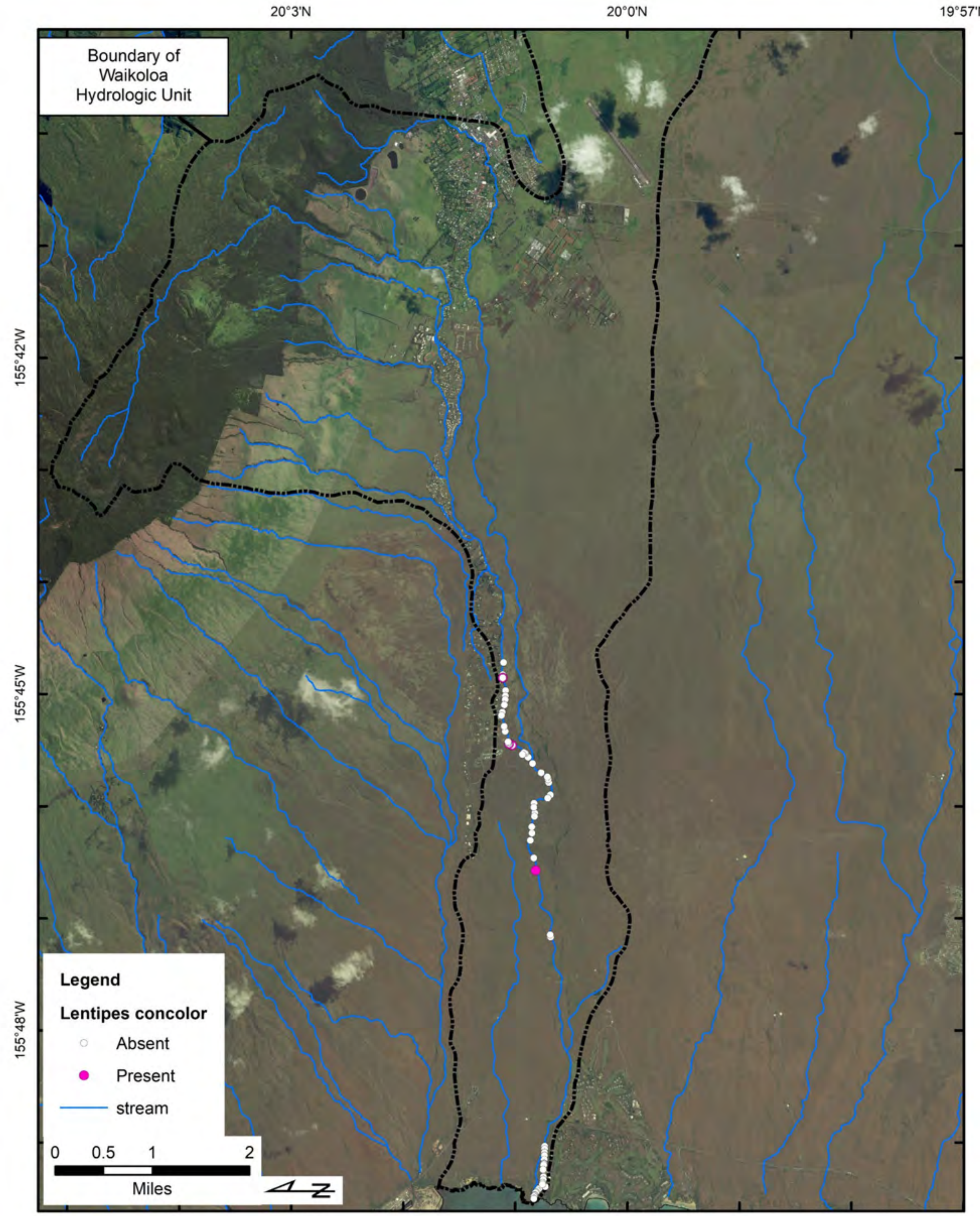
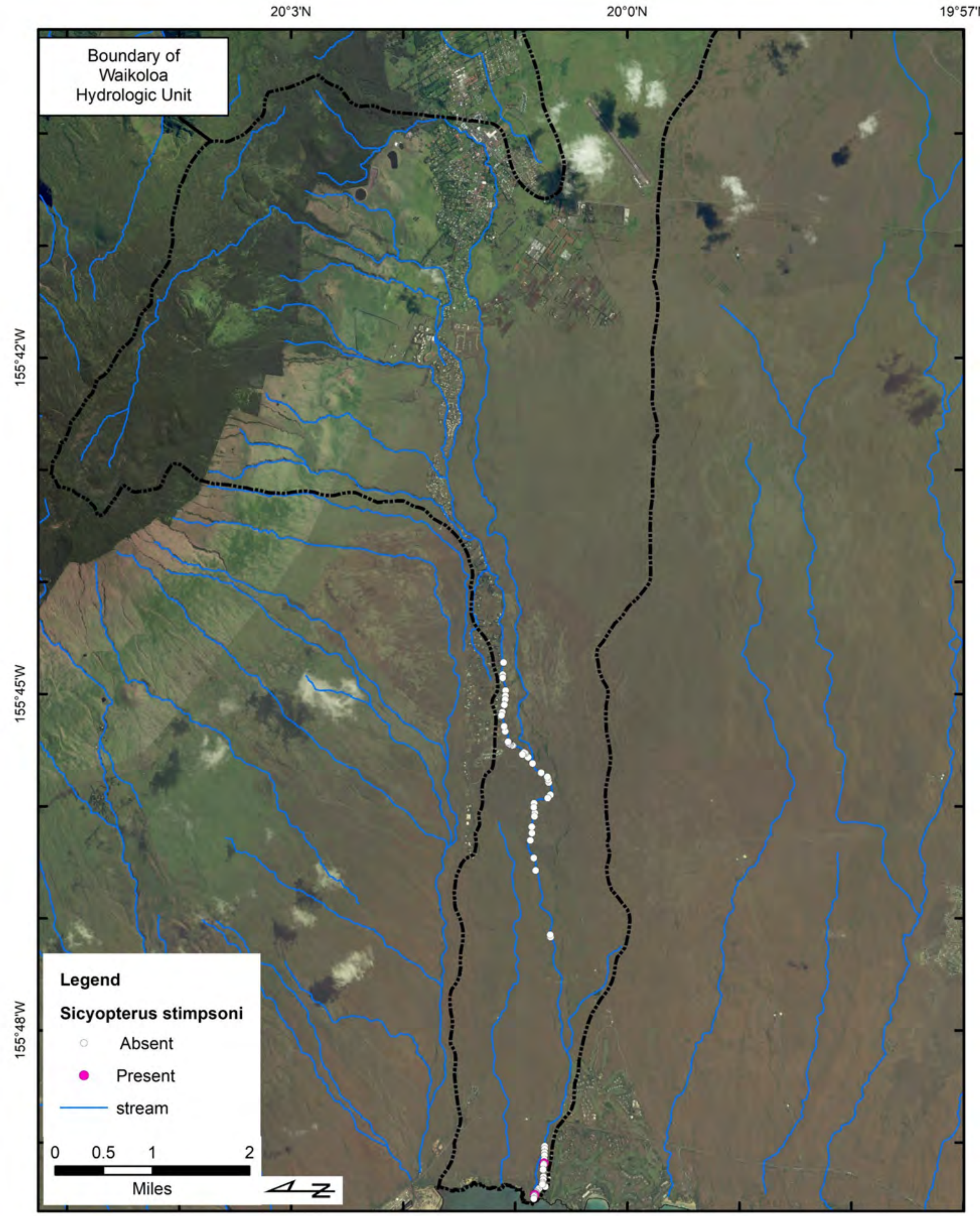


Figure 4-4. Distribution of positive detections of *Sicyopterus stimpsoni* (ʻoʻopū nopili) in February or September 1992 from point-quadrant visual surveys conducted by the State of Hawaiʻi Division of Aquatic Resources.



## 5.0 Outdoor Recreational Activities

Water-related recreation is an integral part of life in Hawaii. Though beaches may attract more users, the value of maintaining streamflow is important to sustaining recreational opportunities for residents and tourists alike. Streams are often utilized for water-based activities, such as boating, fishing, and swimming, while offering added value to land-based activities such as camping, hiking, and hunting. Growing attention to environmental issues worldwide has increased awareness of stream and watershed protection and expanded opportunities for the study of nature; however, this must be weighed in conjunction with the growth of the eco-tourism industry and the burdens that are placed on Hawaii's natural resources.

The Hawaii Stream Assessment identified hiking and scenic views as recreational opportunities in the Waikoloa hydrologic unit with four high quality experiences, providing a "substantial" regional ranking (2 out of 4), and not recommending it for statewide ranking (National Park Service, 1990). Bird and mammal hunting is available in 6.495 square miles (percent) of the Waikoloa hydrologic unit within the Puu O Umi Natural Area Reserve, the Mauna Kea Forest Reserve, and the Kohala Watershed Forest Reserve (Figure 5-2).

Beyond all the archeological evidence that suggests there were pathways and roads constructed by Hawaiians throughout the hydrologic unit, there are two current efforts to construct trails that provide recreation and aesthetic value:

1. ʻŌuli Park along Keanuʻiomano Stream below the confluence with Kohakohau Stream along Kawaihae Road, approximately three miles west of Waimea town. The park is part of the Hawaii Dryland Forest restoration plan of Kaʻahahui ʻO Ka Nāhelehele. This park trail is a priority in the South Kohala Community Development Plan. A park management plan is available at: https://www.drylandforest.org/dry-forest-corridors/ouli-park

2. Ke Ala Kahawai streamside trail winds its way through Waimea Town along Waikoloa Stream for 1.04 miles (Figure 5-1). Part of the trail traverses Waimea Natural Park. This Park along Waikoloa Stream in Waimea Town features 11 planting beds with 36 species of native Hawaiian groundcover, shrubs, and trees. The park offers educational material and the largest collection of ohia lehua trees in the world. The park's mission is to provide a peaceful, accessible area with an education center that cultivates life-long stewardship of the ʻaina for the greater Kohala community. The park is managed by the Waimea Branch of the Outdoor Circle and its general information can be found at: https://www.waimeaoutdoorcircle.org/uploads/3/7/9/7/37971713/natureparkbk.pdf

Additionally, there is a coastal trail that connects Hapuna Beach with Mauna Kea Beach that is part of the Na Ala Hele State Trails program.

Figure 5-1. Map of Ke Ala Kahawai streamside trail in Waimea Town as depicted in the final environmental assessment. (County of Hawai'i, 2011)

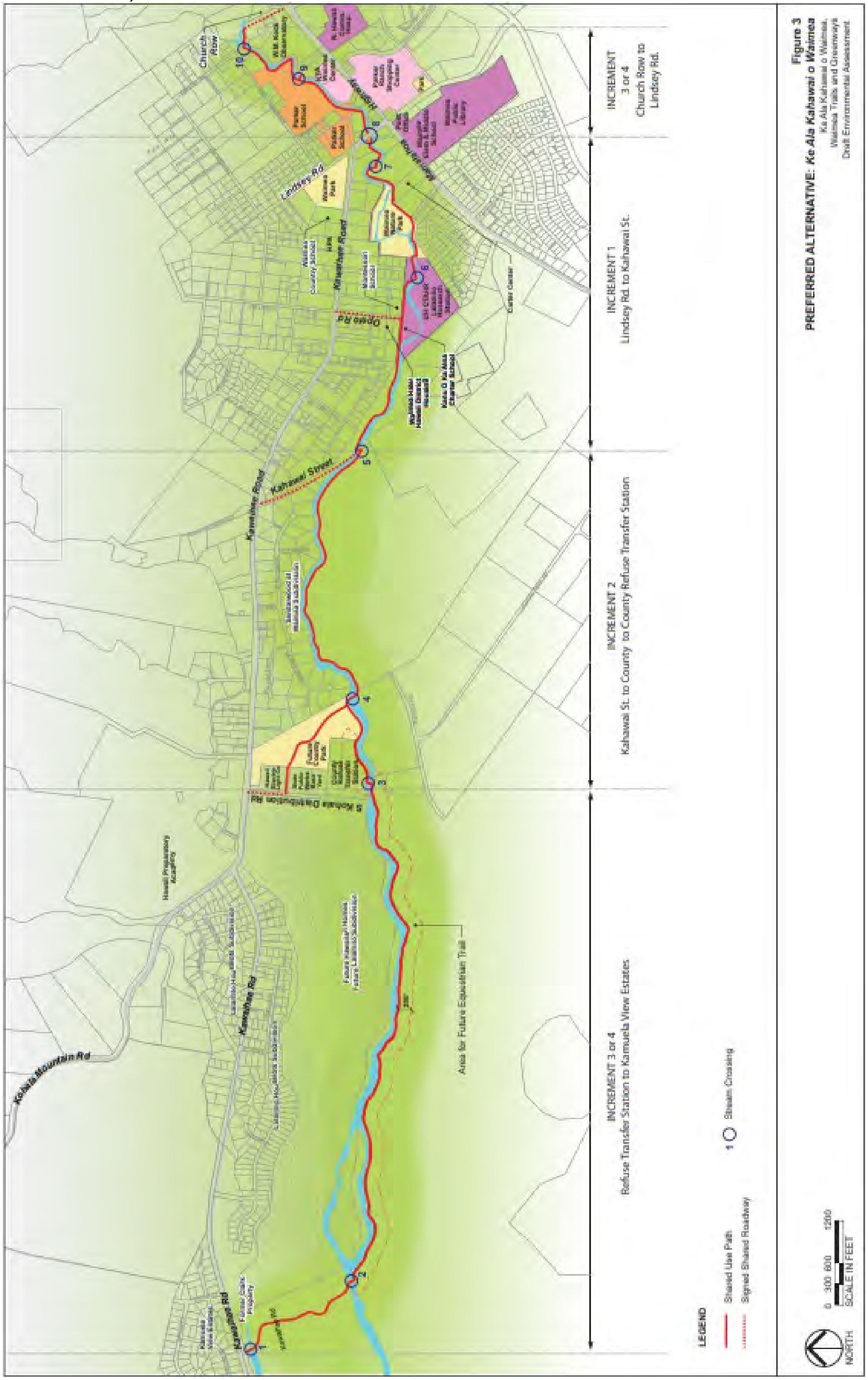
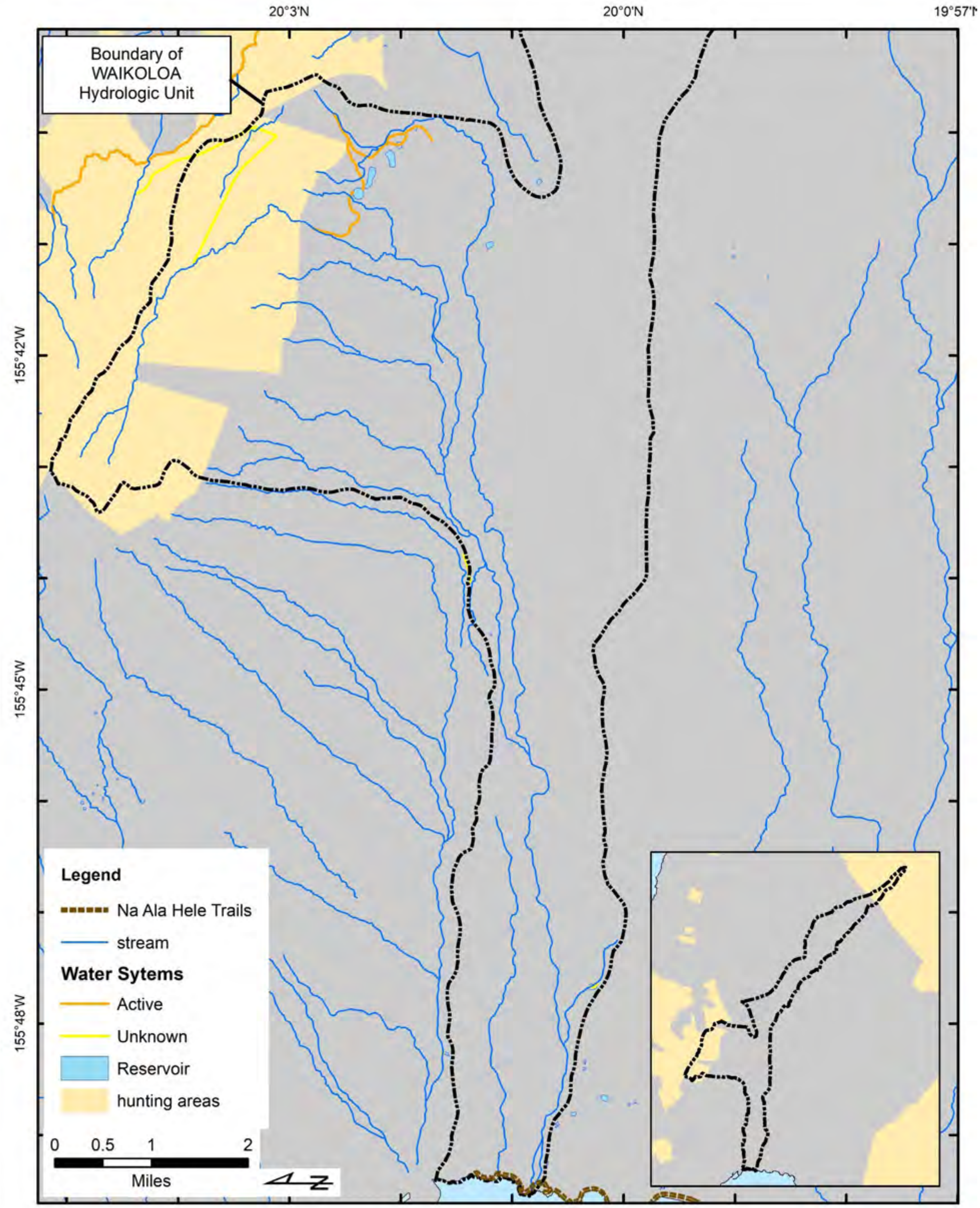


Figure 5-2. Public hunting areas for game mammals and locations for other recreational activies in the Waikoloa hydrologic unit, Hawaiʻi. (Source: State of Hawaii, Office of Planning, 2015)

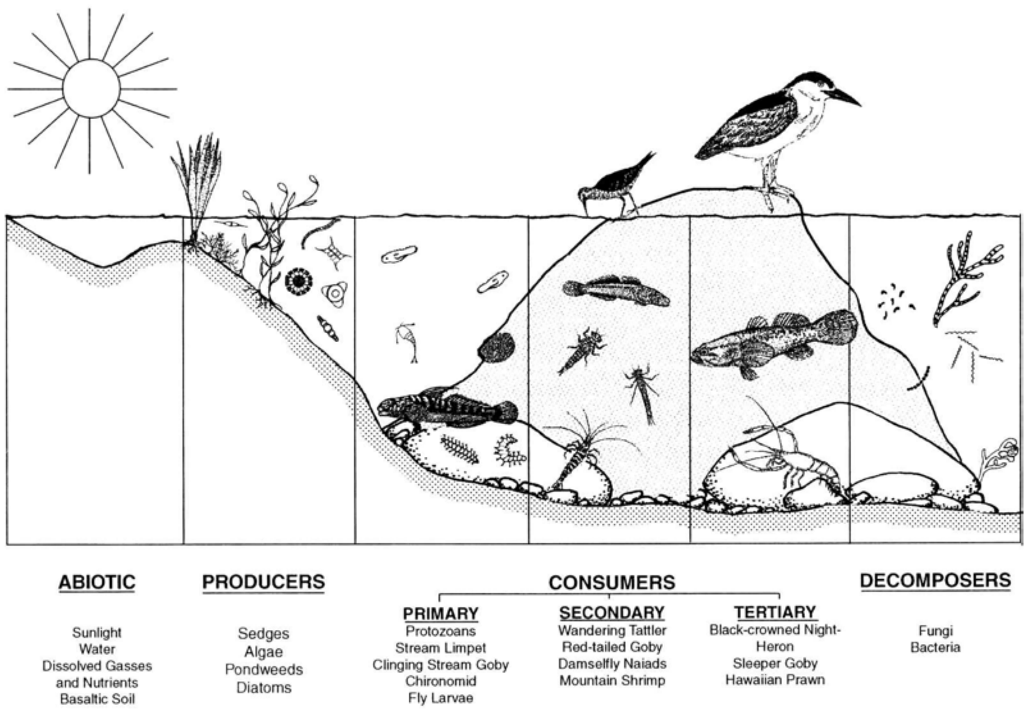


# 6.0 Maintenance of Ecosystems

An ecosystem can be generally defined as the complex interrelationships of living (biotic) organisms and nonliving (abiotic) environmental components functioning as a particular ecological unit. Depending upon consideration of scale, there may be a number of ecosystem types that occur along a given stream such as estuaries, wetlands, and stream vegetation, according to the State Water Code. Figure 6-1 provides a simplified ecosystem represented in a Hawaiian stream. The entire hydrologic unit, as it relates to hydrologic functions of the stream, could also be considered an ecosystem in a very broad context.

The HSA determined that Waikoloa Stream deserved to be a candidate stream for protection based on its outstanding cultural resources, moderate recreational resources, and limited aquatic resources.

Figure 6-1. Simplified ecosystem illustrated in a Hawaiian stream. (Source: Ziegler, 2002, illustration by Keith Kruger).




The Hawaiian resource-use concept of ahupuaa is closely related to the Western concepts of ecosystem maintenance. Native Hawaiians generally utilized natural resources within the limits of their ahupuaa; therefore, it was important to manage and conserve these resources. Likewise, watershed resources must be properly managed and conserved to sustain the health of the stream and the instream uses that are dependent upon it.

The riparian resources of Waikoloa Stream were classified poorly by the HSA (National Park Service, Hawaii Cooperative Park Service Unit, 1990) and ranked according to a scoring system using six of the seven variables (Table 6-1).

For the purpose of this section, management areas are those locales that have been identified by federal, state, county, or private entities as having natural or cultural resources of particular value. The result of various government programs and privately-funded initiatives has been a wide assortment of management areas with often common goals. Such designated areas include forest reserves, private preserves, natural area reserves, wildlife sanctuaries, national parks, historic landmarks, and so on. In Waikoloa, about 6.55 square miles (12.7%) falls within the Mauna Kea Forest Reserve, the Kohala Watershed Forest Reserve, the Puʻu O Umi Natural Area Reserve, or the Puʻukoholā Heiau National Historic Site (Table 6-2, Figure 6-2).

Table 6-1. Hawaii Stream Assessment indicators of riparian resources for Waikoloa hydrologic unit. (National Park Service, 1990)

| Category | Value |
| --- | --- |
| Listed threatened and endangered species:<br>These species are generally dependent upon undisturbed habitat. Their presence is, therefore an indication of the integrity of the native vegetation. The presence of these species along a stream course was considered to be a positive attribute; with the more types of threatened and endangered species associated with a stream the higher the value of the resource. Only federally listed threatened or endangered forest or water birds that have been extensively documented within the last 15 years were included. | None |
| Recovery habitat:<br>Recovery habitat consists of those areas identified by the USFWS and DLNR as essential habitat for the recovery of threatened and endangered species. Streams that have recovery habitat anywhere along their length were included. | None |
| Other rare organisms and communities:<br>Many species that are candidates for endangered or threatened status have not been processed through all of the requirements of the Endangered Species Act. Also a number of plant communities associated with streams have become extremely rare. These rare organisms and communities were considered to be as indicative of natural Hawaiian biological processes as are listed threatened and endangered species. | None |
| Protected areas:<br>The riparian resources of streams that pass through natural area reserves, refuges and other protected areas are accorded special protection from degradation. Protected areas were so designated because of features other than their riparian resources. The presence of these areas along a stream, however, indicates that native processes are promoted and alien influences controlled. | None |
| Wetlands:<br>Wetlands are important riparian resources. They provide habitat for many species and are often important nursery areas. Because they are often extensive areas of flat land generally with deep soil, many have been drained and converted to agricultural or urban uses. Those that remain are, therefore, invaluable as well as being indicators of lack of disturbance. | None |
| Native forest:<br>The proportion of a stream course flowing through native forest provides an indication of the potential "naturalness" of the quality of a stream's watershed; the greater the percentage of a stream flowing through native forest most of which is protected in forest reserves the more significant the resource. Only the length of the main course of a stream (to the nearest 10 percent) that passes through native forest was recorded. | 0% |
| Detrimental organisms:<br>Some animals and plants have a negative influence on streams. Wild animals (e.g., pigs, goats, deer) destroy vegetation, open forests, accelerate soil erosion, and contaminate the water with fecal material. Weedy plants can dramatically alter the nature of a stream generally by impeding water flow. Three species, California grass, hau, and red mangrove, are considered to have the greatest influence. The presence of any of these animals or plants along a stream course was considered a potentially negative factor, while the degree of detriment is dependent on the number of species present. | Pigs |

In addition to the individual management areas outlined, Watershed Partnerships are another valuable component of ecosystem maintenance. Watershed Partnerships are voluntary alliances between public and private landowners who are committed to responsible management, protection, and enhancement of their forested watershed lands. There are currently nine partnerships established statewide, three of which are on Hawaiʻi. Table 6-3 provides a summary of the partnership area, partners, and management goals of the Kohala Watershed Partnership. The Kohala Watershed Forest Reserve, the Puʻu O Umi Natural

Area Reserve and other state and private lands in Waikoloa comprise a portion of the Kohala Watershed Partnership, while Parker Ranch and the Mauna Kea Forest Reserve are part of the Mauna Kea Watershed Alliance (Figure 6-3).

Table 6-2. Forest Reserves and Natural Area Reserves associated with the Waikoloa hydrologic unit, Hawaiʻi. (Source: State of Hawaii, Division of Forestry and Wildlife, 2020a)

| Management Area | Year Established | Total Area (mi²) | Area in Hydrologic Unit (mi²) | Percent of Unit |
|---|---|---|---|---|
| Kohala Watershed Forest Reserve | 1913 | 30.445 | 2.028 | 3.94% |
| Mauna Kea Forest Reserve | 1909 | 113.267 | 1.419 | 2.76% |
| Puʻu O Umi Natural Area Reserve | 1989 | 15.847 | 3.048 | 5.92% |

Table 6-3. Watershed partnerships associated with the Waikoloa hydrologic unit, Hawaiʻi. (Source: State of Hawaii, Division of Forestry and Wildlife, 2020a)

| Management Area | Year Established | Total Area (mi²) | Area in Hydrologic Unit (mi²) | Percent of Unit |
|---|---|---|---|---|
| Kohala Watershed Partnership | 2003 | 106.25 | 10.237 | 19.9 |

The Kohala Watershed Partnership (KWP) is comprised of the Parker Ranch, Kahua Ranch, Ponoholo Ranch, Kamehameha Schools, Queen Emma Foundation, Surety Kohala Corporation, Laupahoehoe Nui, LLC, Hawaii Department of Land and Natural Resources, and the Department of Hawaiian Home Lands. The Hawaii County Department of Water Supply and The Nature Conservancy have joined as non-landowner associate partners. The management priorities of the KWP focus on improvements in water and environmental quality by enabling comprehensive and sustainable watershed management projects that address the threats to the watershed, while maintaining its integrity and protecting its economic, socio-cultural, and ecological resources.

In 1974, the U.S. Fish and Wildlife Service (USFWS) initiated a National Wetlands Inventory that was considerably broader in scope than an earlier 1954 inventory that had focused solely on valuable waterfowl habitat. The inventory for Hawaii was completed in 1978 and utilized a hierarchical structure in the classification of various lands. The USFWS defines wetlands as “lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water” (Cowardin et al., 1979). Ignoring built reservoirs that are classified as freshwater ponds, cumulatively, 3.1 percent (1.578 square miles) of the Waikoloa hydrologic unit is classified as wetlands (freshwater forested, estuarine, or pond), mostly occurring in the upper elevations of the hydrologic unit on Kohala Mountain (Table 6-3 and Figure 6-4).

A series of vegetation maps describing upland plant communities was prepared as part of a USFWS survey in 1976 to 1981 to determine the status of native forest birds and their associated habitats. Figure 6-5 identifies critical habitat for plant species near Waikoloa. The Waikoloa provides a small amount of critical ecosystem habitat in the headwaters as well as critical habitat for plants. Most of the hydrologic unit is dominated by non-native vegetation although almost a quarter of the unit has a high concentration of threatened and endangered species (Table 6-5, Figure 6-6).

Table 6-4. Wetland classifications for Waikoloa hydrologic unit, Hawaiʻi. (Source: US Fish and Wildlife Service, 2018)

| System Type | Class | Area (mi²) | Percent of Unit |
|---|---|---|---|
| Palustrine | Freshwater Forested/Shrub Wetland | 1.55 | 3.0% |
| Palustrine | Emergent Persistent | 0.013 | <0.1% |
| Estuarine and Marine Deepwater | Subtidal | 0.011 | <0.1% |
| Palustrine | Freshwater Pond | 0.004 | <0.1% |

Table 6-5. Distribution of native and alien plant species for Waikoloa hydrologic unit, Hawaiʻi. (Source: State of Hawaii, Office of Planning, 2015f)

| Canopy Type | Area ($mi^2$) | Percent of Unit |
|---|---|---|
| Very High concentration of threatened and endangered species | 0 | 0% |
| High concentration of threatened and endangered species | 11.609 | 22.6% |
| Medium concentration of threatened and endangered species | 30.461 | 59.2% |
| Low concentration of threatened and endangered species | 9.356 | 18.2% |
| Little or no threatened and endangered species | 0 | 0% |

A working paper is being developed by the University of Hawaii's Economic Research Organization (UHERO), entitled *Environmental Valuation and the Hawaiian Economy*, which discusses the use of existing measures of economic performance and alternative statistical devices to provide an economic valuation of threatened environmental resources. The paper focuses on the Koolau, Oahu watershed and illustrates three categories of positive natural capital (forest resources, shoreline resources, and water resources) against a fourth category (alien species) that degrades natural capital. In the case of the Oahu Koolau forests, a benchmark level of degradation is first defined for comparison against the current value of the Oahu Koolau system. The Oahu Koolau case study considers a hypothetical major disturbance caused by a substantial increased population of pigs with a major forest conversion from native trees to the non-indigenous Miconia (*Miconia calvescens*), along with the continued "creep" of urban areas into the upper watershed (Kaiser, B. et al., n.d.). Recognizing that in the United States, the incorporation of environmental and natural resource considerations into economic measures is still very limited, the paper provides the estimated Net Present Value (NPV) for "Koolau [Oahu] Forest Amenities." These values are presented in Table 6-5. Following the results of the Oahu Koolau case study, some of the most valuable aspects of the forested areas are believed to be ecotourism, aesthetic pleasure, species habitat, water quality, and water quantity. There key locations within the Waikoloa hydrologic unit that provides critical habitat for native forest birds, endangered plants or invertebrates.

Table 6-6. Estimated Net Present Value (NPV) for Koolau [Oahu] Forest Amenities. (Source: Kaiser, B. et al., n.d.)

| Amenity | Estimated Net Present Value (NPV) | Important limitations |
|---|---|---|
| Ground water quantity | $4.57 to $8.52 billion NPV | Optimal extraction assumed. |
| Water quality | $83.7 to $394 million NPV | Using averted dredging cost estimates. |
| In-stream uses | $82.4 to $242.4 million NPV | Contingent valuation estimate for a single small fish species. |
| Species habitat | $487 to $1,434 million NPV | Contingent valuation estimate for a single small bird species. |
| Biodiversity | $660,000 to $5.5 million NPV | Average cost of listing 11 species in Koolaus. |
| Subsistence | $34.7 to $131 million NPV | Based on replacement value of pigs hunted. |
| Hunting | $62.8 to $237 million NPV | Based on fraction of hunting expenditures in state. Does not include damages from pigs to the other amenities. |
| Aesthetic values | $1.04 to $3.07 million NPV | Contingent valuation; Households value open space for aesthetic reasons. |
| Commercial harvests | $600,000 to $2.4 million NPV | Based on small sustainable extraction of koa. |
| Ecotourism | $1.0 to $2.98 billion NPV | Based on fraction of direct revenues to ecotourism activities. |
| Climate control | $82.2 million | Based on replacement costs of contribution of all tropical forests to carbon sequestration. |
| **Estimated value of joint services:** | **$7.444 to $14.032 billion** | |

Figure 6-2. Reserves in or nearby the Waikoloa hydrologic unit. (Source: State of Hawaii Division of Forestry and Wildlife, 2020b)

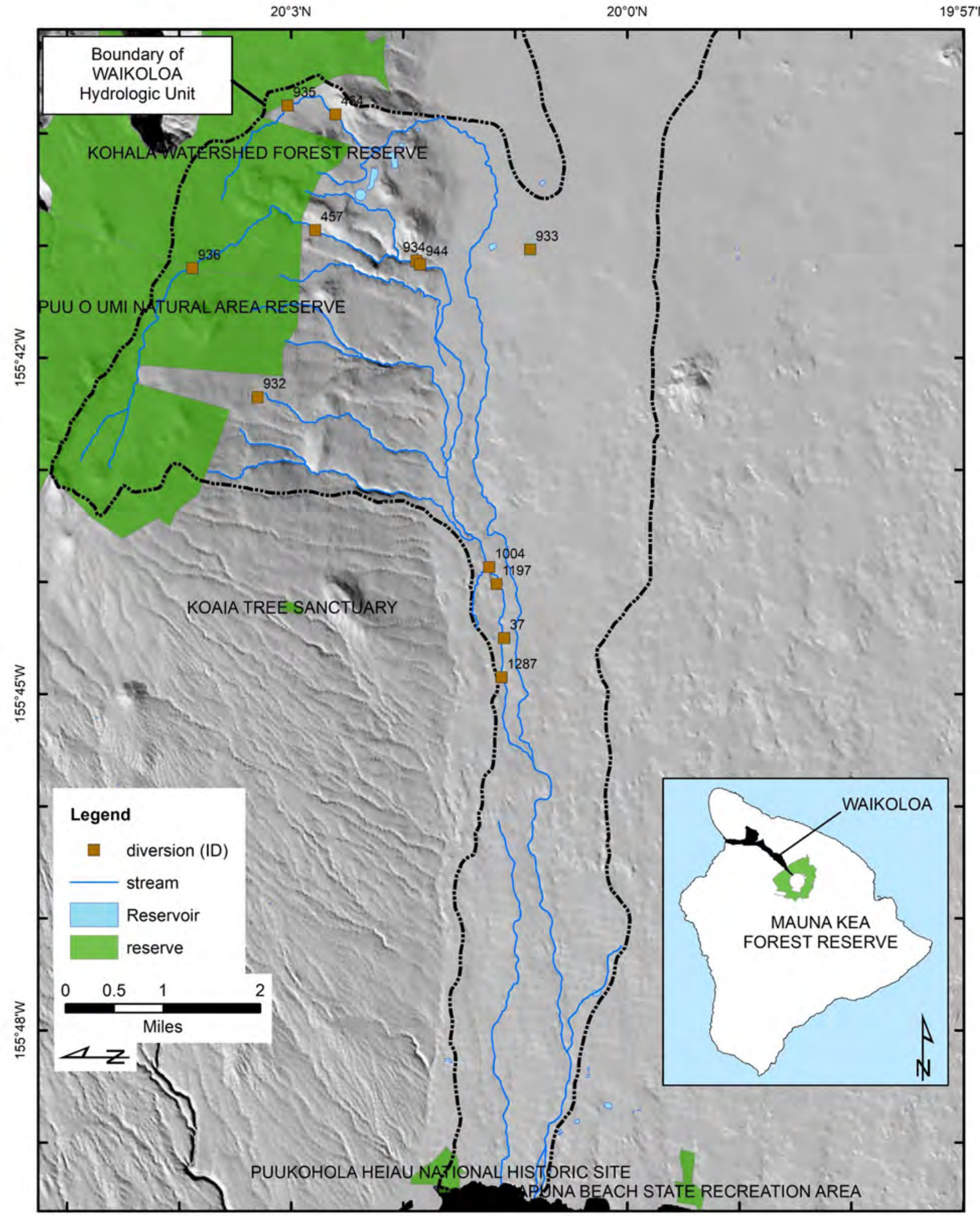


Figure 6-3. The Kohala Watershed Partnership and the Mauna Kea Watershed Alliance in the the Waikoloa hydrologic unit, Hawai'i. (Source: State of Hawaii Division of Forestry and Wildlife, 2020a)

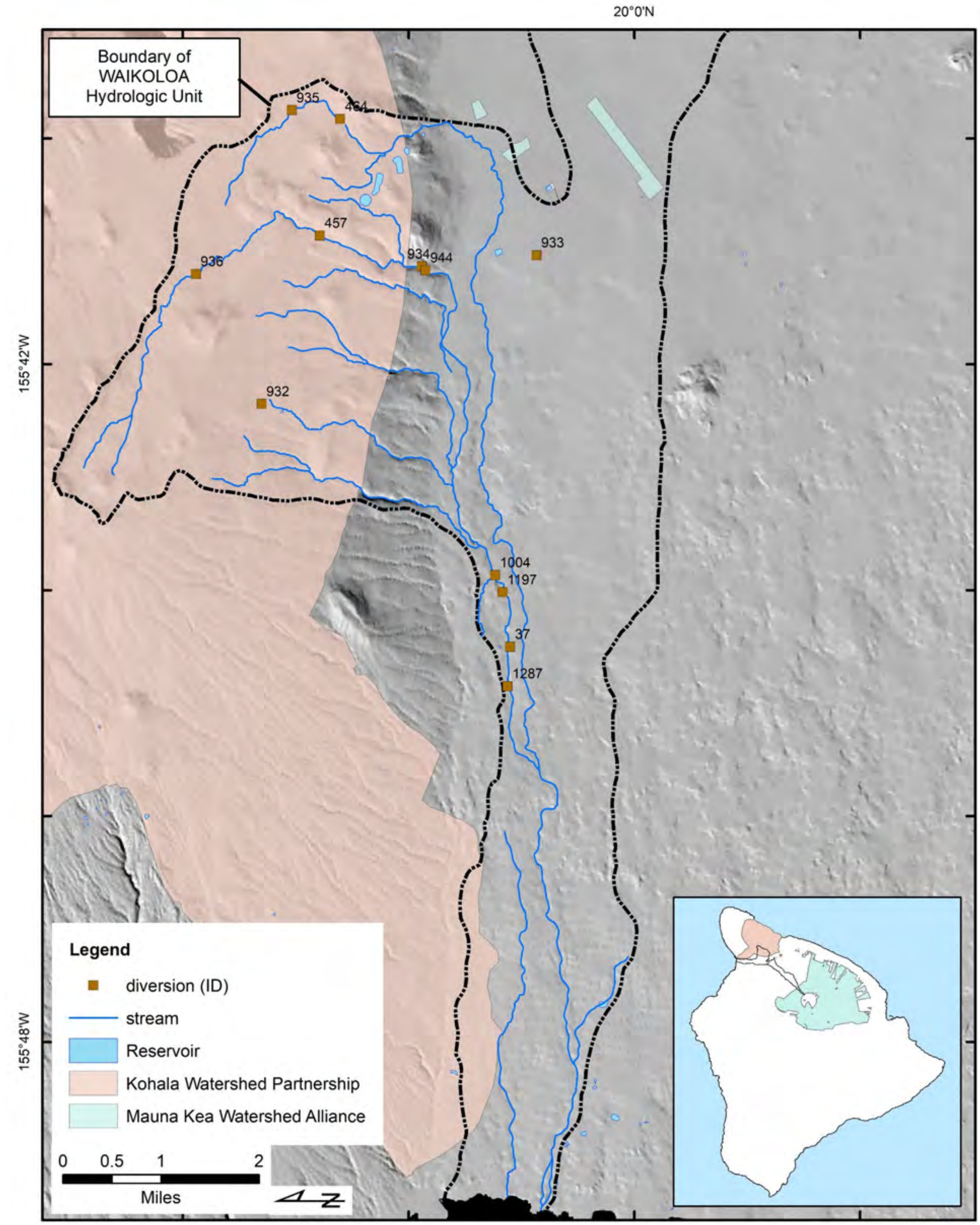


Figure 6-4. Wetlands in the Waikoloa hydrologic unit, Hawai'i. (Source: US Fish and Wildlife Service, 2018)

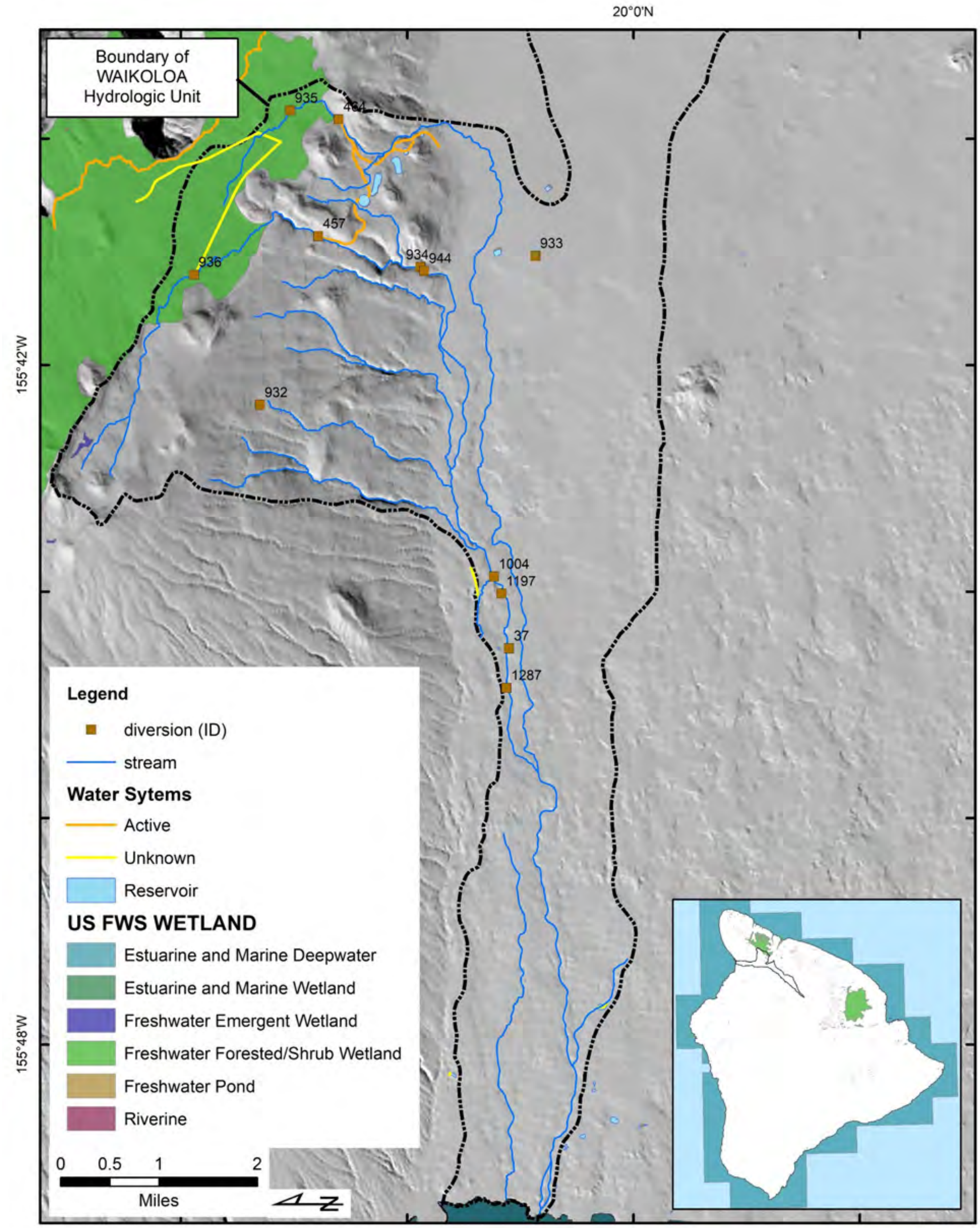


Figure 6-5. Distribution of critical habitat in the Waikoloa hydrologic unit, Hawai'i. (Source: US Fish and Wildlife Service, 2020)

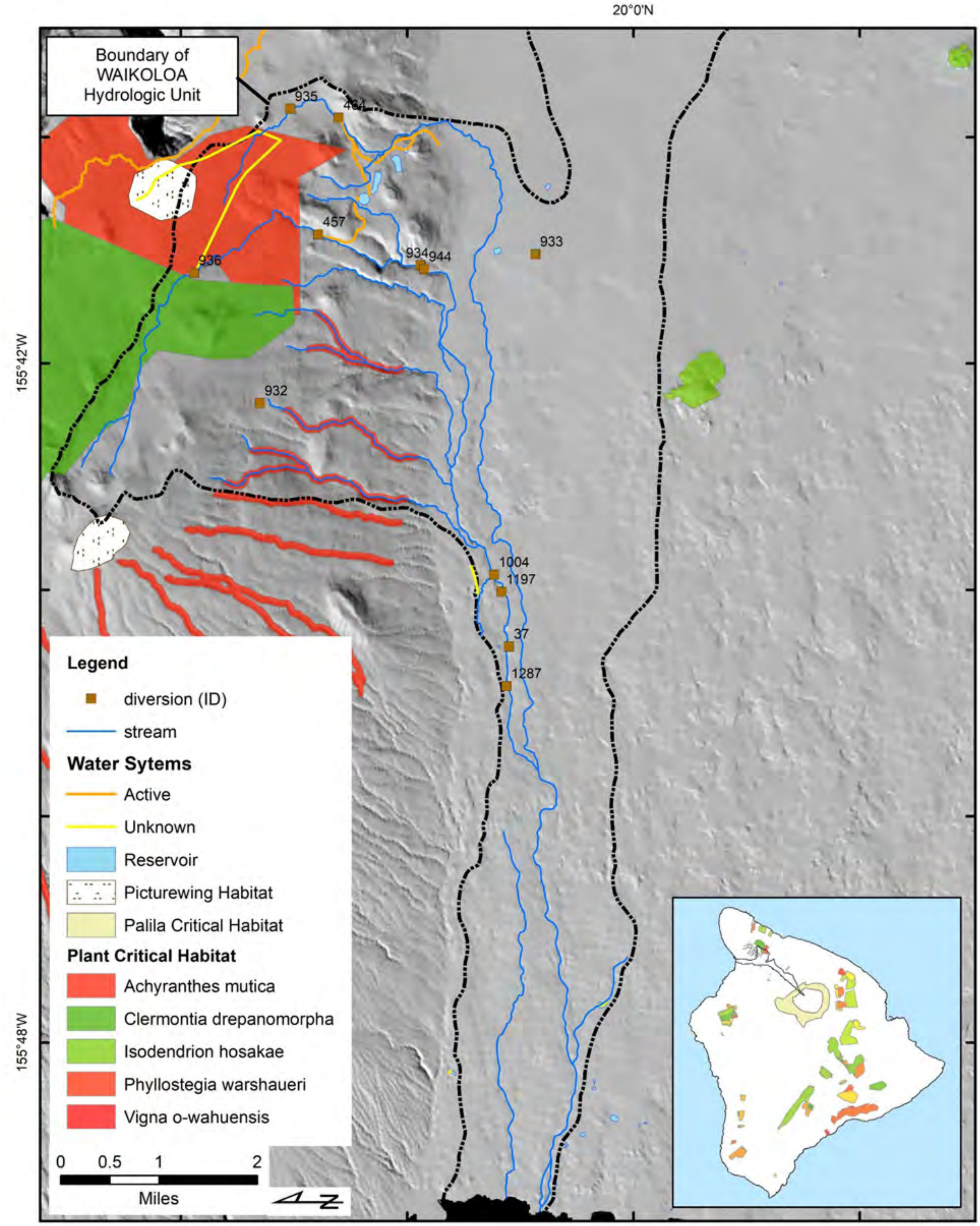
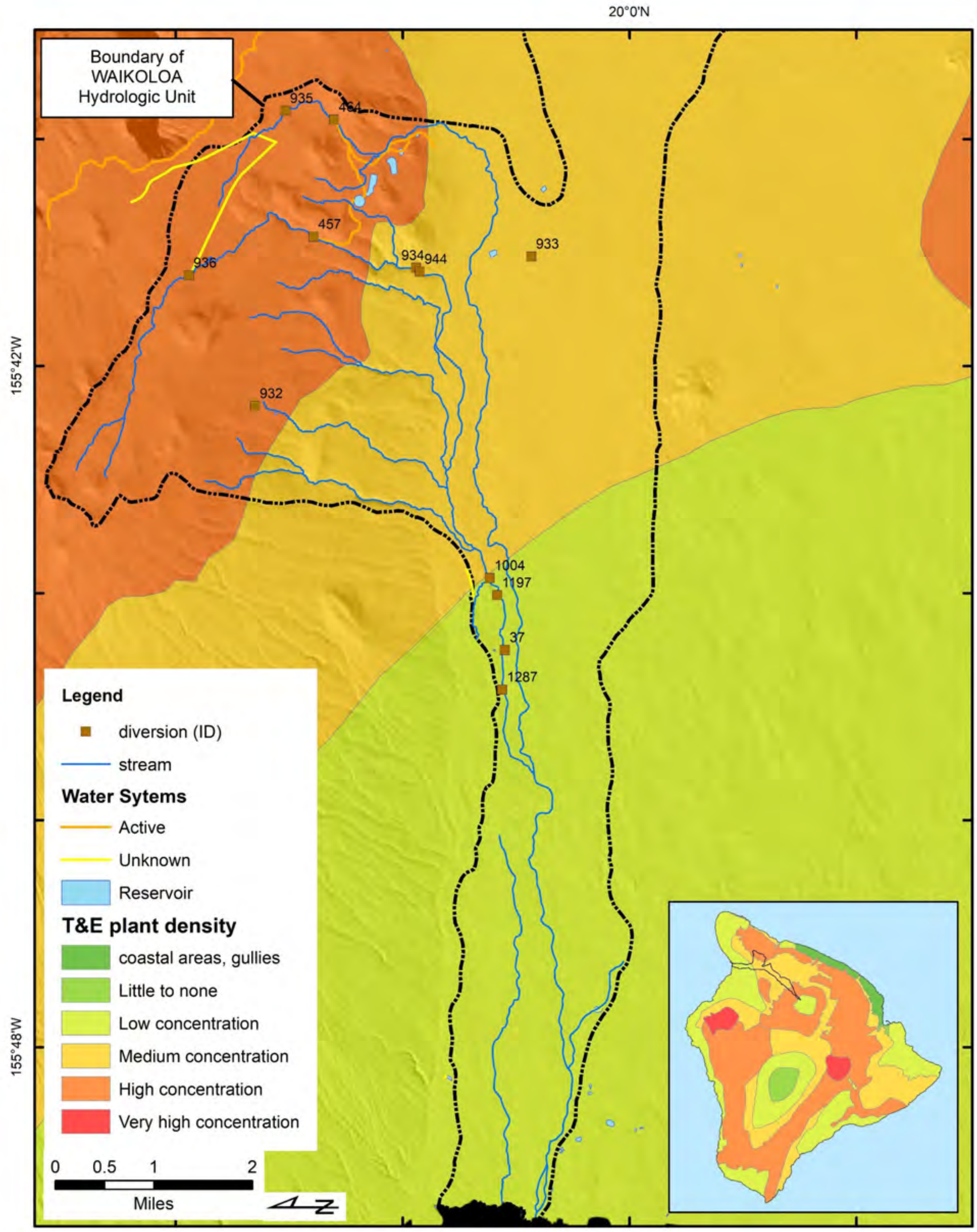


Figure 6-6. Density of threatened and endangered plants in Waikoloa hydrologic unit, Hawai'i. (Source: State of Hawaii, Office of Planning, 2015h)



## 7.0 Aesthetic Values

Aesthetics is a multi-sensory experience related to an individual's perception of beauty. Since aesthetics by definition is a subjective observation, a stream's aesthetic value cannot be determined quantitatively (Wilson Okamoto & Associates, Inc., 1983). However, there are certain elements, either within or surrounding a stream, which appeal to an observer's visual and auditory senses, such as waterfalls and cascading plunge pools. Visitors and residents can identify a point that has aesthetic value and continue to return to such a point to gain that value. Such points can potentially be identified, as maped. However, the points identified are not exhaustive and it is beyond the scope of this report to list all potential aesthetic values.

Large portions of the Waikoloa hydrologic unit support a unique ecosystem home to endemic and endangered birds, plants, and insects in the headwaters. There are multiple hiking trails commonly used by residents and tourists along Waikoloa Stream in Waimea Town, along Kawaihae Road, and along the coastline that provide aesthetic and recreational uses. There are multiple vantage points in the hydrologic unit that have viewscapes that include Waikoloa Stream.

In a 2007 Hawaii State Parks Survey, released by the Hawaii Tourism Authority (OmniTrak Group Inc., 2007), scenic views accounted for 21 percent of the park visits statewide, though that was a decrease from 25 percent in a 2003 survey. Other aesthetic-related motivations include viewing famous landmarks (9 percent), hiking trails and walks (7 percent), guided tour stops (6 percent), and viewing of flora and fauna (2 percent). On the island of Hawai‘i, visitors' preference to visit state parks for ocean/water activity (32%) was followed by outings with family and friends (25%), and scenic views (21%). In comparison, residents primarily used state parks for outings with friends and family (31%), followed by ocean/water activities (24%), and then scenic views (8%). Overall, Hawai‘i residents were very satisfied with scenic views giving a score of 9.2 (on a scale of 1 to 10, with 10 being outstanding), with out-of-state visitors giving a score of 9.3. There are many state and local parks located in the hydrologic unit, that offer opportunities for scenic enjoyment.

## 8.0 Navigation

The State Water Code, Chapter 174C, HRS, includes navigation as one of nine identified instream uses; however, it fails to further define navigation. Navigational water use is largely defined as water utilized for commercial, and sometimes recreational, transportation. In the continental United States, this includes water used to lift a vessel in a lock or to maintain a navigable channel level. Under the provisions of the Clean Water Act, navigable waters also include wetlands (State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources, n.d.).

Hawaii streams are generally too short and steep to support navigable uses. If recreational boating (primarily kayaks and small boats) is included under the definition of navigation, then there are only a handful of streams statewide that actually support recreational boating and even fewer that support commercial boating operations. Kauai's Wailua River is the only fresh water waterway where large boat commercial operations exist, and no streams are believed to serve as a means for the commercial transportation of goods.

The Waikoloa hydrologic unit does not provide any navigation opportunities.

## 9.0 Instream Hydropower Generation

The generation of hydropower is typically accomplished through instream dams and power generators; however, the relatively short lengths and flashy nature of Hawaii's streams often require water to be diverted to offstream power generators. In these "run-of-river" (i.e., utilizes water flow without dams or reservoirs) designs, water is diverted through a series of ditches, pipes, and penstocks to the powerplant, and then returned to the stream. Some designs call for the powerplant to be situated such that the drop of water level (head) exiting the plant can be sent to fields for crop irrigation.

There is no instream hydropower in the Waikoloa hydrologic unit, although there is potential for small hydropower units above Waimea Town, potentially tied to pumped storage or flow between reservoirs.

## 10.0 Maintenance of Water Quality

The maintenance of water quality is important due to its direct impact upon the maintenance of other instream uses such as fish and wildlife habitat, outdoor recreation, ecosystems, aesthetics, and traditional and customary Hawaiian rights. There are several factors that affect a stream's water quality, including physical, chemical, and biological attributes. The State of Hawaii Department of Health (DOH) is responsible for water quality management duties statewide. The DOH Environmental Health Administration oversees the collection, assessment, and reporting of numerous water quality parameters in three high-priority categories:

- Possible presence of water-borne human pathogens;
- Long-term physical, chemical and biological components of inland, coastal, and oceanic waters; and
- Watershed use-attainment assessments, identification of sources of contamination, allocation of those contributing sources, and implementation of pollution control actions.

The Environmental Health Administration is also responsible for regulating discharges into State waters, through permits and enforcement actions. Examples include federal National Pollutant Discharge Elimination System (NPDES) permits for storm water, and discharge of treated effluent from wastewater treatment plants into the ocean or injection wells.

Sediment and temperature are among the primary physical constituents of water quality evaluations. They are directly impacted by the amount of water in a stream. The reduction of streamflow often results in increased water temperatures, whereas higher flows can aid in quickly diluting stream contamination events. According to a book published by the Instream Flow Council, "[w]ater temperature is one of the most important environmental factors in flowing water, affecting all forms of aquatic life (Amear et al, 2004)." While this statement is true for continental rivers, fish in Hawaii are similar, but their main requirement is flowing water. Surface water temperatures may fluctuate in response to seasonal and diurnal variations, but only a few degrees Celsius in natural streams, mainly because streams in Hawaii are so short. However, temperatures in streams with concrete-lined channels, and dewatered streams, may fluctuate widely due to the vertical solar contact. Surface water temperatures may also fluctuate widely due to water column depth, channel substrate, presence of riparian vegetation, and ground water influx. Surface water also differs considerably from ground water, generally exhibiting lower concentrations of total dissolved solids, chlorides, and other major ions, along with higher concentrations of suspended solids, turbidity, microorganisms, and organic forms of nutrients (Lau and Mink, 2006). Findings of a 2004 USGS National Water Quality Assessment (NAWQA) Program report identified land use, storm-related runoff, and ground water inflow as major contributors of surface water contaminants (Anthony et al., 2004). Runoff transports large amounts of sediment from bare soil into surface water bodies, with consequences for in-stream and near-shore environments.

Water body types can be freshwater, marine, or brackish. They can be further delineated as inland fresh waters, estuaries, embayments, open coastal waters, and oceanic waters (HAR 11-54-5 to 11-54-6). Each water body type has its own numeric criteria for State of Hawaii Water Quality Standards (WQS).

Marine water body types are delineated by depth and coastal topography. Open coastal waters are classified for protection purposes from the shoreline at mean sea level laterally to where the depth reaches 100 fathoms (600 feet). Marine water classifications are based on marine conservation areas. The objective of Class AA waters is that they "remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions." Class A waters are protected for recreational purposes and aesthetic enjoyment; and protection of fish, shellfish, and wildlife. Discharge into these waters is only permitted under regulation. The marine waters at the mouth of the Waiulaula Stream are both Class AA and Class A waters (Figure 10-2).

Fresh waters are classified for regulatory purposes, according to the adjacent land's conservation zoning. There are two classes for the inland fresh waters. Class 1 inland waters are protected to "remain in their natural state as nearly as possible with an absolute minimum of pollution from any human-caused source." These waters are used for a number of purposes including domestic water supply, protection of native breeding stock, and baseline references from which human-caused changes can be measured. Class 2 inland waters are protected for uses such as recreational purposes, support of aquatic life, and agricultural water supplies. Class 1 waters are further separated into Classes 1a and 1b. Class 1a waters are protected for the following uses: scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other non-degrading uses which are compatible with the protection of the ecosystems associated with waters of this class. Streams that run through natural reserves, preserves, sanctuaries, refuges, national and state parks, and state or federal fish and wildlife refuges are Class 1a. Streams adjacent to the most environmentally sensitive conservation subzone, "protective," are Class 1b, and are protected for the same uses as Class 1a waters, with the addition of domestic water supplies, food processing, and the support and propagation of aquatic life (HAR 11-54-3). These classifications are used for regulatory purposes, restricting what is permitted on the land around receiving waters. For example, public access to Class 1b waters may be restricted to protect drinking water supplies. Waikoloa Stream is classified as Class 1 inland waters from its headwaters to approximately the 3,600 feet elevation as the surrounding land is in the conservation subzone "protective." It should be noted that the conservation subzone map utilized for this interpretation is general and elevations are not exact. It should also be noted that there is no direct relationship between elevation and attainment of water quality standards. Some tributaries are also classified as Class 1 inland waters due to their conservation status associated with endangered or threatened species (Figure 10-1).

Land use affects water quality because direct runoff (rainfall that flows overland into the stream) can transport sediment and its chemical contaminants into the stream. According to the U.S. Environmental Protection Agency (USEPA), "[a] TMDL or Total Maximum Daily Load is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. Water quality standards are set by States, Territories, and Tribes. They identify the uses for each waterbody, for example, drinking water supply, contact recreation (swimming), and aquatic life support (fishing as well as ecological health), and the scientific criteria required to support those uses. A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and nonpoint sources. The calculation must include a margin of safety to ensure that the waterbody can be used for the purposes the State has designated. The calculation must also account for seasonal variation in water quality. The Clean Water Act, section 303, establishes the water quality standards and TMDL programs (USEPA, 2008)."

The DOH, Environmental Health Administration maintains the State of Hawaii Water Quality Standards (WQS), a requirement under the Federal Clean Water Act (CWA) regulated by the EPA. The CWA aims to keep waters safe for plants and animals to live and people to wade, swim, and fish. Water Quality Standards are the measures that states use to ensure protection of the physical, chemical, and biological health of their waters. "A water quality standard defines the water quality goals of a water body, or portion thereof, by designating the use or uses to be made of the water and by setting criteria necessary to protect the uses (CWA §131.2)." Each state specifies its own water uses to be achieved and protected ("designated uses"), but CWA §131.10 specifically protects "existing uses", which it defines as "…those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards (CWA §131.3)."[1] Although the State WQS do not specify any designated uses in terms of traditional and customary Hawaiian rights, the "protection of native breeding stock," "aesthetic enjoyment," and "compatible recreation" are among the designated uses of Class 1 inland waters, and "recreational purposes, the support and propagation of aquatic life, and agricultural and industrial water supplies" are among the designated uses of Class 2 inland waters. This means that uses tied to the exercise of traditional and customary Hawaiian rights that are protected by the State Constitution and the State Water Code (Section 12.0, Protection of Traditional and Customary Hawaiian Rights), including but not limited to gathering, recreation, healing, and religious practices are also protected under the CWA and the WQS as designated and/or existing uses. Therefore, the Commission's interim IFS recommendation may impact the attainment of designated and existing uses, water quality criteria, and the DOH antidegradation policy, which together define the WQS and are part of the joint Commission and DOH obligation to assure sufficient water quality for instream and noninstream uses.

State of Hawaii WQS define: 1) the classification system for State surface waters, which assigns different protected uses to different water classes; 2) the specific numeric or narrative water quality criteria needed to protect that use; and 3) a general antidegradation policy, which maintains and protects water quality for the uses defined for a class. Quantitative and qualitative data are utilized. Numeric water quality criteria have specific concentrations (levels of pollutants) that must be attained based on water body type, e.g. fresh water stream. Qualitative standards are general narrative statements that are applicable to all State waters, such as "all waters shall be free of substances attributable to domestic, industrial, or other controllable sources of pollutants (State of Hawaii, Department of Health, 2004)." Conventional pollutants include nutrients and sediments. Toxic pollutants include pesticides and heavy metals. Indicator bacteria are utilized to assess bacterial levels. Biological assessments of aquatic communities are also included in the data collected.

Once data are gathered and evaluated for quality and deemed to be representative of the waterbody segment, a decision is made as to whether the appropriate designated uses are being attained. This set of decisions are then tabulated into a report to the EPA that integrates two CWA sections; (§) 305(b) and §303(d). This Integrated Report is federally required every even-numbered year. CWA §305(b) requires states to describe the overall water quality statewide. They must also describe the extent to which water quality provides for the protection and propagation of a balanced population of shellfish, fish, and wildlife and allows recreational activities in and on the water. Additionally, they determine whether the designated uses of a water body segment are being attained, and if not, what are the potential causes and sources of pollution. The CWA §303(d) requires states to submit a list of Water-Quality Limited Segments, which are waters that do not meet state water quality standards and those waters' associated uses. States must also provide a priority ranking of waters listed for implementation of pollution controls, which are prioritized based on the severity of pollution and the uses of the waters. In sum, the §303(d) list leads to action.

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[1] Existing uses as defined in the CWA should not be confused with existing uses as defined in the State Water Code, although there is some overlap and linkage between the two. Under the Water Code, if there are serious threats to or disputes over water resources, the Commission may designate a "water management area." Water quality impairments, including threats to CWA existing uses, are factors that the Commission may consider in its designation decisions. Once such a management area is designated, people who are already diverting water at the time of designation may apply for water use permits for their "existing uses." The Commission then must weigh if the existing use is "reasonable and beneficial." The Water Code defines "reasonable-beneficial use" as "the use of water in such a quantity as is necessary for economic and efficient utilization, for a purpose, and in a manner which is both reasonable and consistent with the state and county land use plans and the public interest." The relationships between a Commission existing use and a CWA existing use can help determine the appropriateness of the use and its consistency with the public interest.

The sources for the 2020 Integrated Report are Hawaii's 2020 §303(d) list, plus readily-available data collected from any State water bodies over the preceding 6 years (State of Hawaii, Department of Health, 2007). Per §303(d), impaired waters are listed after review of "'all existing and readily available water quality-related data and information' from a broad set of data sources" (State of Hawaii, Department of Health, 2004, p.57). However, available data are not comprehensive of all the streams in the State. According to the Hawaii Administrative Rules Title 11 Chapter 54 (HAR 11-54) all State waters are subject to monitoring; however, in the most recent list published (from the 2018 list that was published in 2020), only 71 streams statewide had sufficient data for evaluation of whether exceedance of WQS occurred. Waiulaula marine waters appeared on the 2020 List of Impaired Waters in Hawaii, Clean Water Act §303(d) as a result of not attaining water quality standards for total nitrogen, nitrate-nitrite, ammonium, total phosphate, turbidity, or chlorophyl *a*. Results of physiochemical water quality monitoring are provided in Table 10-1 and of bacteria water quality monitorin in Table 10-2.

The 2006 Integrated Report indicates that the current WQS require the use of *Enterococci* as the indicator bacteria for evaluating public health risks in the waters of the State; however, no new data were available for this parameter in inland waters. DOH maintains WQS for inland recreational waters based on the geo-mean statistic of *Enterococci*: 33 colony-forming units per 100 mL of water or a single-sample maximum of 89 colonies per 100 mL. This is for full-body contact (swimming, jumping off cliffs into waterfall pools, etc.). If *Enterococci* count exceeds those values, the water body is considered to be impaired. DOH Clean Water Branch efforts have been focused on coastal areas (State of Hawaii, Department of Health, 2006, Chapter II, p.20). The marine recreational zone, which extends from the shoreline seaward to 1,000 feet from shore, requires an *Enterococci* geo-mean of less than 7 colony-forming units per 100 mL of water to protect human health (HAR 11-54-8.). Results of bacterial water quality monitoring are provided in Table 10-2.

The 2012 Integrated Report also states: "Public health concerns may be underreported. *Leptospirosis* is not included as a specific water quality standard parameter. However, all fresh waters within the state are considered potential sources of *Leptospirosis* infection by the epidemiology section of the Hawaii State Department of Health. No direct tests have been approved or utilized to ascertain the extent of the public health threat through water sampling. Epidemiologic evidence has linked several illness outbreaks to contact with fresh water, leading authorities to issue blanket advisories for all fresh waters of the state (State of Hawaii, Department of Health, 2007, Chapter II, p.3)." The presence of on-site sewage disposal systems (OSSDS) is commonly linked to increased nutrient and bacterial contamination of nearby waters. Figure 10-2 identifies the locations of all 998 OSSDS in the Waikoloa hydrologic unit.

Table 10-1. Mean and standard deviation (SD) physiochemical water quality parameters for Waiulaula Stream at 21HI-001247 in the Waikoloa hydrologic unit (Source: EPA, 2023)

| temperature | | Ammonia | | Chlorophyll a | | Nitrate + Nitrite | | Nitrogen | |
|---|---|---|---|---|---|---|---|---|---|
| n | Mean (SD) | n | Mean (SD) | n | Mean (SD) | n | Mean (SD) | n | Mean (SD) |
| 201 | 26.6 (1.9) | 146 | 0.009 (0.007) | 154 | 0.76 (2.43) | 145 | 0.013 (0.013) | 154 | 0.14 (0.11) |
| Phosphorous | | Silica | | pH | | Suspended Solids | | Turbidity | |
| n | Mean (SD) | n | Mean (SD) | n | Mean (SD) | n | Mean (SD) | n | Mean (SD) |
| 151 | 0.018 (0.012) | 108 | 1.23 (1.09) | 193 | 8.26 (0.25) | 154 | 18.54 (19.94) | 201 | 2.87 (3.35) |

Table 10-2. Mean and standard deviation (SD) bacterial water quality parameters for Waiulaula Stream at 21HI-001247 in the Waikoloa hydrologic unit (Source: EPA, 2023)

| Enterococcus | | Clostridium perfringens | | Dissolved Oxygen | |
|---|---|---|---|---|---|
| n | Mean (SD) | n | Mean (SD) | n | Mean (SD) |
| 47 | 98.7 (260.8) | 18 | 3.56 (5.06) | 196 | 6.06 (0.59) |

Figure 10-1. Water quality standards and water quality sample sites for the Waikoloa hydrologic unit, Hawai'i. (Source: State of Hawaii, Office of Planning, 2015e; USEPA, 2020). The classifications are general in nature and should be used in conjunction with Hawaii Administrative Rules, Chapter 11-54, Water Quality Standards.

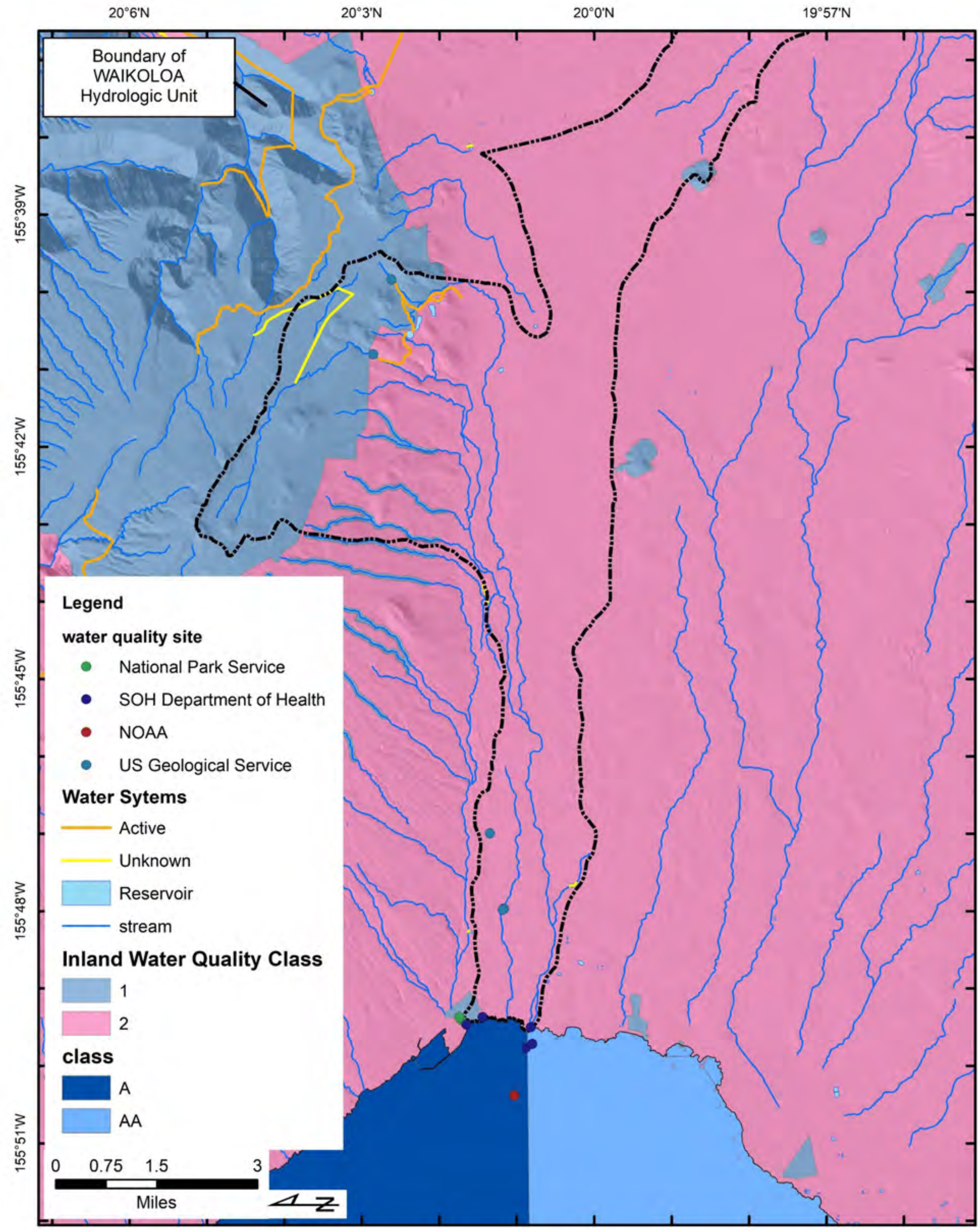
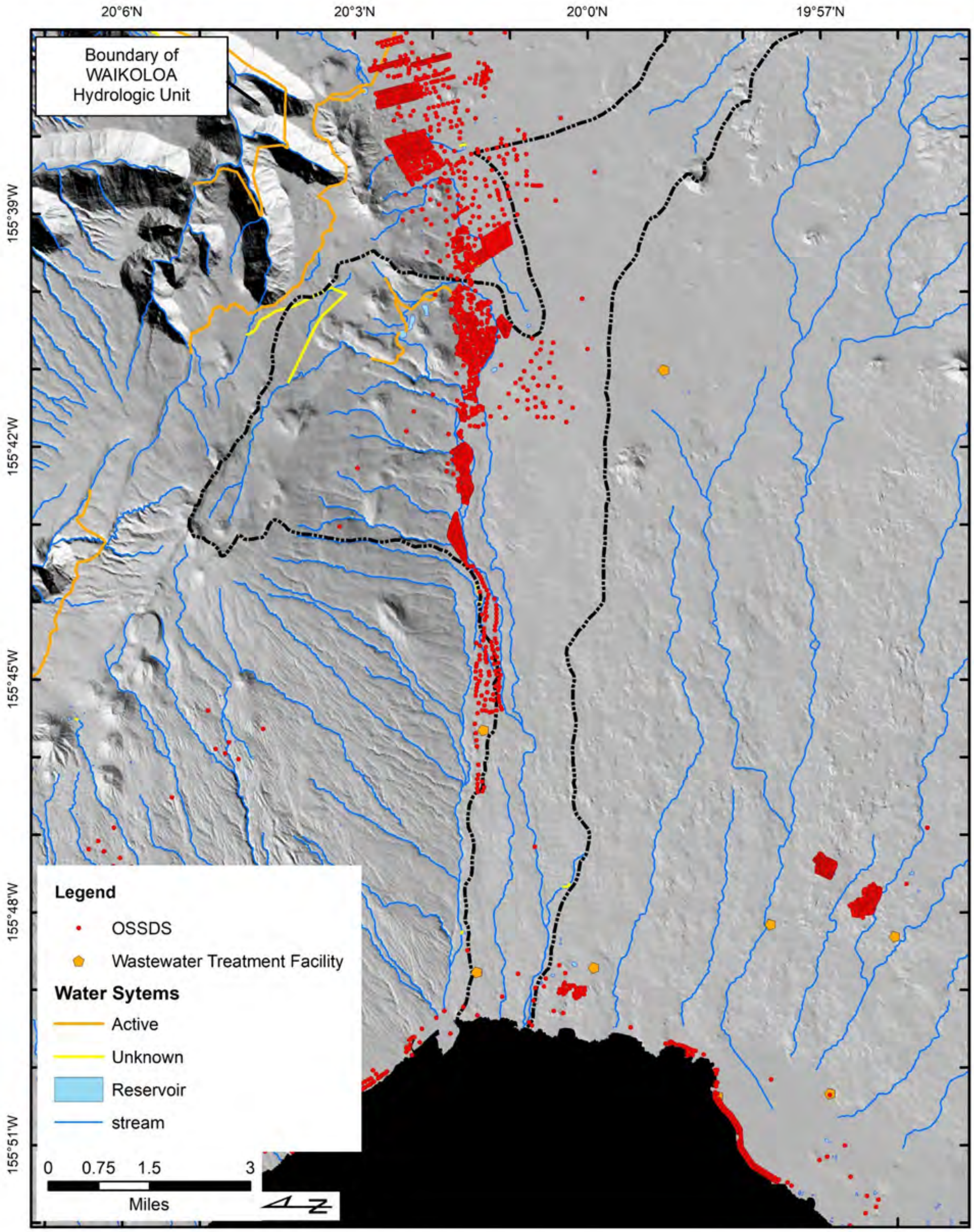


Figure 10-2. On-site sewage disposal systems and wastewater treatment facilities -in or near the Waikoloa hydrologic unit, Hawai'i. (Source: State of Hawaii Department of Health, 2020)



## 11.0 Conveyance of Irrigation and Domestic Water Supplies

Under the State Water Code, the conveyance of irrigation and domestic water supplies to downstream points of diversion is included as one of nine listed instream uses. The thought of a stream as a conveyance mechanism for noninstream purposes almost seems contrary to the concept of instream flow standards. However, the inclusion of this instream use is intended to ensure the availability of water to all those who may have a legally protected right to the water flowing in a stream. Of particular importance in this section is the diversion of surface water for domestic purposes. In its August 2000 decision on the Waiahole Ditch Combined Contested Case Hearing, the Hawaii Supreme Court identified domestic water use of the general public, particularly drinking water, as one of, ultimately, four trust purposes.

Neither the State nor the County keeps a comprehensive database of households whose domestic water supply is not part of a municipal system (i.e. who use stream and / or catchment water). The City and County of Honolulu Board of Water Supply does not have data for water users who are not on the county system and may be using catchment or surface water for domestic use. The State of Hawaii Department of Health Safe Drinking Water Branch administers Federal and State safe drinking water regulations to public water systems in the State of Hawaii to assure that the water served by these systems meets State and Federal standards. Any system which services 25 or more people for a minimum of 60 days per year or has at least 15 service connections is subject to these standards and regulations. Once a system is regulated by the Safe Drinking Water Branch, the water must undergo an approved filtration and disinfection process when it has been removed from the stream. It would also be subject to regulatory monitoring. However, the private water system (PUC-regulated South Kohala Water Corporation in the Waikoloa hydrologic unit services non-potable water needs in the Mauna Kea Resort development and is not regulated by the DOH, Safe Drinking Water branch.

The Waikoloa Stream is not used to convey water between reservoirs or ditches. However, Hawai‘i DWS often diverts water from Waikoloa Stream in excess of reservoir capacity and this excess is discharged into Kohākōhau Stream.

# 12.0 Protection of Traditional and Customary Hawaiian Rights

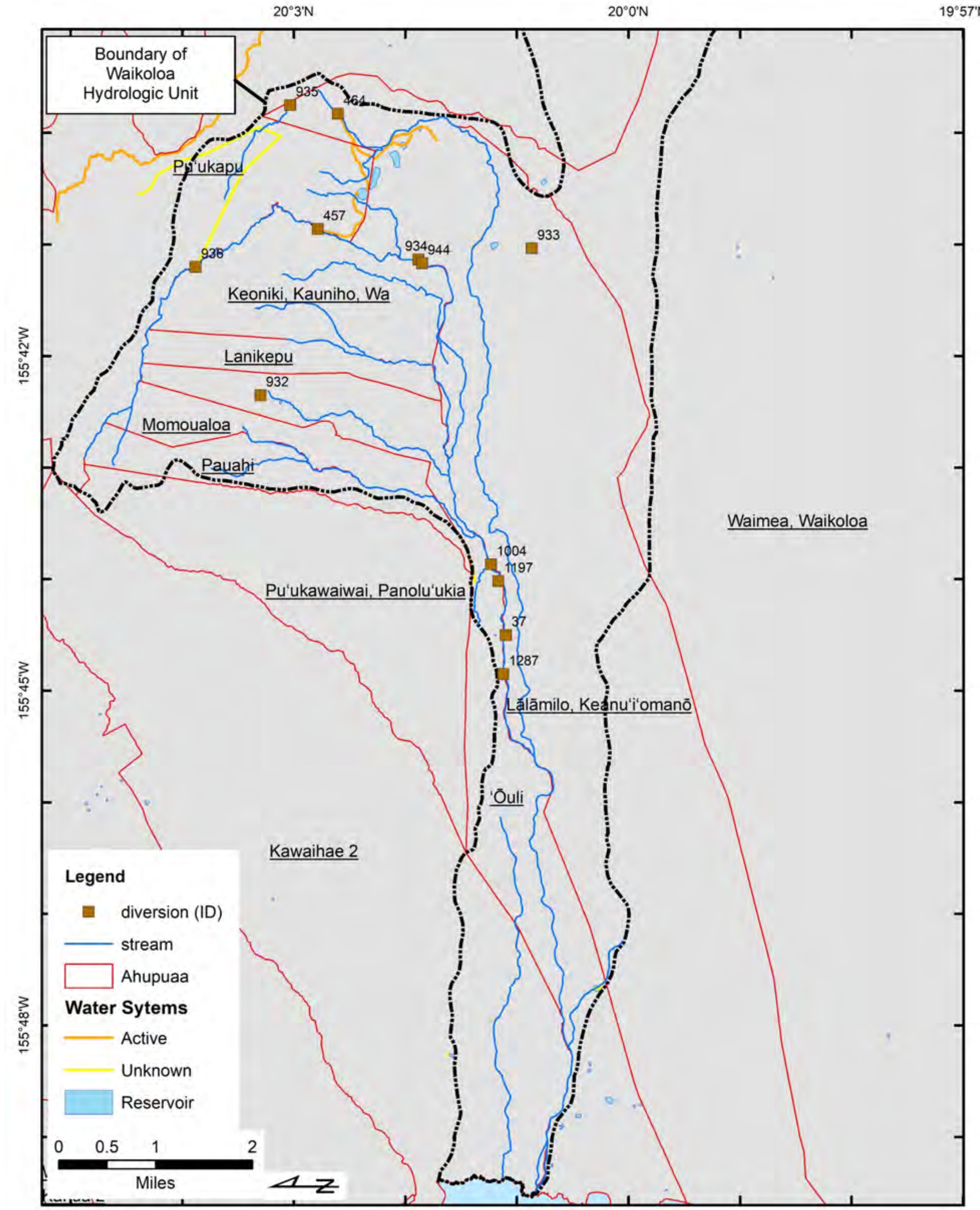
The maintenance of instream flows is important to the protection of traditional and customary Hawaiian rights, as they relate to the maintenance of stream resources (e.g., hihiwai, opae, oopu) for gathering, recreation, and the cultivation of taro. Article XII, Section 7 of the State Constitution addresses traditional and customary rights: "The State reaffirms and shall protect all rights, customarily and traditionally exercised for subsistence, cultural and religious purposes and possessed by ahupuaʻa tenants who are descendants of native Hawaiians who inhabited the Hawaiian Islands prior to 1778, subject to the right of the State to regulate such rights." Case notes listed in this section indicate, "Native Hawaiian rights protected by this section may extend beyond the ahupuaʻa in which a native Hawaiian resides where such rights have been customarily and traditionally exercised in this manner. 73 H.578, 837 P.2d 1247."

It is difficult to fully represent in words the depth of the cultural aspects of streamflow, including traditions handed down through the generations regarding gathering, ceremonial and religious rites, and the ties to water that are pronounced in Hawaiian legend and lore. "There is a great traditional significance of water in Hawaiian beliefs and cultural practices…The flow of water from mountain to sea is integral to the health of the land. A healthy land makes for healthy people, and healthy people have the ability to sustain themselves (Kumu Pono Associates, 2001b, p.II:8)."

Taro cultivation is addressed in this section of the report as well as section 14. This is because instream flow standards take into account both social and scientific information. For sociological and cultural purposes, taro cultivation can be considered an instream use as part of the "protection of traditional and customary Hawaiian rights," that is specifically listed as an instream use in the Water Code. Taro cultivation can also be considered a noninstream use since it removes water from a stream (even if water from taro loi is later returned to the stream). It could be argued that for scientific analysis, taro cultivation is an instream use since taro loi provide habitat for stream biota, but because the water is physically taken out of the stream, it is also a noninstream use. Another way to look at the approach of indentifying taro cultivation as both instream and noninstream uses is that when the Commission addresses taro cultivation as an instream use, it is generally in the context of traditional and customary Hawaiian rights; whereas when the Commission addresses taro cultivation as a noninstream use, it is approaching the issue from the aspects of agriculture and water use.

In ancient Hawaii, the islands (*moku*) were subdivided into political subdivisions, or ahupuaa, for the purposes of taxation. The term *ahupuaʻa* in fact comes from the altar (*ahu*) that marked the seaward boundary of each subdivision upon which a wooden head of a pig (*puaa*) was placed at the time of the *Makahiki* festival when harvest offerings were collected for the rain god and his earthly representative (Handy et al., 1972). Each ahupuaa had fixed boundaries that were usually delineated by natural features of the land, such as mountain ridges, and typically ran like a wedge from the mountains to the ocean thus providing its inhabitants with access to all the natural resources necessary for sustenance. The beach, with its fishing rights, were referred to as *ipu kai* (meat bowl), while the upland areas for cultivation were called *umeke ai* (poi container hung in a net) (Handy et al., 1972). As noted earlier in Section 6.0, Maintenance of Ecosystems, Western concepts of ecosystem maintenance and watersheds are similar to the Hawaiian concept of *ahupuaʻa*, and so the Commission's surface water hydrologic units often coincide with or overlap *ahupuaʻa* boundaries. The hydrologic unit of Waikoloa includes portions of the Waimea-Waikoloa, Lālāmilo-Keanuʻiʻomanō, Keoniki-Kauniho-Wa, Lanikepu, Momoualoa, Pauahi, Puʻukawaiwai-Panoluʻukia, ʻŌuli, Kawaihae ahupuaʻa as shown in Figure 12-1. The ahupuaa boundaries are delineated based on the USGS Digital Line Graphs. These boundaries may be different from the information listed on legal documents such as deeds.

Figure 12-1. Traditional ahupuaʻa boundaries in the Waikoloa hydrologic unit, Hawaiʻi. (Source: State of Hawaii, Office of Planning, 2015j)



An appurtenant water right is a legally recognized right to a specific amount of surface freshwater – usually from a stream – on the specific property that has that right. This right traces back to the use of water on a given parcel of land at the time of its original conversion into fee simple lands: When the land allotted during the 1848 Mahele was confirmed to the awardee by the Land Commission and/or when the Royal Patent was issued based on such award, the conveyance of the parcel of land carried with it the appurtenant right to water if water was being used on that land at or shortly before the time of the Mahele (State of Hawaii, Commission on Water Resource Management, 2007).

An appurtenant right is different from a riparian right, but they are not mutually exclusive. Riparian rights are held by owners of land adjacent to a stream. They and other riparian landowners have the right to reasonable use of the stream's waters on those lands. Unlike riparian lands, the lands to which appurtenant rights attach are not necessarily adjacent to the freshwater source (i.e., the water may be carried to the lands via auwai or ditches), but some pieces of land could have both appurtenant and riparian rights.

Appurtenant rights are provided for under the State Water Code, HRS §174C-101, Section (c) and (d) as follows:

- Section (c). Traditional and customary rights of ahupuaa tenants who are descendants of native Hawaiians who inhabited the Hawaiian Islands prior to 1778 shall not be abridged or denied by this chapter. Such traditional and customary rights shall include, but not be limited to, the cultivation or propagation of taro on one's own kuleana and the gathering of hihiwai, opae, oopu, limu, thatch, ti leaf, aho cord, and medicinal plants for subsistence, cultural, and religious purposes.

- Section (d). The appurtenant water rights of kuleana and taro lands, along with those traditional and customary rights assured by this section, shall not be diminished or extinguished by a failure to apply for or to receive a permit under this chapter.

The exercise of an appurtenant water right is still subject to the water use permit requirements of the Water Code, but there is no deadline to exercise that right without losing it, as is the case for correlative and riparian rights, which must have been exercised before designation of a water management area.

In August 2000, the Hawai'i Supreme Court issued its decision in the Waiāhole Ditch Combined Contested Case Hearing, upholding the exercise of Native Hawaiian and traditional and customary rights as a public trust purpose. These rights are described in the Commission's 2007 *Water Resource Protection Plan – Public Review Draft*, incorporating a later revision[1] as follows:

> Appurtenant water rights are rights to the use of water utilized by parcels of land at the time of their original conversion into fee simple lands i.e., when land allotted by the 1848 Mahele was confirmed to the awardee by the Land Commission and/or when the Royal Patent was issued based on such award, the conveyance of the parcel of land carried with it the appurtenant right to water.[2] The amount of water under an appurtenant right is the amount that was being used at the time of the Land Commission award and is established by cultivation methods that approximate the methods utilized at the time of the Mahele, for example, growing wetland taro.[3] Once established, future uses are not limited to the cultivation of traditional products approximating

[1] Although the final Water Resource Protection Plan had not been printed as of the date of this report, most edits had already been incorporated into the latest version, which the Commission utilized for this report.
[2] 54 Haw. 174, at 188; 504 .2d 1330, at 1339.
[3] 65 Haw. 531, at 554; 656 P.2d 57, at 72.

those utilized at the time of the Mahele[4], as long as those uses are reasonable, and if in a water management area, meets the State Water Code's test of reasonable and beneficial use ("the use of water in such a quantity as is necessary for economic and efficient utilization, for a purpose, and in a manner which is both reasonable and consistent with the State and county land use plans and the public interest"). As mentioned earlier, appurtenant rights are preserved under the State Water Code, so even in designated water management areas, an unexercised appurtenant right is not extinguished and must be issued a water use permit when applied for, as long as the water use permit requirements are met (Figure 12-2).

The Hawaii Legislative Session of 2002 clarified that the Commission is empowered to "determine appurtenant rights, including quantification of the amount of water entitled to by that right," (HRS §174C-5(15)). In those cases where a Commission decision may affect an appurtenant right, it is the claimant's duty to assert the appurtenant right and to gather the information required by the Commission to rule on the claim. The Commission is currently in the process of developing a procedural manual to aid in the understanding and assembling of information to substantiate an appurtenant rights claim.

In accordance with the State Water Code and the Supreme Court's decision in the Waiāhole Ditch Combined Contested Case Hearing, the Commission is focused on the assertion and exercise of appurtenant rights as they largely relate to the cultivation of taro. Wetland kalo or taro (*Colocasia esculenta* (L.) Schott) is an integral part of Hawaiian culture and agricultural tradition. The preferred method of wetland taro cultivation, where terrain and access to water permitted, was the construction of lo'i (flooded terraces) and lo'i complexes. These terraces traditionally received stream water via carefully engineered open channels called 'auwai. The auwai carried water, sometimes great distances, from the stream to the loi via gravity flow. In a system of multiple lo'i, water may either be fed to individual lo'i through separate little ditches if possible, or in the case of steeper slopes, water would overflow and drain from one lo'i to the next. Outflow from the loi may eventually be returned to the stream.

The lo'i also served other needs including the farming of subsidiary crops such as banana, sugar cane, and ti plants that were planted on its banks, and the raising of fish such as 'o'opu, awa, and aholehole within the waters of the lo'i itself. At least 85 varieties of taro were collected in 1931, each of which varied in color, locale, and growing conditions. The water needs of taro under wet conditions depend upon: 1) climate; 2) location and season (weather); 3) evaporation rate; 4) soil type; 5) ground water hydrology; 5) water temperature; and 6) agronomic conditions (crop stage; planting density and arrangement; taro variety; soil amendment and fertilization regime; lo'i drainage scheme; irrigation system management; and weed, pest, and disease prevalence and management).

The Commission conducted a cursory assessment of tax map key parcels to identify their associated Land Commission Awards, in an attempt to identify the potential for future appurtenant rights claims within the Waikoloa hydrologic unit. Table 12-1 presents the results of the Commission's assessment.

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[4] *Peck v Bailey*, 8 Haw. 658, at 665 (1867).

Figure 12-2. Generalized process for determining appurtenant water rights. This process is generalized and may not fully explain all possible situations. It does not apply to Hawaiian Homes Lands. If you are Native Hawaiian you may have other water rights.

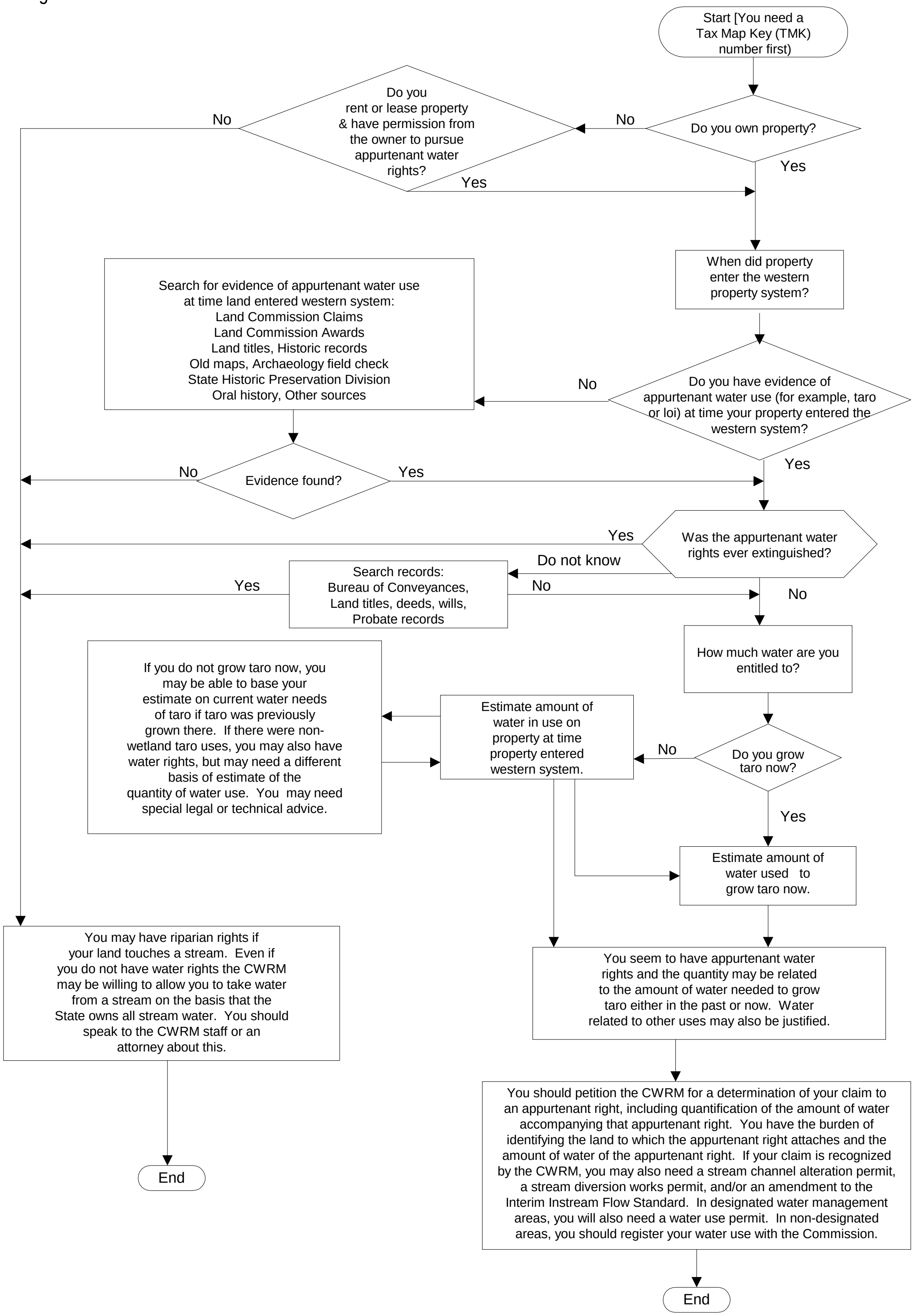


**Table 12-1.** Land Awards and claimants for the Waikoloa hydrologic unit, Hawai'i. [LCA is Land Commission Award; Gr. is Grant; por. is portion; and G.L. is Government Lease; BOE is Board of Education]

| Land Award | Claimant | Land Award | Claimant |
|---|---|---|---|
| LCA 8518 B:1 | Kanehoa, James Young | LCA 3672:1 | Mana |
| LCA 8515:5.1 | Ana, Keoni | LCA 3733:1 | Nakuala |
| LCA 3762:1 | Auwae | LCA 4212:1 | Kualehelehe |
| LCA 4195 | Kanehailua | LCA 3923:1 | Mauae |
| Gr 2129 | Lindsey, GK | | |
| LCA 976:2 | Beckley, William | | |
| LCA 3828 | Palea, JA | | |
| Gr 2183 | Ohiaku | | |
| LCA 4124 | Kalua, P | | |
| LCA 4123 | Kalawaia | | |
| LCA 590 B:1 | Ikiiki | | |
| LCA 590 B:2 | Ikiiki | | |
| LCA 3903:1 | Naaho | | |
| Gr 1157 | Macey, GW & J Louzada | | |
| LCA 8513 B | Hoolulu, Kuamoo | | |
| LCA 989 | Davis, John | | |
| LCA 8520 B:1 | Lahilahi, Gini | | |
| LCA 8521 B:1 | Hueu, GD | | |
| LCA 589 & 2258:1 | Fay, James | | |
| LCA 4513:1 | Paukeaho | | |
| LCA 4513:2 | Paukeaho | | |
| LCA 4207:2 | Kiai | | |
| Gr 1070 | Kiai | | |
| LCA 4885 | French, William | | |
| LCA 3674 | Barenaba | | |
| LCA 3915 | Nahoena | | |
| LCA 3785 | Olepau | | |
| LCA 988 | Collins, John | | |
| LCA 4198 | Kaaiunahi | | |
| LCA 3682 | Mahu | | |
| LCA 4198 | Kaaiunahi | | |
| LCA 987 | Hughes, William | | |
| Land Award Kamehameha IV Deed | Bishop, CR | | |
| LCA 2271 | Oili | | |
| LCA 4026 | Thomas, John | | |
| Gr 481 | Bright, James E | | |
| LCA 9971:58 | Leleiohoku, William P | | |
| LCA 4505 | Manuwa | | |
| Land Award Kamehameha IV Deed | Waimea Grazing Co | | |
| BOE Gr 13:2 | Board of Education | | |
| LCA 4231 | Kaulua, G | | |
| LCA 3844 | Pauhala | | |
| LCA 4024 | Seabury, James | | |
| LCA 3738 | Waiāhole | | |
| LCA 3762:2 | Auwae | | |
| LCA 3686:2 | Moluhi | | |
| LCA 4183 B:2 | Kaluahinenui & Kanaue | | |
| LCA 4230:2 | Kukahekahe | | |
| LCA 4230:1 | Kukahekahe | | |
| LCA 3686:1 | Moluhi | | |
| LCA 4183:1 | Kaluahinenui | | |
| LCA 4183 B:1 | Kanaue | | |
| LCA 3685:1 | Mahoe | | |
| LCA 4227:1 | Kaulunui | | |
| LCA 4210:1 | Kalua | | |
| LCA 4130:1 | Kanakaole | | |
| LCA 4132:1 | Kanekuapuu | | |
| LCA 4214:1 | Hanehane, James | | |
| LCA 4210 | Mokuhia | | |
| LCA 3675:1 | Kalua | | |
| LCA 4218:1 | Kaohimaunu | | |
| LCA 3842:1 | Paukumoku | | |

## Taro Production

In 2002, the State Office of Hawaiian Affairs cosponsored a “No Ka Lo‘i Conference”, in the hopes of bringing together taro farmers from around the state to share knowledge on the cultivation of taro. An outcome of the conference was an acknowledgement that farmers needed to better understand the water requirements of their taro crops to ensure and protect their water resource interests. The result of this effort was a 2007 USGS wetland kalo water use study, prepared in cooperation with the State Office of Hawaiian Affairs, which specifically examined flow and water temperature data in a total of 10 cultivation areas on four islands in Hawai‘i.

The study reiterated the importance of water temperature in preventing root rot. Typically, the water in the taro loi is warmer than water in the stream because of solar heating. Consequently, a taro loi needs continuous flow of water to maintain the water temperature at an optimum level. Multiple studies cited in Gingerich, et al., 2007, suggest that water temperature should not exceed 77ºF (25ºC). Low water temperatures slow taro growth, while high temperatures may result in root rot (Penn, 1997). When the flow of water in the stream is low, possibly as a result of diversions or losing reaches, the warmer water in the taro loi is not replaced with the cooler water from the stream at a quick enough rate to maintain a constant water temperature. As a result, the temperature of the water in the taro loi rises, triggering root rot.

The 2007 USGS study noted that “although irrigation flows for kalo cultivation have been measured with varying degrees of scientific accuracy, there is disagreement regarding the amount of water used and needed for successful kalo cultivation, with water temperature recognized as a critical factor. Most studies have focused on the amount of water consumed rather than the amount needed to flow through the irrigation system for successful kalo cultivation (Gingerich, et al., 2007).” As a result, the study was designed to measure the throughflow of water in commercially viable loi complexes, rather than measuring the consumption of water during taro growth.

Because water requirements for taro vary with the stage of maturity of the plants, all the cultivation areas selected for the study were at approximately the same stage (i.e. near harvesting, when continuous flooding is required). Temperature measurements were made every 15 minutes for approximately 2 months. Flow measurements were collected at the beginning and the end of that period. Data were collected during the dry season (June – October), when water requirements for cooling kalo are higher. Surface water temperatures generally begin to rise in April and remain elevated through September, due to increased solar heating. Water inflow temperature was measured in 17 loi complexes, and only three had inflow temperatures rising above 27ºC (the threshold temperature above which wetland kalo is more susceptible to fungi and associated rotting diseases).

The average and median inflows from all 10 cultivation areas studied are listed in Table 12-2 below. The study indicated that the “values are consistent with previously reported inflow and are significantly higher than values generally estimated for consumption during kalo cultivation.” It should also be noted that farmers were interviewed during field visits; most “believed that their supply of irrigation water was insufficient for proper kalo cultivation.” The study results are presented in Table 12-2 (discharge measurements) and Table 12-3 (water-temperature statistics).

## Archaeological Evidence for Hawaiian Agriculture

Individual cultural resources of Waikoloa hydrologic unit was not classified by the Hawai‘i Stream Assessment (HSA), but generally classified based on the Historic Preservation Division database. Data were collected in three general areas of: 1) archaeological; 2) historical; and 3) modern practices. Archaeological data were originally compiled by the State Historic Preservation Division and are only current to 1990, the date of the HSA (Table 12-4). There are 257 identified archaeological site in the

Waikoloa hydrological unit (Table 12-4). While modeling suggest a lack of wetland pre-contact agriculture, the archaeological evidence suggests the hydrologic unit supported large tracks of dryland agriculture utilizing irrigation water from Waikoloa, Keaimano and Waiulaula streams associated with the Waikoloa hydrologic unit as modeled by Ladefoged et al. (2009) who modeled the extent of pre-contact agriculture across the Hawaiian Islands (Figure 12-3).

Table 12-2. Summary of water use calculated from loi and loi complexes by island, and the entire state. (Source: Gingerich et al., 2007, Table 10) [gad = gallons per acre per day; na = not available]

| Island | Complex | | | | Loi | | | |
|---|---|---|---|---|---|---|---|---|
| | Number | Average water use (gad) | Average windward water use (gad) | Average leeward water use (gad) | Number | Average water use (gad) | Average windward water use (gad) | Average leeward water use (gad) |
| Kauai | 6 | 120,000 | 97,000 | 260,000 | 2 | 220,000 | 220,000 | na |
| Oahu | 5 | 310,000 | 380,000 | 44,000 | 4 | 400,000 | 460,000 | 210,000 |
| Maui | 6 | 230,000 | 230,000 | na | na | na | na | na |
| Hawaii | 2 | 710,000 | 710,000 | na | na | na | na | na |
| Average of all measurements | | 260,000 | 270,000 | 150,000 | | 350,000 | 370,000 | 210,000 |
| Median of all measurements | | 150,000 | 150,000 | 150,000 | | 270,000 | 320,000 | 210,000 |

Table 12-3. Water-temperature statistics based on measurements collected at 15-minute intervals for loi complexes on the island of Maui. (Source: Gingerich et al., 2007, Table 7) [ºC = degrees Celsius; na = not applicable]

| Geographic designation | Area | Station | Period of record | Temperature (ºC) | | | Temperature measurements greater that 27ºC (percent) |
|---|---|---|---|---|---|---|---|
| | | | | Mean | Range | Mean daily range | |
| Windward | Waihee | Ma08A-CI | 7/29/2006 - 9/22/2006 | 21.6 | 19.9 - 24.0 | 2.0 | 0.0 |
| | | Ma08B-CIL | 7/29/2006 - 9/22/2006 | 24.9 | 20.3 - 34.0 | 7.6 | 25.4 |
| | | Ma08B-CO | 7/29/2006 - 9/22/2006 | 25.5 | 20.0 - 35.5 | 5.7 | 27.0 |
| Windward | Wailua (Lakini) | Ma09-CIT | 7/30/2006 - 9/21/2006 | 20.7 | 18.5 - 23.4 | 2.3 | 0.0 |
| | | Ma09-CO | 7/30/2006 - 9/21/2006 | 23.2 | 18.4 - 31.7 | 7.4 | 16.9 |
| Windward | Wailua | Ma10-CI | 7/30/2006 - 9/21/2006 | 22.5 | 20.5 - 25.9 | 1.9 | 0.0 |
| Windward | Wailua (Waikani) | Ma11-CI | 7/30/2006 - 9/21/2006 | 22.2 | 21.0 - 24.0 | 0.7 | 0.0 |
| | | Ma11-CO | 7/30/2006 - 9/21/2006 | 26.1 | 22.1 - 31.8 | 3.3 | 29.1 |
| Windward | Keanae | Ma12-CI | 7/31/2006 - 9/21/2006 | 20.0 | 19.0 - 21.9 | 1.0 | 0.0 |
| | | Ma12-CO | equipment malfunction | na | na | na | na |

Table 12-4. Archaeological sites in the Waikoloa hydrologic unit, Hawai'i. (Source: Kipuka Database, 2023)
[LCA is Land Commission Award; Gr. is Grant;

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 02611 | 50-10-05-02611 | H-00321 | LCA 8515:5.1 | Boulder pile; marker |
| 02622 | 50-10-05-02622 | H-00019 | LCA 8515:5.1 | C-shape; wall; lava tube; storage site |
| 02684 | 50-10-06-02684 | H-00019 | LCA 8521 B:1 | Depression; auwai; trail; alignment; road |
| 02686 | 50-10-06-02686 | | LCA 8521 B:1 | None |
| 02776 | 50-10-06-02776 | H-00321 | LCA 8521 B:1 | Artifact; c-shape; midden deposit; firepit; lithic deposit; habitation site |
| 02779 | 50-10-06-02779 | H-00015 | LCA 8521 B:1 | Lithic deposit; mound; burial; firepit; midden; artifact; agriculture site/habitation complex |
| 02790 | 50-10-06-02790 | H-00019 | LCA 8521 B:1 | Alignment; artifact; depression; midden; walls; firepit; lava tube; habitation site |
| 02802 | 50-10-06-02802 | H-00015 | LCA 8521 B:1 | Terrace; mound; undetermined site Lalamilo complex |
| 02803 | 50-10-06-02803 | H-00015 | LCA 8521 B:1 | Mound; terrace; undetermined site Lalamilo complex |
| 02813 | 50-10-06-02813 | H-00015 | unmapped | Mound; terrace; undetermined site |
| 02867 | 50-10-06-02867 | H-00015 | unmapped | Mound; shelter; wall; Ag/habitation site Lalamilo complex |
| 02876 | 50-10-06-02876 | H-00015 | unmapped | Mound; shelter; c-shape; habitation site Lalamilo complex |
| 05947 | 50-10-06-05947 | H-00321 | LCA 8521 B:1 | Lithic deposit; midden; u-shape; alignment; firepit; L-shape; historic artifact; habitation complex |
| 05950 | 50-10-06-05957 | | LCA 8521 B:1 | |
| 05957 | 50-10-06-05950 | H-00019 | LCA 8521 B:1 | Enclosure; wall; agriculture site |
| 05961 | 50-10-06-05961 | | unmapped | None |
| 05962 | 50-10-06-05962 | H-00321 | LCA 8521 B:1 | Alignment; platform; terrace; agriculture site |
| 08820 | 50-10-05-08820 | H-00321 | LCA 8515:5.1 | Sinkhole with shelves makde from shell and coral to create surfaces; activity area |
| 08828 | 50-10-06-08828 | H-00321 | LCA 8518 B:1 | Terrace; c-shape; alignment; mound; firepit; habitation site |
| 08829 | 50-10-05-08829 | | LCA 8518 B.1 | none |
| 08830 | 50-10-05-08830 | H-00019 | LCA 8518 B.1 | alignment; cairn; terrace; wall; shelter; oval; habitation site |
| 08831 | 50-10-05-08831 | H-00019 | LCA 8518 B.1 | Wall shelter; alignment; midden; enclosure; habitation site |
| 08833 | 50-10-05-08833 | H-00019 | LCA 8518 B.1 | Wall, shelter; cairn; open; habitation site; military site |
| 08838 | 50-10-05-08838 | H-00243 | LCA 8518 B.1 | Cairn, shelter, boulder; military site |
| 08839 | 50-10-05-08839 | H-00243 | LCA 8518 B.1 | shelter, wall; boulder; undetermined site |
| 08841 | 50-10-05-08841 | H-00243 | LCA 8518 B.1 | Cairn; undetermined site |
| 08842 | 50-10-05-08842 | H-00243 | LCA 8518 B.1 | Cairn; undetermined site |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 08846 | 50-10-05-08846 | H-00243 | LCA 8518 B.1 | Cairn; undetermined site |
| 08849 | 50-10-05-08846 | H-00243 | LCA 8518 B.1 | Cairn; alignment; c-shape; firepit; midden; undetermined site |
| 08861 | 50-10-05-08861 | H-00243 | unmapped | Cairn; open shelter; undetermined site |
| 08862 | 50-10-05-08862 | H-00243 | unmapped | Cairn; undetermined site |
| 08863 | 50-10-05-08863 | H-00243 | unmapped | U-shaped; undetermined site |
| 08864 | 50-10-05-08864 | H-00243 | unmapped | Cairn; undetermined site |
| 08865 | 50-10-05-08865 | H-00243 | unmapped | Cairn; undetermined site |
| 08866 | 50-10-06-08867 | H-00243 | unmapped | Alignment; enclosure; open shelter; military site |
| 08867 | 50-10-06-08866 | H-00243 | unmapped | Cairn; undetermined site |
| 08869 | 50-10-06-08869 | H-00243 | unmapped | Cairn; shelter; military site |
| 08870 | 50-10-06-08870 | H-00243 | unmapped | Mound; platform; u-shaped; military site |
| 08871 | 50-10-06-08871 | H-00243 | unmapped | u-shape; shelter; military site |
| 08872 | 50-10-06-08872 | H-00243 | unmapped | Wall shelter; undetermined site |
| 08874 | 50-10-06-08874 | H-00243 | unmapped | Boulder shelter; u-shape; undetermined site |
| 08875 | 50-10-06-08875 | H-00243 | unmapped | Cairn; depression; enclosure; road; trench; alignment; military site |
| 08876 | 50-10-06-08876 | H-00243 | unmapped | Enclosure; shelter; military site |
| 08877 | 50-10-06-08877 | H-00243 | unmapped | shelter; undetermined site |
| 08878 | 50-10-06-08878 | H-00243 | unmapped | Road; shelter; abutment; military site |
| 08879 | 50-10-06-08879 | H-00243 | unmapped | Cairn, mound; L-shaped; terrace; enclosure; depression; agriculture site |
| 08880 | 50-10-06-08880 | H-00243 | unmapped | u-shaped; shelter; undetermined site |
| 08881 | 50-10-06-08881 | H-00243 | unmapped | Alignment; wall, shelter; undetermined site |
| 08882 | 50-10-05-08882 | H-00243 | unmapped | Alignment; cairn; depression; boulder shelter; undetermined site |
| 08883 | 50-10-06-08883 | H-00243 | unmapped | Enclosure; midden; wall; shelter; military site |
| 08884 | 50-10-05-08884 | H-00243 | unmapped | Alignment; road; l-shaped shelter; military site |
| 08885 | 50-10-05-08885 | H-00243 | unmapped | Cairn, shelter; undetermined site |
| 08886 | 50-10-05-08886 | H-00243 | LCA 8518 B.1 | Alignment; cairn, circular, auwai; trail |
| 08887 | 50-10-06-08887 | H-00243 | unmapped | Cairn, conical; shelter; c-shape; wall; alignment; enclosure; terrace; undetermined site |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 08888 | 50-10-06-08888 | H-00243 | unmapped | Terraces 2x; alignment; undetermined site |
| 08889 | 50-10-06-08889 | H-00243 | unmapped | Cairn; conical; rock concentration; terrace; shelter; military site |
| 08890 | 50-10-06-08890 | H-00243 | unmapped | Alignment; c-shape; cairn; conical; firepit; l-shape; undetermined site |
| 08891 | 50-10-06-08891 | H-00243 | unmapped | Wall; burial; enclosure; mound; shelter; burial site |
| 08894 | 50-10-05-08894 | H-00243 | unmapped | Alignment; road |
| 08895 | 50-10-06-08895 | H-00015 | unmapped | c-shape; habitation site Lalamilo complex |
| 08896 | 50-10-06-08896 | H-00015 | unmapped | Terrace; habitation site |
| 08897 | 50-10-06-08897 | H-00015 | unmapped | Wall; mound; depression; lined; undetermined site |
| 08898 | 50-10-06-08898 | H-00015 | unmapped | Enclosure; habitation site |
| 08901 | 50-10-06-08901 | H-00015 | unmapped | shelter; habitation site Lalamilo complex |
| 08906 | 50-10-06-08906 | H-00015 | unmapped | Terrace; undetermined site |
| 08908 | 50-10-06-08908 | H-00015 | unmapped | Enclosure; undetermined site |
| 08909 | 50-10-06-08909 | H-00015 | unmapped | Rockshelter; terrace; habitation site |
| 08910 | 50-10-06-08910 | H-00015 | unmapped | Terrace; mound; depression; lined; enclosure; habitation site |
| 08911 | 50-10-06-08911 | H-00015 | unmapped | Mound; c-shape; habitation site Lalamilo complex |
| 08917 | 50-10-06-08917 | H-00015 | unmapped | Terrace; alignment; enclosure; habitation site Lalamilo complex |
| 08920 | 50-10-06-08920 | H-00015 | unmapped | C-shape; habitation site |
| 08932 | 50-10-06-08932 | H-00015 | unmapped | Enclosure; depression; terrace; habitation site Lalamilo complex |
| 08933 | 50-10-06-08933 | H-00015 | unmapped | Enclosure; habitation site Lalamilo complex |
| 08934 | 50-10-06-08934 | H-0015 | unmapped | Firepit; mound; undetermined site |
| 08935 | 50-10-06-08935 | H-00015 | unmapped | C-shape; box; shelter; U-shape habitation site |
| 08937 | 50-10-06-08937 | H-00015 | unmapped | Shelter; foxhole; military site |
| 08939 | 50-10-06-08939 | H-00015 | unmapped | Platform; Lalamilo complex |
| 08941 | 50-10-06-08941 | H-00015 | unmapped | Terrace; habitation site Lalamilo complex |
| 08942 | 50-10-06-08942 | H-00015 | unmapped | Terrace; habitation site Lalamilo complex |
| 08944 | 50-10-06-08944 | H-00015 | unmapped | Firepit, wall, c-shape, box; habitation site Lalamilo complex |
| 08945 | 50-10-06-08945 | H-00015 | unmapped | c-shape; habitation site Lalamilo complex |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 08946 | 50-10-06-08946 | H-00015 | unmapped | Rockshelter; habitation site Lalamilo complex |
| 08948 | 50-10-06-08948 | H-00015 | unmapped | Firepit; alignment; terrace; habitation site Lalamilo complex |
| 08949 | 50-10-06-08949 | H-00015 | unmapped | Mound; undetermined site Lalamilo complex |
| 08954 | 50-10-06-08954 | H-00015 | unmapped | Firepit; terrace; habitation site Lalamilo complex |
| 08955 | 50-10-06-08955 | H-00015 | unmapped | Terrace; midden deposit; lithic deposit; habitation site Lalamilo complex |
| 08956 | 50-10-06-08956 | H-00015 | unmapped | Rockshelter; terrace; mound; habitation site Lalamilo complex |
| 08957 | 50-10-06-08957 | H-00015 | unmapped | L-shape; habitation site Lalamilo complex |
| 08959 | 50-10-06-08959 | H-00015 | unmapped | C-shape; shelter; linear; habitation site Lalamilo complex |
| 08960 | 50-10-06-08960 | H-00015 | unmapped | Mound; undetermined site |
| 08962 | 50-10-06-08962 | H-00015 | unmapped | C-shape; habitation site Lalamilo complex |
| 08963 | 50-10-06-08963 | | unmapped | none |
| 08967 | 50-10-06-08967 | H-00015 | unmapped | Alignment; undetermined site |
| 08969 | 50-10-06-08969 | H-00015 | unmapped | Terrace; undetermined site |
| 08972 | 50-10-06-08972 | H-00015 | unmapped | Shelter; linear; habitation site Lalamilo complex |
| 08973 | 50-10-06-08973 | H-00015 | unmapped | Shelter; linear; mound; habitation site Lalamilo complex |
| 08974 | 50-10-06-08974 | H-00015 | unmapped | Mound; terrace; agriculture site Lalamilo complex |
| 08975 | 50-10-06-08975 | H-00015 | unmapped | L-shape; habitation site Lalamilo complex |
| 08976 | 50-10-06-08976 | H-00015 | unmapped | Terrace; habitation site Lalamilo complex |
| 08977 | 50-10-06-08977 | H-00015 | unmapped | Terrace; mound; agriculture site Lalamilo complex |
| 08978 | 50-10-06-08978 | H-00015 | unmapped | C-shape; box; habitation site Lalamilo complex |
| 08979 | 50-10-06-08979 | H-00015 | unmapped | Shelter; linear; habitation site Lalamilo complex |
| 08980 | 50-10-06-08980 | H-00015 | unmapped | Enclosure; rockshelter; habitation site Lalamilo complex |
| 08982 | 50-10-06-08982 | H-00015 | unmapped | C-shape; habitation site Lalamilo complex |
| 08983 | 50-10-06-08983 | H-00015 | unmapped | Shelter; linear; habitation site Lalamilo complex |
| 08984 | 50-10-06-08984 | H-00015 | unmapped | C-shape; habitation site Lalamilo complex |
| 08985 | 50-10-06-08985 | H-00015 | unmapped | Terrace; L-shape; C-shape; habitation site Lalamilo complex |
| 08986 | 50-10-06-08986 | H-00015 | unmapped | C-shape; mound; cupboard; shelter; ahu; habitation site Lalamilo complex |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 08987 | 50-10-06-08987 | H-00015 | unmapped | Firepit; mound; wall; undetermined site |
| 08988 | 50-10-06-08987 | H-00015 | unmapped | L-shape; habitation site |
| 08990 | 50-10-06-08990 | H-00015 | unmapped | Enclosure; habitation site |
| 08991 | 50-10-06-08991 | H-00015 | unmapped | alignment; undetermined site |
| 08992 | 50-10-06-08992 | H-00015 | unmapped | Terrace; habitation site Lalamilo complex |
| 08993 | 50-10-06-08993 | H-00015 | unmapped | Enclosure; terrace; wall; habitation site Lalamilo complex |
| 08996 | 50-10-06-08996 | H-00015 | unmapped | Shelter; linear; habitation site Lalamilo complex |
| 08997 | 50-10-06-08998 | H-00015 | unmapped | Enclosure; habitation site Lalamilo complex |
| 08998 | 50-10-06-08998 | H-00015 | unmapped | Alignment; enclosure; habitation site Lalamilo complex |
| 09001 | 50-10-06-09001 | H-00015 | unmapped | C-shape; mound; alignment; habitation site Lalamilo complex |
| 09002 | 50-10-06-09002 | H-00015 | unmapped | C-shape; mound; habitation site Lalamilo complex |
| 09003 | 50-10-06-09003 | H-00015 | unmapped | Enclosure; undetermined site |
| 09011 | 50-10-06-09011 | H-00015 | unmapped | Terrace; habitation site |
| 09012 | 50-10-06-09012 | H-01192 | LCA 8521 B:1<br>LCA 8518 B:1 | Wall 4000 x 11.5 x 1 m forms west boundary of Ouli ranch site |
| 09014 | 50-10-06-09014 | H-01192 | unmapped | Mound; terrace; undetermined site |
| 09017 | 50-10-06-09017 | H-00015 | unmapped | Alignment; undetermined site |
| 09022 | 50-10-06-09022 | H-00015 | unmapped | Enclosure; habitation site Lalamilo complex |
| 09023 | 50-10-06-09023 | H-00015 | unmapped | Firepit; c-shape; lithic deposit; habitation site Lalamilo complex |
| 09024 | 50-10-06-09024 | H-00015 | unmapped | C-shape; firepit; habitation site Lalaminlo complex |
| 09025 | 50-10-06-09025 | H-00015 | unmapped | Enclosure; habitation site Lalaminlo complex |
| 09027 | 50-10-06-09027 | H-00015 | unmapped | C-shape; firepit; shelter; linear; habitation site Lalamilo complex |
| 09029 | 50-10-06-09029 | H-00015 | unmapped | Firepit; c-shape; habitation site Lalamilo complex |
| 09032 | 50-10-06-09032 | H-00015 | unmapped | C-shape; firepit; habitation site Lalamnlo complex |
| 09034 | 50-10-06-09034 | H-00015 | unmapped | Mound; terrace; habitation site Lalamilo complex |
| 09071 | 50-10-06-09071 | H-00015 | unmapped | Terrace; mound; agriculture site Lalamilo complex |
| 09081 | 50-10-06-09081 | | unmapped | None Lalaminlo complex |
| 09087 | 50-10-06-09087 | | unmapped | None Lalaminlo complex |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 09096 | 50-10-06-09096 | | unmapped | None Lalaminlo complex |
| 09097 | 50-10-06-09097 | | unmapped | None Lalaminlo complex |
| 09119 | 50-10-06-09119 | | unmapped | None Lalaminlo complex |
| 09130 | 50-10-06-09130 | | unmapped | None Lalaminlo complex |
| 09159 | 50-10-06-09159 | | unmapped | None Lalaminlo complex |
| 09163 | 50-10-06-09163 | | unmapped | None Lalaminlo complex |
| 11097 | 50-10-06-11097 | H-00625 | LCA 8518 B:1 | Wall, mound, earth, Lalamilo agriculture complex |
| 13936 | 50-10-05-13936 | H-00988 | LCA 8515:5.1 | C-shaped; terrace; alignment; cupboard; midden, cairn; agriculture site |
| 13937 | 50-10-05-13937 | H-00988 | LCA 8515:5.1 | C-shaped; terrace; enclosure; agriculture site |
| 13939 | 50-10-05-13939 | H-00988 | LCA 8515:5.1 | C-shaped; terrace; agriculture site |
| 13955 | 50-10-05-13955 | H-00988 | LCA 8515:5.1 | Wall; terrace; enclosure; agriculture site |
| 13959 | 50-10-05-13959 | | LCA 8515:5.1 | none |
| 13943 | 50-10-05-13943 | H-00620 | LCA 8515:5.1 | L-shaped; rubble pile; terrace; agriculture site |
| 13944 | 50-10-05-13944 | H-00620 | LCA 8515:5.1 | Artifact; wall, c-shape; habitation complex |
| 13945 | 50-10-05-13945 | H-00620 | LCA 8515:5.1 | Boundary wall |
| 13946 | 50-10-05-13946 | H-00620 | LCA 8515:5.1 | Cupboard; terrace; agriculture site |
| 13955 | 50-10-05-13955 | H-00620 | LCA 8515:5.1 | Wall; terrace; enclosure; agriculture site |
| 13958 | 50-10-05-13958 | H-00988 | LCA 8515:5.1 | U-shape cupboard; terrace; enclosure; habitation site |
| 13959 | 50-10-05-13959 | H-00988 | LCA 8515:5.1 | C-shape habitation site |
| 13960 | 50-10-05-13960 | H-00620 | LCA 8515:5.1 | enclosure; midden; fire pit; cupboard; habitation site |
| 13961 | 50-10-05-13961 | H-00988 | LCA 8515:5.1 | Cultural deposit; midden; habitation site |
| 13962 | 50-10-05-13962 | H-00988 | LCA 8515:5.1 | terrace |
| 13963 | 50-10-05-13963 | H-00988 | LCA 8515:5.1 | Cave; petroglyph; artifact; habitation site |
| 13964 | 50-10-05-13964 | H-00988 | LCA 8515:5.1 | Midden; rockshelter; artifact; habitation site |
| 13965 | 50-10-05-13965 | H-00620 | LCA 8515:5.1 | boundary cairn |
| 13971 | 50-10-05-13971 | H-00988 | LCA 8515:5.1 | Enclosure; wall; mound; c-shape cupboard 2x; agriculture/habitation site |
| 13975 | 50-10-05-13975 | H-00988 | LCA 8515:5.1 | Mound; habitation site |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 13977 | 50-10-05-13977 | H-00988 | LCA 8515:5.1 | Midden; platform; possible burial site |
| 13992 | 50-10-05-13992 | H-00988 | LCA 8515:5.1 | C-shape; midden; habitation site |
| 13996 | 50-10-05-13996 | H-00988 | LCA 8515:5.1 | C-shape; terrace; habitation site |
| 14006 | 50-10-05-14007 | H-00620 | LCA 8515:5.1 | Midden; boundary cairn |
| 14007 | 50-10-05-14007 | H-00620 | LCA 8515:5.1 | Midden; boundary cairn |
| 14008 | 50-10-05-14008 | H-00620 | LCA 8515:5.1 | 5 boundary cairns |
| 14009 | 50-10-05-14009 | H-00620 | LCA 8515:5.1 | boundary cairn |
| 14010 | 50-10-05-14010 | H-00988 | LCA 8515:5.1 | transportation cairn |
| 14012 | 50-10-05-14012 | H-00988 | LCA 8515:5.1 | Enclosure; oval; military site |
| 14013 | 50-10-05-14013 | H-00620 | LCA 8515:5.1 | C-shape; foxhole; surface midden; historic structure; habitation site |
| 14026 | 50-10-05-14026 | H-00988 | LCA 8515:5.1 | boundary cairn |
| 14028 | 50-10-05-14028 | H-00988 | LCA 8515:5.1 | Platform/mound, historic artifact; boundary cairn |
| 14031 | 50-10-05-14031 | H-00988 | LCA 8515:5.1 | Rubble pile |
| 14032 | 50-10-05-14033 | H-00620 | LCA 8515:5.1 | Terrace 2x; agriculture site |
| 14033 | 50-10-05-14032 | H-00988 | LCA 8515:5.1 | Rubble pile |
| 14044 | 50-10-05-14044 | H-00988 | LCA 8515:5.1 | c-shape; stepped terrace 2x; historic artifact; agriculture site |
| 14051 | 50-10-05-14051 | H-00988 | LCA 8515:5.1 | c-shaped; midden; WWII military site |
| 14052 | 50-10-05-14052 | H-00988 | LCA 8515:5.1 | boundary cairn |
| 14054 | 50-10-05-14054 | H-00988 | LCA 8515:5.1 | c-shape; midden, enclosure; habitation site |
| 14055 | 50-10-05-14055 | H-00988 | LCA 8515:5.1 | Enclosure; midden; habitation site |
| 14057 | 50-10-05-14057 | H-00988 | LCA 8515:5.1 | Old Kawaihae-Puako Road |
| 14060 | 50-10-05-14060 | H-00988 | LCA 8515:5.1 | none |
| 14061 | 50-10-05-14061 | H-00988 | LCA 8515:5.1 | Boundary wall; bedrock bowl |
| 14062 | 50-10-05-14062 | H-00988 | LCA 8515:5.1 | Ditch; terrace; rubble pile; auwai; agriculture site |
| 14063 | 50-10-05-14063 | H-00988 | LCA 8515:5.1 | Cave; possible petroglyph; habitation site |
| 14068 | 50-10-05-14068 | H-00988 | LCA 8515:5.1 | Midden; wall; agriculture site |
| 14680 | 50-10-05-14680 | H-01192 | LCA 8518 B:1 | Cairn; ranching site |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 14681 | 50-10-05-14681 | H-01192 | LCA 8518 B:1 | c-shape on west facing slope of ridge; military site |
| 14682 | 50-10-05-14682 | H-01192 | LCA 8518 B:1 | Berm; military site |
| 14683 | 50-10-05-14683 | H-01192 | LCA 8518 B:1 | Cairn; mound; ranching site |
| 14684 | 50-10-05-14684 | H-00799 | LCA 8515:5.1 | Charcoal, coral, midden; terrace; historic artifacts; volcanic glass; agriculture ste |
| 14684 | 50-10-05-14684 | H-01192 | LCA 8518 B:1 | Cairn; ranching site |
| 14686 | 50-10-05-14686 | H-01192 | LCA 8518 B:1 | Circular cairn; Ouli ranching site |
| 14687 | 50-10-05-14687 | H-01192 | LCA 8518 B:1 | Midden; pavement; historic artifact; enclosure; habitation site |
| 14688 | 50-10-05-14688 | H-01192 | LCA 8518 B:1 | Enclosure; ranching site |
| 14691 | 50-10-05-14691 | H-01192 | LCA 8518 B:1 | Cairn; boundary site |
| 14692 | 50-10-05-14692 | H-01192 | LCA 8518 B:1 | c-shape; military site |
| 14693 | 50-10-05-14693 | H-01192 | LCA 8518 B:1 | c-shape; military site |
| 14694 | 50-10-05-14694 | H-01192 | LCA 8518 B:1 | Cairn; ranching site |
| 14695 | 50-10-05-14695 | H-01192 | LCA 8518 B:1 | Cairn; boundary site |
| 14696 | 50-10-05-14696 | H-01192 | LCA 8518 B:1 | Cairn; boundary site |
| 14697 | 50-10-05-14697 | H-01192 | LCA 8518 B:1 | Alignment; military site |
| 14698 | 50-10-05-14698 | H-01192 | LCA 8518 B:1 | Enclosure; c-shape; military site |
| 14699 | 50-10-05-14699 | H-01192 | LCA 8518 B:1 | Cairn; military site |
| 14700 | 50-10-05-14700 | H-01192 | LCA 8518 B:1 | Cairn; military site |
| 14701 | 50-10-05-14701 | H-01192 | LCA 8518 B:1 | C-shape; military site |
| 14702 | 50-10-05-14702 | H-01192 | LCA 8518 B:1 | Historic trash; enclosure; military site |
| 14703 | 50-10-05-14703 | H-01192 | LCA 8518 B:1 | Historic trash; alignment; military site |
| 14704 | 50-10-05-14704 | H-01192 | LCA 8518 B:1 | C-shape; military site |
| 14705 | 50-10-05-14705 | H-01192 | LCA 8518 B:1 | C-shape; military site |
| 14706 | 50-10-05-14706 | H-01192 | LCA 8518 B:1 | C-shape; cairn; military site |
| 14707 | 50-10-05-14707 | H-01192 | LCA 8518 B:1 | Alignment; berm; military site |
| 14708 | 50-10-05-14708 | H-00744 | LCA 8518 B:1 | Cairn; boundary site |
| 14709 | 50-10-05-14709 | H-01192 | LCA 8518 B:1 | Alignment; military site |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 14710 | 50-10-05-14710 | H-01192 | LCA 8518 B:1 | Cairn; boundary site |
| 14711 | 50-10-05-14711 | H-01192 | LCA 8518 B:1 | Cairn; boundary site |
| 14712 | 50-10-05-14712 | H-01192 | LCA 8518 B:1 | C-shape, historic trash; wall; military site |
| 14713 | 50-10-05-14713 | H-01192 | LCA 8518 B:1 | Cairn; rectangular; ranching site |
| 14714 | 50-10-05-14714 | H-01192 | LCA 8518 B:1 | Historic trash; enclosure; military site |
| 14715 | 50-10-05-14715 | H-01192 | LCA 8518 B:1 | Cairn; boundary site |
| 14716 | 50-10-05-14717 | H-01192 | LCA 8518 B:1 | C-shape, military site |
| 14717 | 50-10-05-14717 | H-01192 | LCA 8518 B:1 | C-shape, rectangular; military site |
| 14718 | 50-10-05-14718 | H-01192 | LCA 8518 B:1 | Modified outcrop; enclosure; military site |
| 14719 | 50-10-05-14719 | H-01192 | LCA 8518 B:1 | Enclosure; military site |
| 14720 | 50-10-05-14720 | H-01192 | LCA 8518 B:1 | Cairn; historic trash; military site |
| 14721 | 50-10-05-14721 | H-01192 | LCA 8518 B:1 | Modified outcrop; cairn; historic trash; enclosure; military site |
| 14722 | 50-10-05-14722 | H-01192 | LCA 8518 B:1 | Historic trash; c-shape; military site |
| 14723 | 50-10-05-14723 | H-01192 | LCA 8518 B:1 | Historic trash; c-shape; alignment; military site |
| 14724 | 50-10-05-14724 | H-01192 | LCA 8518 B:1 | Historic trash; alignment; military site |
| 14725 | 50-10-05-14725 | H-01192 | LCA 8518 B:1 | Wall; military site |
| 14726 | 50-10-05-14726 | H-00945 | LCA 8518 B:1 | 3 walls; agriculture site |
| 14727 | 50-10-05-14727 | H-01192 | LCA 8518 B:1 | Historic trash; cairn; c-shape; military site |
| 14728 | 50-10-05-14728 | H-01192 | LCA 8518 B:1 | Historic trash; cairn; c-shape; military site |
| 14729 | 50-10-05-14729 | H-01192 | LCA 8518 B:1 | Cairn; remnant of kawaihae-waimea road |
| 14730 | 50-10-05-14730 | H-01192 | LCA 8518 B:1 | Cairn; ranching site |
| 14731 | 50-10-05-14731 | H-01192 | LCA 8518 B:1 | Cairn; historic trash; historic artifact; military site |
| 14732 | 50-10-05-14732 | H-01192 | LCA 8518 B:1 | Cairn; historic trash; ranching site |
| 14734 | 50-10-05-14734 | H-01192 | LCA 8518 B:1 | Alignment; military site |
| 14735 | 50-10-05-14735 | H-01192 | LCA 8518 B:1 | Historic trash; modified outcrop; military site |
| 14736 | 50-10-05-14736 | H-01192 | LCA 8518 B:1 | Historic trash; c-shape; military site |
| 14739 | 50-10-05-14739 | H-01192 | LCA 8518 B:1 | Modified outcrop; military site |

Table 12-4. [continued]

| Historic Site # | State Site # | SHPD Library | Land Award | Description |
|---|---|---|---|---|
| 14741 | 50-10-05-14741 | H-01192 | LCA 8518 B:1 | Rockshelter; habitation site |
| 14744 | 50-10-05-14745 | H-01192 | LCA 8518 B:1 | Circular structure; cairn; military site |
| 14745 | 50-10-05-14745 | H-01192 | LCA 8518 B:1 | Cairn; military site |
| 14746 | 50-10-05-14746 | H-01192 | LCA 8518 B:1 | Historic trash; c-shape; military site |
| 14747 | 50-10-05-14747 | H-01192 | LCA 8518 B:1 | Historic trash; c-shape; military site |
| 14748 | 50-10-05-14748 | H-01192 | LCA 8518 B:1 | historic trash; wall; military site |
| 14749 | 50-10-05-14749 | H-01192 | LCA 8518 B:1 | Cairn; ranching site |
| 14750 | 50-10-05-14750 | H-01192 | LCA 8518 B:1 | Midden; rockshelter; habitation site |
| 14751 | 50-10-05-14751 | H-01192 | LCA 8518 B:1 | Midden; rockshelter; habitation site |
| 16095 | 50-10-06-16095 | H-00989 | LCA 8521 B:1<br>LCA 4026 | Auwai; ditch; depression; linear |
| 19643 | 50-10-06-19643 | H-01381 | LCA 8520 B:1 | Auwai; modified drainage; Wai‘aka Agriculture complex |
| 19644 | 50-10-06-19644 | H-01381 | LCA 8520 B:1 | Terrace 6x; Wai‘aka Agriculture complex |
| 19645 | 50-10-06-19645 | H-01381 | LCA 8520 B:1 | Terrace; Wai‘aka Agriculture complex |
| 19647 | 50-10-06-19647 | H-01381 | LCA 8520 B:1 | Terrace; Wai‘aka Agriculture complex |

## Fishponds

Fishponds are another integral part of traditional Hawaiian culture, which speaks volumes of native Hawaiian skill and knowledge of aquaculture, which has also seen a resurgence of interest in recent years. Fishponds are found throughout the Hawaiian Islands and were either man-made or natural enclosures of water used for the raising and harvesting of fish and other aquatic organisms. Kikuchi (1973) identified six main types of fishponds, two of which are associated with streams (*loko wai*, *loko ia kalo*) and one type is associated with fresh water springs (*kaheka* or *hapunapuna*).

- Type III – *Loko Wai*: An inland fresh water fishpond which is usually either a natural lake or swamp, which can contain ditches connected to a river, stream, or the sea, and which can contain sluice grates. Although most frequently occurring inland, *loko wai* are also located along the coast near the outlet of a stream.
- Type IV – *Loko Ia Kalo*: A fishpond utilizing irrigated taro plots. *Loko ia kalo* are located inland along streams and on the coast in deltas and marshes.
- Type VI – *Kaheka* and *Hapunapuna*: A natural pool or holding pond. The majority, if not all of these types of ponds, are anchialine ponds with naturally occurring shrimp and mollusks.

According to a 1990 Hawaii Coastal Zone Management Program *Hawaiian Fishpond Study, Islands Of Oahu, Molokai And Hawaii,* there are three historic fishponds near the Waikoloa hydrologic unit but none in the immediate vicinity (DHM, Inc., 1989).

Figure 12-3. Zones of pre-contact intensive agriculture in Waikoloa, Hawaiʻi. (Source: Ladefoged et al., 2009)

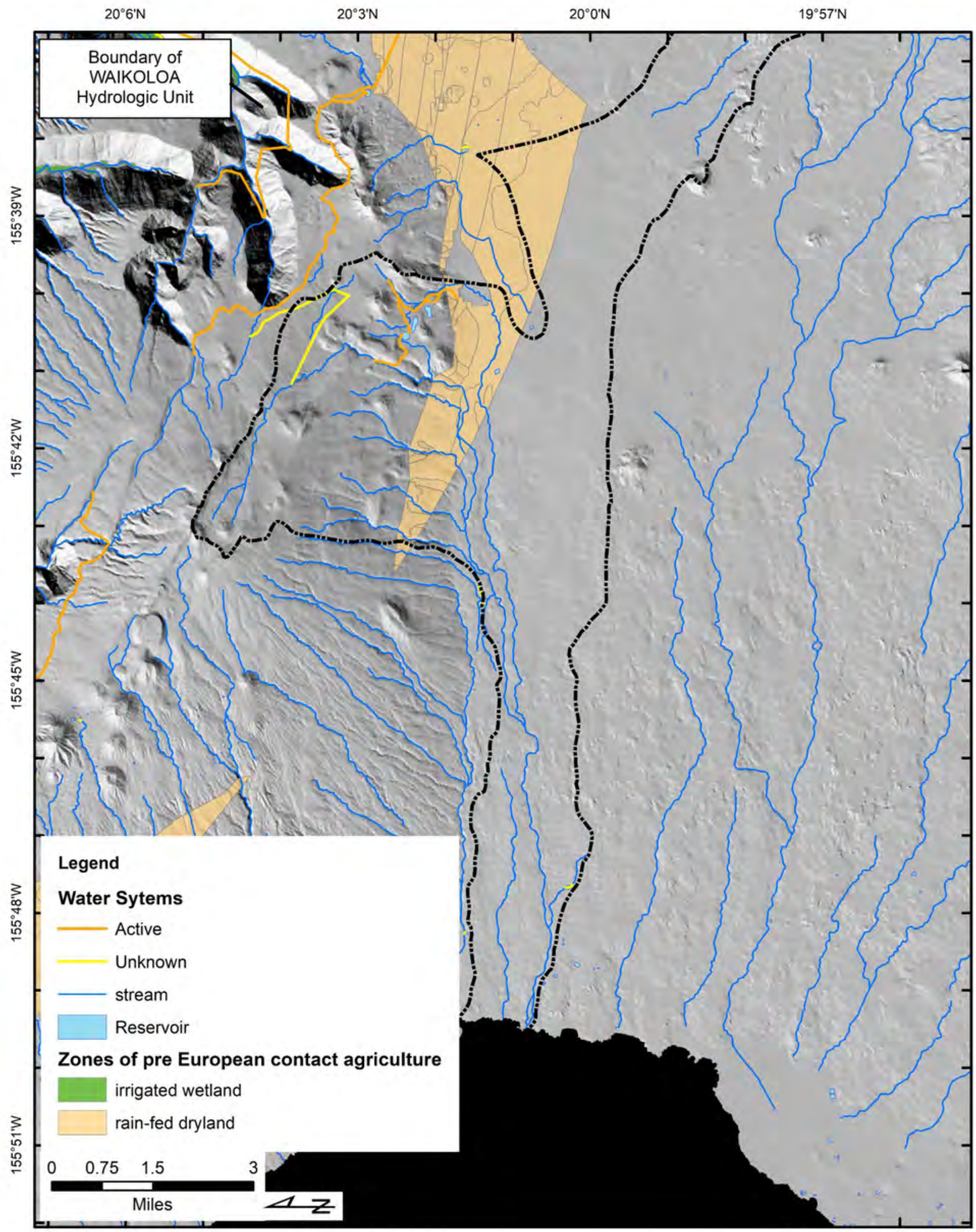


Table 12-5. Cultural resource elements evaluated as part of the Hawaiʻi Stream Assessment for Waikoloa stream.

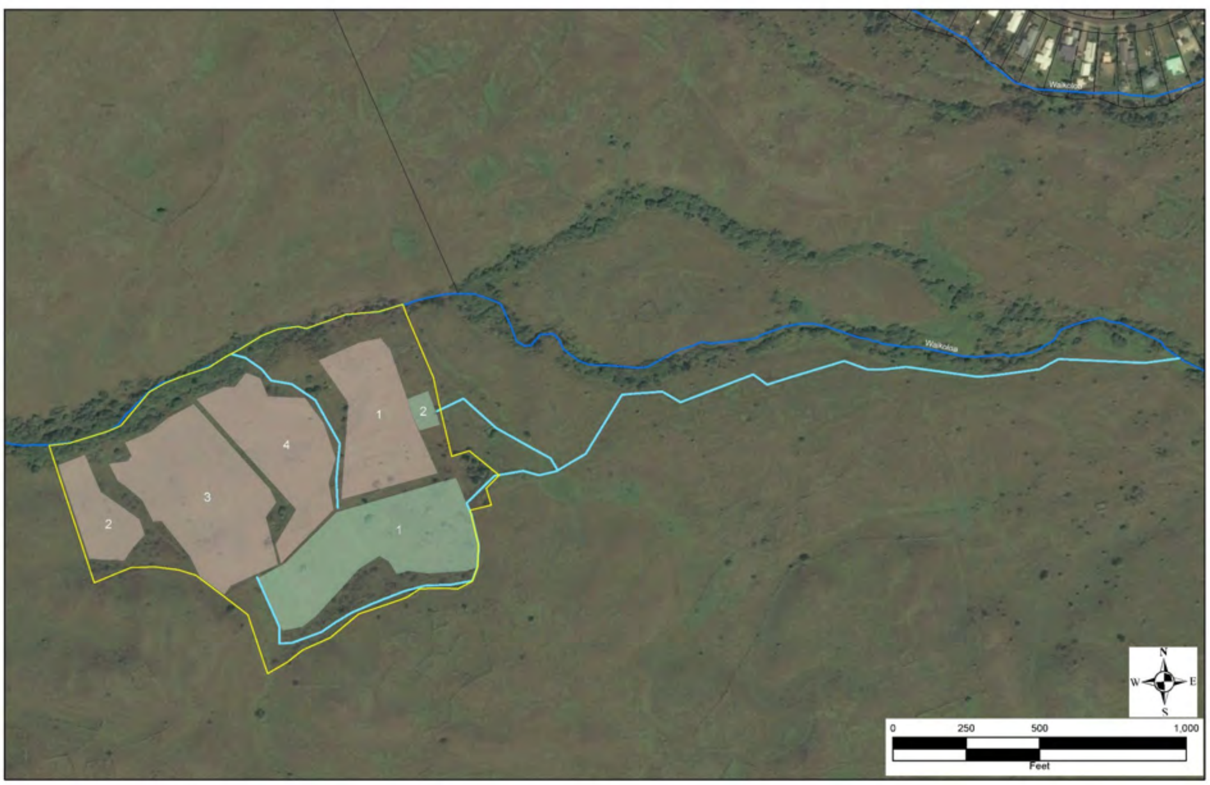
| Category | Value |
|---|---|
| Survey coverage: The extent of archaeological survey coverage was analyzed and recorded as complete, partial, very limited, and none. Few valleys are completely surveyed. Many have little or no survey coverage. | Partial |
| Predictability: The ability to predict what historic sites might be in unsurveyed areas was scored as high, medium, or low predictability or unable to predict. A high score was assigned if archaeologists were able to predict likely site patterns in a valley given historic documents, extensive archaeological surveys in nearby or similar valleys, and/or partial survey coverage. A low score was assigned if archaeologists were unable to predict site patterns in a valley because of a lack of historical or archaeological information. A medium score was assigned to all other cases. | High |
| Number of Sites: The actual number of historic sites known in each valley is straightforward yet very time consuming to count. Instead, archaeologists used survey information to estimate the number of sites in each valley. These figures, adequate for this broad-based assessment, are only rough estimates. | 100 |
| Valley significance as a Whole District: The overall evaluation of each valley's significance was made considering each valley a district. The significance criteria of the National and Hawaii Registers of Historic Places were used. Criterion A applies if the district is significant in addressing broad patterns of prehistory or early history. Criterion B applies if the district is associated with important people (rulers) or deities. Criterion C applies if the district contains excellent examples of site types. Criterion D applies if the district is significant for information contained in its sites. Finally, Criterion E applies if the district is culturally significant for traditionally known places or events or for sites such as burials, religious structures, trails, and other culturally noteworthy sites. | ABCDE |
| Site Density: The density patterns of historic sites make up a variable extremely important to planners. Three ranks were assigned: low for very few sites due either to normal site patterning or extensive land alteration, moderate for scattered clusters of sites, and high for continuous sites. Valleys with moderate or high density patterns are generally considered moderate or high sensitivity areas. | High |
| Site Specific Significance: The site specific significance variable was developed for valleys that had low densities of sites (very few sites) due either to normal site patterning or to extensive land alteration. An example of the first type might be a valley with housing sites on the side but too narrow for taro or housing sites on the valley floor. The second type might be a valley in which there had been sugar cane cultivation but a large heiau was left. The site specific significance of these valleys was categorized as either: 1) sites significant solely for information content which can undergo archaeological data recovery; or 2) sites significant for multiple criteria and merit preservation consideration. Those categorized as meriting preservation consideration would likely include large heiau, burial sites, and excellent examples of site types. | n/a |
| Overall Sensitivity: The overall sensitivity of a valley was ranked very high, high, moderate, low, or unknown. Very high sensitivity areas have moderate or high densities of sites with little or no land alteration. They are extremely important archaeological and/or cultural areas. High sensitivity areas have moderate or high densities of sites with little or no land alteration. Moderate sensitivity areas have very few sites with the sites meriting preservation consideration due to multiple criteria or moderate densities of sites with moderate land alteration. Low sensitivity areas have very few sites due to normal site patterning or due to extensive land alteration. The sites present are significant solely for their informational content, which enable mitigation through data recovery. Those valleys where no surveying had been undertaken and the ability to predict what might be found was low were ranked unknown. | Very High |

| | |
|---|---|
| Historic Resources:<br>Several types of sites were considered by inclusion in this section, particularly bridges, sugar mills and irrigation systems. Those that are listed on the State or National register were inventoried, but none of them assessed. | n/a |
| Taro Cultivation:<br>Streams and stream water have been and continue to be an integral part of the Hawaiian lifestyle. The committee identified a number of factors important to current Hawaiian practices. These include current taro cultivation, the potential for taro cultivation, appurtenant rights, subsistence gathering areas, and stream-related mythology. The committee felt that a complete assessment of the cultural resources of Hawaii's streams should include these items but, due to limits of information, only the current cultivation of taro was included. | n/a |

## Subsistance Agriculture Riparian to Waikoloa Stream

There is substantial archeological evidence that irrigated dryland agriculture thrived along the riparian corridor of Waikoloa Stream. As recently as the 1980s, traditional Hawaiian agriculture was practiced below the current Lalamilo Farm lots (Figure 12-4). With population growth increasing pressure on Hawaiʻi DWS to provide water supply to the greater Waimea nui region, more water has been diverted from Waikoloa Stream, leaving the stream dry during low-flow conditions more regularly.

Figure 12-4. Map of irrigated fields (colored polygons) within the Lindsey LCA along Waikoloa Stream below Lalamilo Farm lots with the field verified location of the poʻowai, ʻauwai, and hoʻi.



# 13.0 Public Trust Uses of Water

The State Water Code (Hawai‘i Revised Statutes 174C-2) states that:

> The state water code shall be liberally interpreted to obtain maximum beneficial use of the waters of the State for purposes such as domestic uses, aquaculture uses, irrigation and other agricultural uses, power development, and commercial and industrial uses. However, adequate provision shall be made for the protection of traditional and customary Hawaiian rights, the protection and procreation of fish and wildlife, the maintenance of proper ecological balance and scenic beauty, and the preservation and enhancement of waters of the State for municipal uses, public recreation, public water supply, agriculture, and navigation.

Article 11, Section 1 of the Hawai‘i State Constitution maintains that the:

> State and its political subdivisions shall conserve and protect Hawaii's natural beauty and all natural resources, including land, water, air, minerals, and energy sources, and shall promote the development and utilization of these resources in a manner consistent with their conservation and in furtherance of the self-sufficiency of the State. All public natural resources are held in trust by the State for the benefit of the people.

This solidified the Public Trust Doctrine as constitutional law. Further, Article 11, Section 7, states that the "State has an obligation to protect, control, and regulate the use of Hawaii's water resources for the benefit of its people." The Public Trust Doctrine now identifies four priority uses of water as: (1) water for traditional and customary practices, including the growing of taro; (2) reservations of water for Hawaiian Home Land allotments; (3) water for domestic use of the general public; (4) maintenance of waters in its natural state.

In the Waikoloa hydrologic unit, the use of water for traditional and customary practices was covered in Chapter 12 and water in its natural state is covered in Chapters 3-7. Other than private wells, there are four distinct water systems that serve areas in the Waikoloa hydrologic unit: The Hawai‘i County DWS South Kohala municipal water system, the Department of Agriculture Waimea Irrigation System (Upper Hāmākua Ditch) water system, the Parker Ranch water system, and the Mauna Kea Resort irrigation well field. Other than the Mauna Kea Resort irrigation well field, each of these systems relies almost exclusively on water diverted from streams on Kohala Mountain. The following is an analysis of Hawai‘i County DWS's South Kohala System, which provides for domestic water use and the reservations of water for Hawaiian Home Lands. In its regulation of water resources, the Commission delegates to the county the authority to allocate the use of water for municipal purposes. The counties are also tasked with adopting water use and development plans, setting forth the allocation of water to land use in that county (§174C-31, HRS).

## Hawai‘i County DWS South Kohala Municipal Water System

The Hawai‘i County DWS operates the South Kohala Water System which, in 2010, served a population of through 1,694 service connections. This system provides water to the Waimea area as well as the developments along Kawaihae Road, Kawaihae community, and the Puako community incorporating portions of the Waimea Kohala (2020 population of 6,366), Waimea Pu‘u Anahulu (2020 population of 3,795), and Waikoloa-South Kohala (2020 population of 4,997) tracks. The principal sources for the system are Waikoloa Stream, first developed in 1925 and rebuilt in 1941 by the Marine Corps to support troop training in the region during World War II, and the Kohākōhau Stream diversion, which was completed in 1971. Originally, a diversion on Hauani Stream supplied both Hawai‘i DWS and Parker

Ranch with water, primarily for lands in the Pu‘ukapu area east of Waimea Town. However, no stream diversion was registered on this stream. Supplementing these sources are two high-elevation wells, Waimea Deepwell and Parker Deepwell previously described in section 3.0. Previously (pre-1980s) a diversion on Hauani stream was also used, although this diversion and transmission pipeline are no longer functional. Low-head dams impound water in these streams and water is diverted to a series of reservoirs located on the south slope of Puu Ki, above Waimea Town. By 1963, there were three lined reservoirs with a total capacity of 15.3 million gallons.

The South Kohala Water System spans three aquifer sector areas; however, the majority of the service area is within the Kohala ASEA in the Makuhona Aquifer System. This includes the majority of Waimea Village, and the areas north of Mamalahoa Highway from Kawaihae to the Kamuela Highlands subdivision and extends along Mamalahoa Highway to Kawaihae surrounding areas and to the two connections to the Haina Water System at the judicial boundary near Mud Lane. Since 1950, improvements to the system have increased reservoir capacity, enlarged the distribution pipelines, and extended the system to meet the growth of this rapidly developing community.

With the construction of the Kawaihae deep draft harbor, the small pipeline from Waimea to Kawaihae was replaced with a 6-inch pipeline and additional storage tanks were constructed. Two wells constructed in the 1960s along Kawaihae Road had marginal quality due to high chloride content and needed to be blended with imported surface water. To support additional growth in the Mauna Kea and Mauna Lani restort communities, the state drilled a series of wells in the Lalamilo-Waikoloa region at 1200 ft elevation. Subsequent wells in the area, two booster pump stations, and nine storage tanks now make up the Lalamilo public water system which serves the coastal communities.

Today, the South Kohala Water System has been expanded to include seven tanks spanning eight pressure zones, with a focus on the communities around Waimea Town. As of the 2019 water audit, there were 1,694 service connections, 114 miles of water mains, a customer retail unit cost of $3.94 per 1,000 gallons, and a variable production cost of $1,370.50 per million gallons ($1.37 per 1,000 gallons) in the South Kohala water system. The water audit identified 28.64 million gallons of apparent losses and 37.952 million gallons of real losses for the year, which equated to 46.3 gallons per connection per day (78,432 gallons per day) or 912.09 gallons per water main mile per day. The total water losses (66.592 million gallons) represent 11.8% of the sourced water. This resulted in an annual cost of apparent losses of $112,842 and an annual cost of real losses of $52,013.

The stream sources are now supplemented by the Parker Ranch Deepwell (well 6239-002) and the Waimea Deepwell (well 6240-002), both owned and operated by Hawai‘i DWS. These wells are drilled into high-level groundwater sources. From 2013 to 2021, the Waimea Deepwell was pumped approximately 23% of the time, while the Parker Ranch Deepwell was pumped approximately 36% of the time. Surface water is treated at the Waimea Water Treatment Facility (WTF) by conventional filtration for odor and color control, and for corrosion control and disinfection. The surface water is blended with the groundwater at the Waimea WTF before distribution. Summary statistics related to water production for the South Kohala water system are provided in Table 13-1.

Mean daily water production and percent of total production by source in the South Kohala water system since 2013 is provided in Figure 13-2. The South Kohala system is capable of exporting water to the Haina water system (PWS 161) and the Kukuihaele water system (PWS 133), however, this occurs infrequently and the amount exported is relatively small (Figure 13-3). Hawai‘i DWS originally operated an extension of the water system towards Hāmākua named the Ahualoa-Honokaa-Kalopa water system. A filter/chlorinating plant located at the uppermost end of the Ahualoa service area originally received water from the Pu‘u Pulehu Reservoir sourced from the Upper Hāmākua Ditch. Pipelines and tanks gravity fed the water to users all the way to Kalopa. The original Kawaihae-Puako extension of the water system was build with a 6-inch line along the Waimea-Kawaihae Road with a 3-inch line to Puako. Wells located at the 490 ft and 570 ft elevations drilled in 1961 yielded 200 gpm but had relatively high chlorides and required blending with surface water prior to distribution. New wells drilled further inland now meet the potable demands of the coastline.

Figure 13-1. Hawai‘i DWS water system distribution pipelines in the Kohala and Hāmākua regions. (Source: Hawaii DWS, 2010)

Table 13-1. Mean, median, maximum, and minimum production statistics (million gallons per day) for the South Kohala water system by source from 2013-2021.

| statistic | Waimea surface water sources | Waimea Deepwell | Parker Ranch Deepwell | Total Production |
|---|---|---|---|---|
| Mean | 1.46 | 0.16 | 0.17 | 1.79 |
| Medium | 1.50 | 0.00 | 0.00 | 1.81 |
| Minimum | 0.51 | 0.00 | 0.00 | 1.25 |
| Maximum | 2.24 | 1.18 | 0.84 | 2.33 |

## Hawai‘i DWS South Kohala Water Use

The South Kohala water system services residential, agricultural, government, and commercial water needs in the Waimea region. The majority of use is residential, followed by commercial, agriculture, and government use (Figure 13-4). Summary statistics by use are provided in Table 13-2. Total water use in the South Kohala water system service area from 2018 to 2021 averaged 1.357 mgd with a median of 1.349 mgd and a maximum of 1.565 mgd. Approximately 65% of the water demand serviced by the South Kohala water system would be considered domestic use (a public trust use), and approximately 35% would be considered non-public trust. However, a certain portion of the metered agricultural usage is delivered to DHHL, which would also be considered a public trust use.

Figure 13-2. Mean daily production (top) and percent of mean daily production (bottom) by Hawai'i DWS's Waimea Water Treatment Facility (WTF), pumpage from the Hawai'i DWS operated Parker Ranch Deepwell (well 6239-002), and pumpage from the Hawai'i DWS operated Waimea Deepwell (well 6240-002) for the South Kohala Public Water System from January 2013 to December 2022.

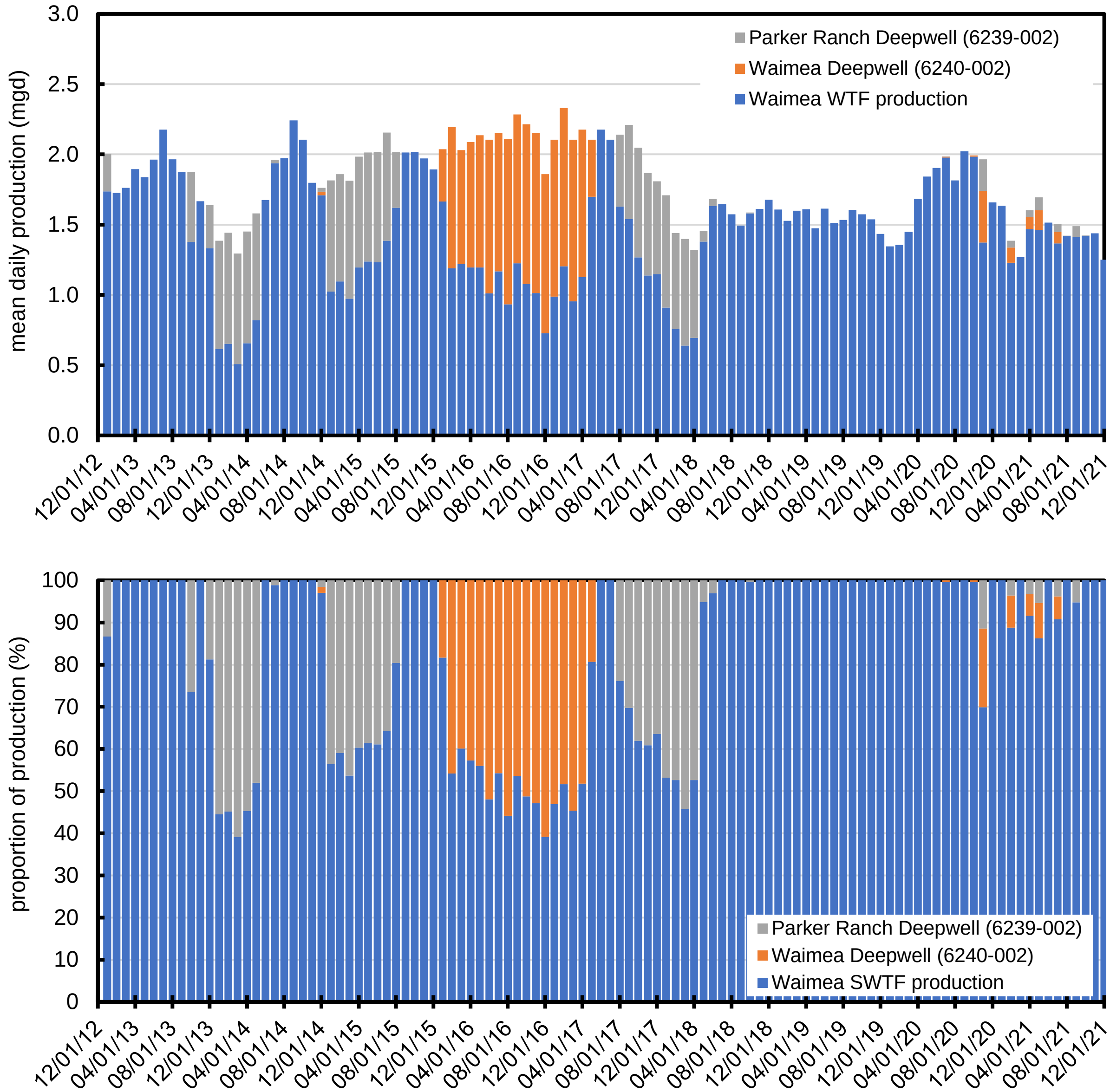


Figure 13-3. Mean daily production (gray line) and mean daily export to either the Haina (blue) or Kukuihaele (orange) public water system from 2013 to 2021

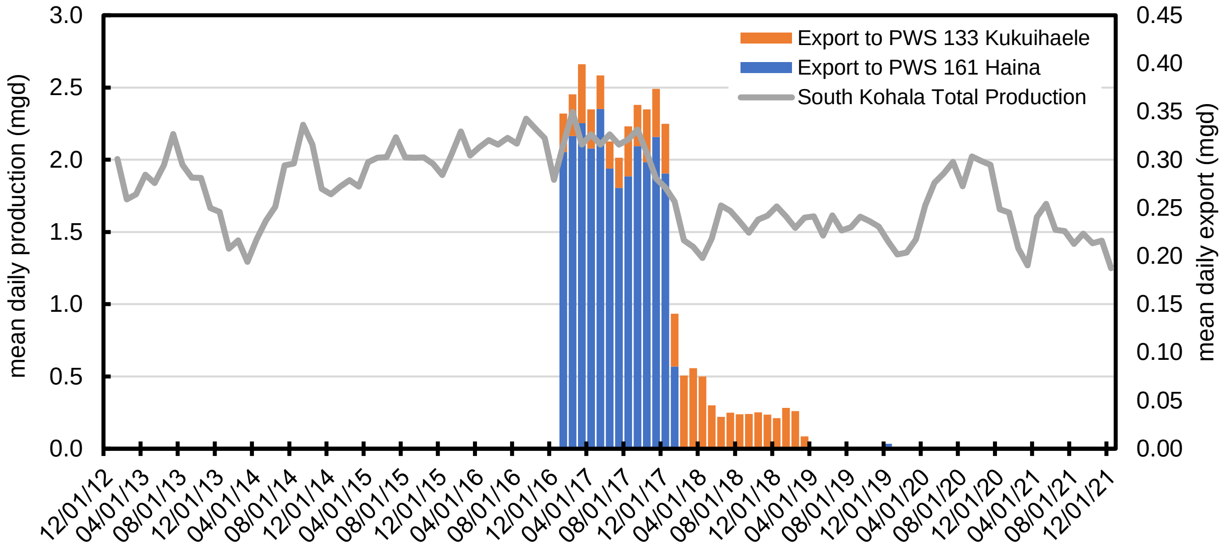



Figure 13-4. Percent of total metered end use by category for the Hawai'i DWS South Kohala water system from 2018 to 2021.

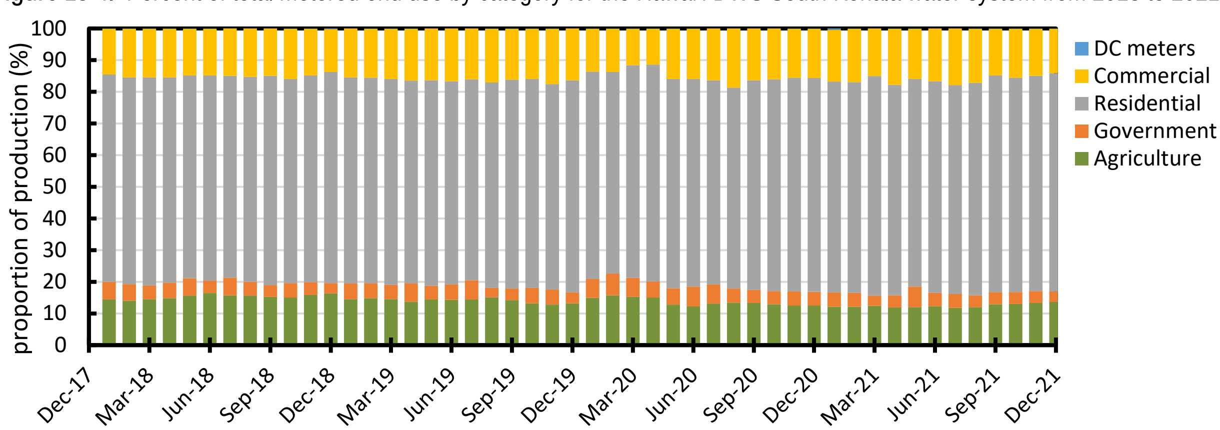



Table 13-2. Mean, median, and maximum total (kgal), daily (mgd), and proportion (%) monthly metered water use by category for the 2018-2021 period. [note: DC category omitted due to the negligent monthly use]

| | Agriculture | | | Government | | | Residental | | | Commercial | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kgal | mgd | % | kgal | mgd | % | kgal | mgd | % | kgal | mgd | % |
| mean | 5711.8 | 0.188 | 13.9 | 1910.7 | 0.063 | 4.6 | 27,223 | 0.894 | 65.9 | 6457.6 | 0.212 | 15.6 |
| median | 5683.4 | 0.188 | 13.9 | 1863.8 | 0.062 | 4.4 | 27,513 | 0.907 | 65.6 | 6369.1 | 0.212 | 15.7 |
| maximum | 6733.9 | 0.222 | 16.4 | 3124.3 | 0.101 | 6.9 | 31,830 | 1.027 | 69.3 | 8531.7 | 0.275 | 18.6 |

## Projected Growth in Water Demand

The County of Hawai'i has not released an updated Water Use and Development Plan since 2010. The 2010 plan utilizes historic trends in population growth and water use data up to 2005 based on the County's General Plan and standard water use demands. The county then used these values to estimate potential growth scenarios and water demand scenarios as detailed in Table 13-3 and 13-4 and illustrated in Figure 13-5.

Table 13-3. Historic and projected (after 2000, following the County's General Plan published in 2005) low, medium, and high growth populations for the Makuhona, West Mauna Kea, and Hamakua Aquifer Systems. (Source: Hawaii DWS, 2010)

| Year | Makuhona | | | West Mauna Kea | | |
|---|---|---|---|---|---|---|
| 1980 | | 5,133 | | | 2,084 | |
| 1990 | | 7,807 | | | 4,134 | |
| 2000 | | 11,000 | | | 5,939 | |
| | Low | Medium | High | Low | Medium | High |
| 2005 | 12,447 | 12,487 | 13,008 | 7,060 | 7,082 | 7,378 |
| 2010 | 14,569 | 14,697 | 15,618 | 8,153 | 8,224 | 8,740 |
| 2015 | 17,021 | 17,271 | 18,628 | 9,392 | 9,531 | 10,279 |
| 2020 | 19,913 | 20,309 | 22,140 | 10,831 | 11,048 | 12,042 |

Figure 13-5. Projected population growth and water demand for Hawai'i County at 5-year increments. (Source: Hawaii DWS, 2010; Page 2-11; Figure 2-5)

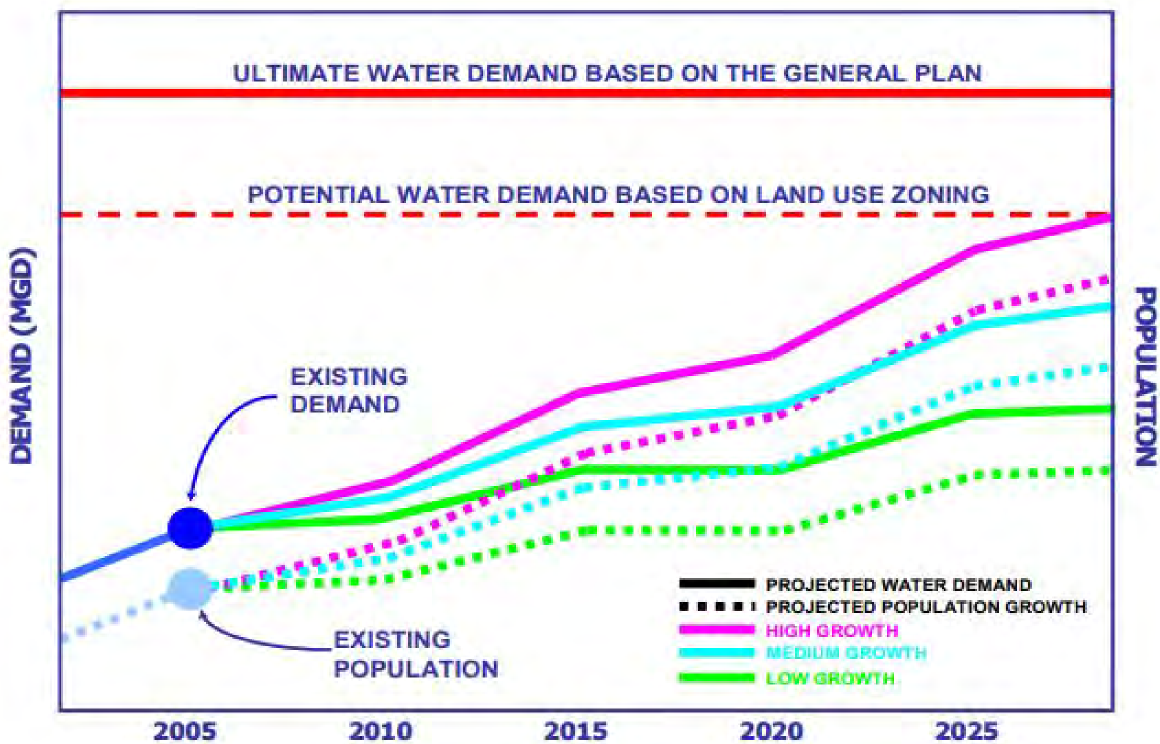


Table 13-4. 2010 estimated full build out demand projection by aquifer system based on the Hawaii County General Plan or the County Zoning Full Build Out Plan. (Source: Hawaiʻi DWS, 2010).

| | Makuhona Aquifer | | West Mauna Kea Aquifer | |
|---|---|---|---|---|
| Zone Designation | General Plan Full Build Out | County Zoning Full Build Out | General Plan Full Build Out | County Zoning Full Build Out |
| Residential* | 28.3 | 3.9 | 38.4 | 11.5 |
| Commercial | | 0.7 | | 0.4 |
| Resort | 0.8 | 0.3 | 9.4 | 1.1 |
| Industrial | 1.1 | 0.4 | 3.7 | 0.2 |
| Agriculture | 90.6 | 89.7 | 134.6 | 136.8 |
| DHHL | 2.4 | 2.4 | 0.6 | 0.6 |

*In the county general plan, there are classes labeled urban and urban expansion, but it is not broken down by residential or commercial.

## Hawaiian Home Lands

A component in the assessment of water use includes an analysis of the presence of Department of Hawaiian Home Lands (DHHL) parcels within or near the surface water hydrologic unit. The mission of DHHL is to effectively manage the Hawaiian Home Lands trust and to develop and deliver land to native Hawaiians (PBR Hawaii, 2002). In June 2002, DHHL published the Hawaiʻi Island Plan which served to examine infrastructure needs, provide development cost estimates, and identify priority areas for homestead development. Of the more than 116,963 acres of DHHL land on the island of Hawaiʻi, there are multiple tracks that are within or nearby the Waikoloa hydrologic unit (Figure 13-6). A summary of each of the tracks in or nearby the Waikoloa hydrologic unit as identified within the Waimea Nui Regional Plan are provided in Table 13-5. The Lalamilo and Honokaia tracks were identified in 2002 as priority tracks for residential development and or subsistence agriculture use. Currently some potable demand is met with water from Hawaiʻi DWS South Kohala system and some non-potable water demand is met with the Upper Hāmākua Ditch (Figure 13-7). There are numerous potential sources of water to meet potable and non-potable water needs for DHHL in the Waimea Nui Region. These include the Upper Hāmākua Ditch, the Hawaiʻi DWS system, the Parker Ranch system, the Kahena Ditch (Figure 13-8). Investments in reservoir, well, or diversion infrastructure could be made to expand access to potable and non-potable water.

Figure 13-6. Summary of DHHL land holdings and landuse designations in the Waimea nui region. (Source: DHHL, 2012)

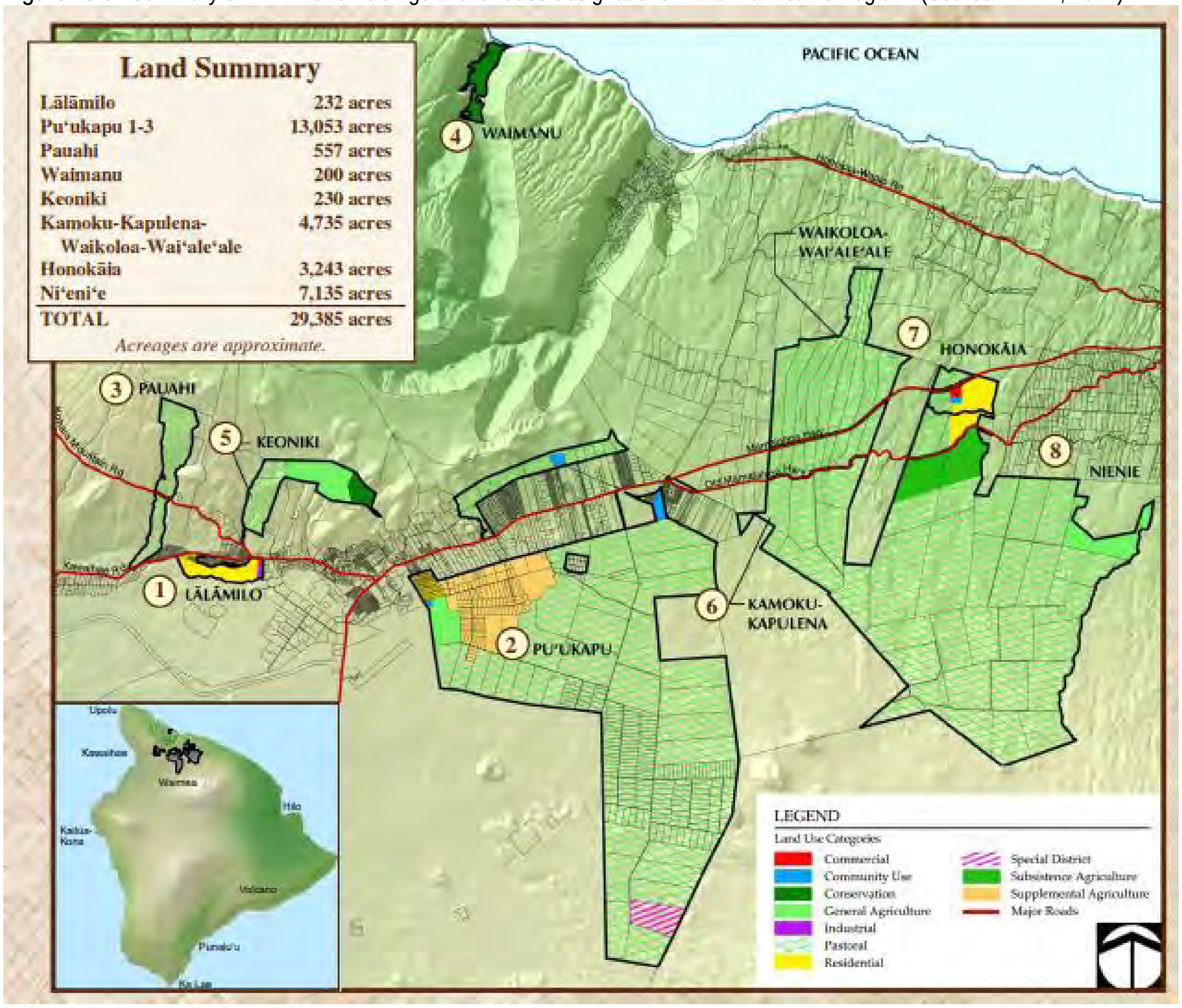


Table 13-5. Summary information for DHHL tracks in or nearby the Waikoloa hydrologic unit as identified in the Waimea Nui Regional Plan. (Source: DHHL )

| Track | Area (acres) | Use | Water Issues | Projected Potable water demand | Projected non-potable water demand |
|---|---|---|---|---|---|
| Lalamilo | 232 | residential | | | |
| Honokāia | 3243 | residential & subsistence | | | |
| Kawaihae | 10153 | Residential, community, commercial, industrial, and general agriculture | Limited water available | | |
| Keoniki | 230 | Homestead pastoral use | | | |
| Ni‘eni‘e | 612 | General agriculture | No water or sewer services available | | |
| Pu‘ukapu (3 parcels) | 392 | | No water or sewer services available | | |
| Pu‘ukapu 1 | 11,000 | Primarily pastoral use; Kuhio Village residential lots | | | |
| Pu‘ukapu 2 | | | | | |
| Pu‘ukapu Farmlots | | | | | |
| Pu‘ukapu 3 | 378 | Homestead pastoral use | | | |
| Pauahi | 550+ | Pastoral use; split by Kohala Mountain Rd | | | |
| Kamoku-Kapulena-Waikoloa-Wai‘ale‘ale | 4,700+ | Homestead pastoral use | | | |

Figure 13-7. Current water-related infrastructure associated with the DHHL Waimea Nui Regional Plan. (Source: DHHL, 2012)

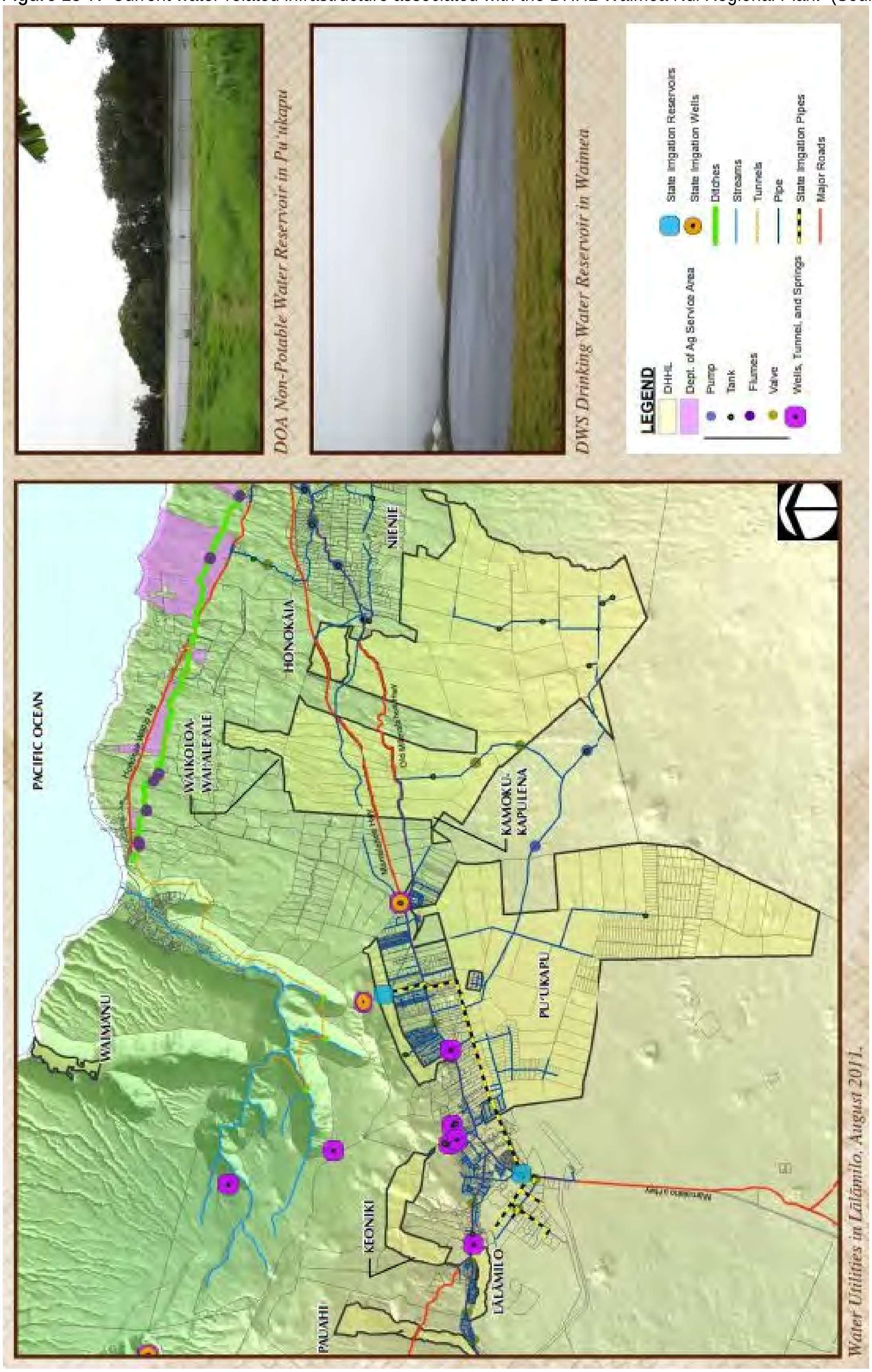
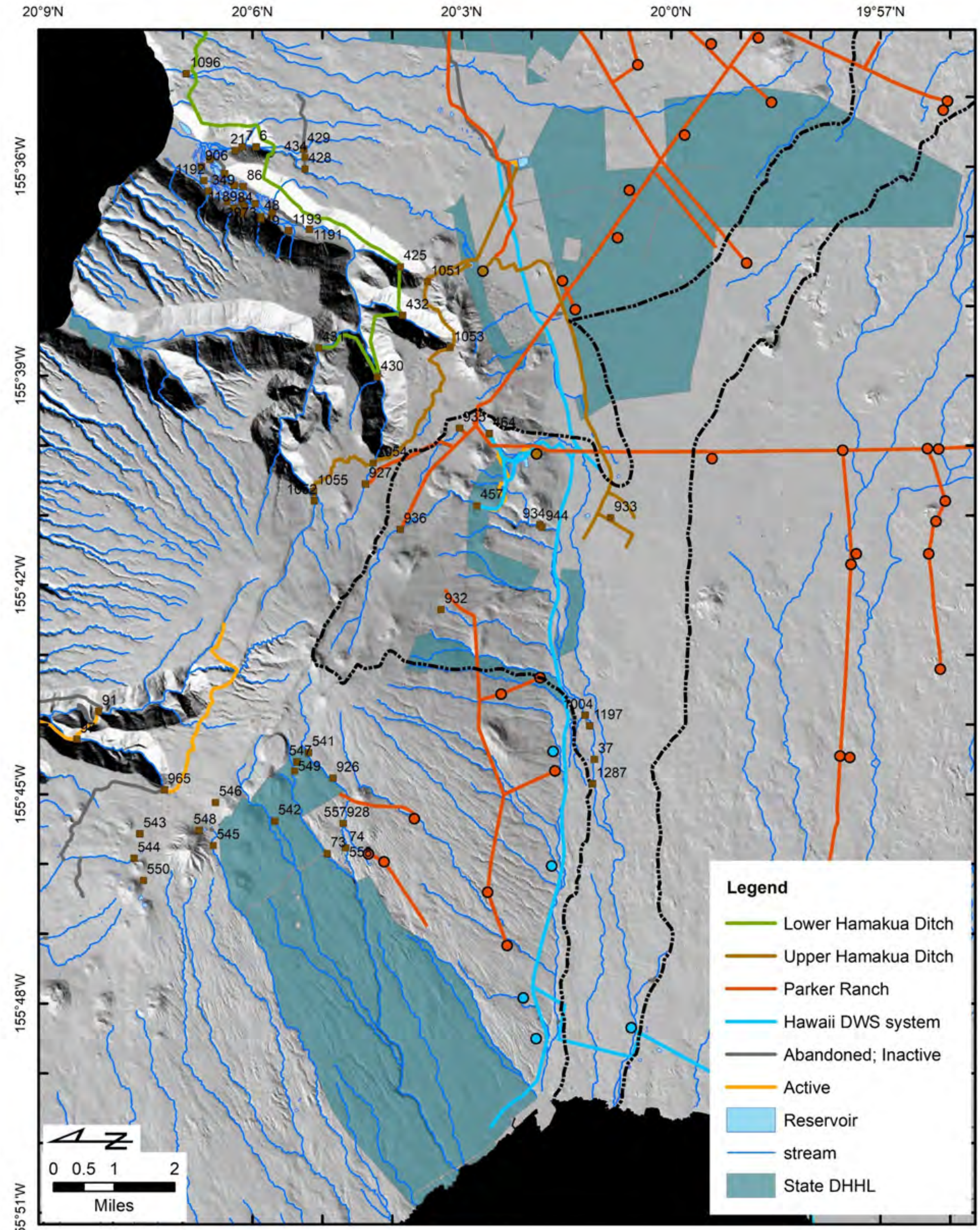


Figure 13-8. Current water-related infrastructure in South Kohala which may serve DHHL.



# 14.0 Noninstream Uses

Under the State Water Code, noninstream uses are defined as "water that is diverted or removed from its stream channel…and includes the use of stream water outside of the channel for domestic, agricultural, and industrial purposes." Article XI, Section 3 of the State Constitution states: "The State shall conserve and protect agricultural lands, promote diversified agriculture, increase agricultural self-sufficiency and assure the availability of agriculturally sustainable lands." Water is crucial to agriculture and agricultural sustainability. Article XI, Section 3 also states, "Lands identified by the State as important agricultural lands needed to fulfill the purposes above shall not be reclassified by the State or rezoned by its political subdivisions without meeting the standards and criteria established by the legislature and approved by a two-thirds vote of the body responsible for the reclassification or rezoning action. [Add Const Con 1978 and election Nov 7, 1978]." It is the availability of water that allows for the designation of Important Agricultural Lands. The Hawaii Farm Bureau Federation, Hawaii's largest advocacy organization for general agriculture, states that agriculture is a public trust entity worthy of protection, as demonstrated in its inclusion in the State Constitution. They, on behalf of farmers and ranchers, point to the importance of large-scale agriculture to sustainability and self-sufficiency of our islands, particularly in times of catastrophe when imports are cut off.

In most cases, water is diverted from the stream channel via a physical diversion structure. Diversions take many forms, from small PVC pipes in the stream that remove relatively small amounts of water, to earthen auwai (ditches), hand-built rock walls, and concrete dams that remove relatively larger amounts of water. Water is most often used away from the stream channel and is not returned; however, as in the case of taro fields, water may be returned to the stream at some point downstream of its use. While the return of surface water to the stream would generally be considered a positive value, this introduces the need to consider water quality variables such as increased temperature, nutrients, and dissolved oxygen, which may impact other instream uses. Additionally, discharge of water from a ditch system into a stream may introduce invasive species.

In addition to the amount of water currently (or potentially) being diverted offstream, the Commission must also consider the diversion structure and the type of use, all of which impact instream uses in different ways. The wide range of diversion structures, as noted above, is what makes regulation of surface water particularly difficult, since one standard method cannot be depended upon for monitoring and measuring flow. The ease of diverting streamflow, whether it be by gravity-flow PVC pipe, pump, or a dug channel, also plays a role in the convenience of diverting surface water and the abundance of illegal, non-permitted diversions.

## Water Leaving the Waikoloa and nearby Hydrologic Units

Upon the enactment of the State Water Code and subsequent adoption of the Hawaii Administrative Rules, the Commission required the registration of all existing stream diversions statewide. The Commission categorized the diversions and filed registrations according to the registrant's last name or company name. While it is recognized that the ownership and/or lease of many of the properties with diversions has changed since then, the file reference (FILEREF) remains the name of the original registrant file.

In 2007, the Commission initiated a contract for the purpose of conducting statewide field investigations to verify and inventory surface water uses and stream diversions, and update existing surface water information. Priority areas included Kaua'i and Maui stream diversions and there was limited verification on Hawai'i Island. Information collected from Commission staff site visits, and information extracted from the original registration files are included in Table 14-1.

In the Waikoloa hydrologic unit, Hawai‘i Department of Water Supply operates two diversions, one on Waikoloa Stream and one on Kohakohau Stream, that supply water to the county reservoirs above Waimea Town (Table 14-1). Stored water is then made potable through the Waimea Water Treatment Facility and supplies municipal water for the public. Additionally, Parker Ranch diverts water from Kohakohau at three locations and Waikoloa stream at one location for cattle water.

Since the enactment of HAR Title 13 Chapter 168, stream diversion works permits are required for the construction of new diversions or alteration of existing diversions, with the exception of routine maintenance. These permitted (as opposed to “registered”) diversion works are not part of the Commission’s verification effort, nor have any new diversions been permitted in the Waikoloa hydrologic unit. However, a number of unpermitted stream diversions have been found in the Waikoloa hydrologic unit through fieldwork.

Continuous flow data are not readily available for any individual diversions. However, Hawai‘i DWS began to monitor and report the flow of water diverted from Kohakohau Stream at diversion 457 in 2022. In 2018, USGS began to monitor the flow in Waikoloa Stream at USGS 16757000. Flow duration curves are also common and effective way to assess streamflow variability and availability. Generally, flow duration curves for large streams with persistent input from ground water sources are flatter than those for streams where ground water inflow is minimal, making streamflow rather responsive to each rainfall event. The flows at 50 ($Q_{50}$) and 90 ($Q_{90}$) percent exceedence probability are common indices of median total flow and low flow, respectively. When a flow duration curve is plotted for measurements made at a ditch, it shows the variability in the amount of water diverted for agricultural or domestic uses. The $Q_{50}$ flow indicates the median amount of water diverted during the period of record. Flow duration curves were plotted for each of the USGS gaging stations located on Upper and Lower Hāmākua Ditches (Table 14-1).

Figure 14-1. All registered diversions (ID), pipelines, and ditches identified in the Waikoloa hydrologic unit, Hawai'i. (Source: State of Hawaii, Commission on Water Resource Management, 2015g)

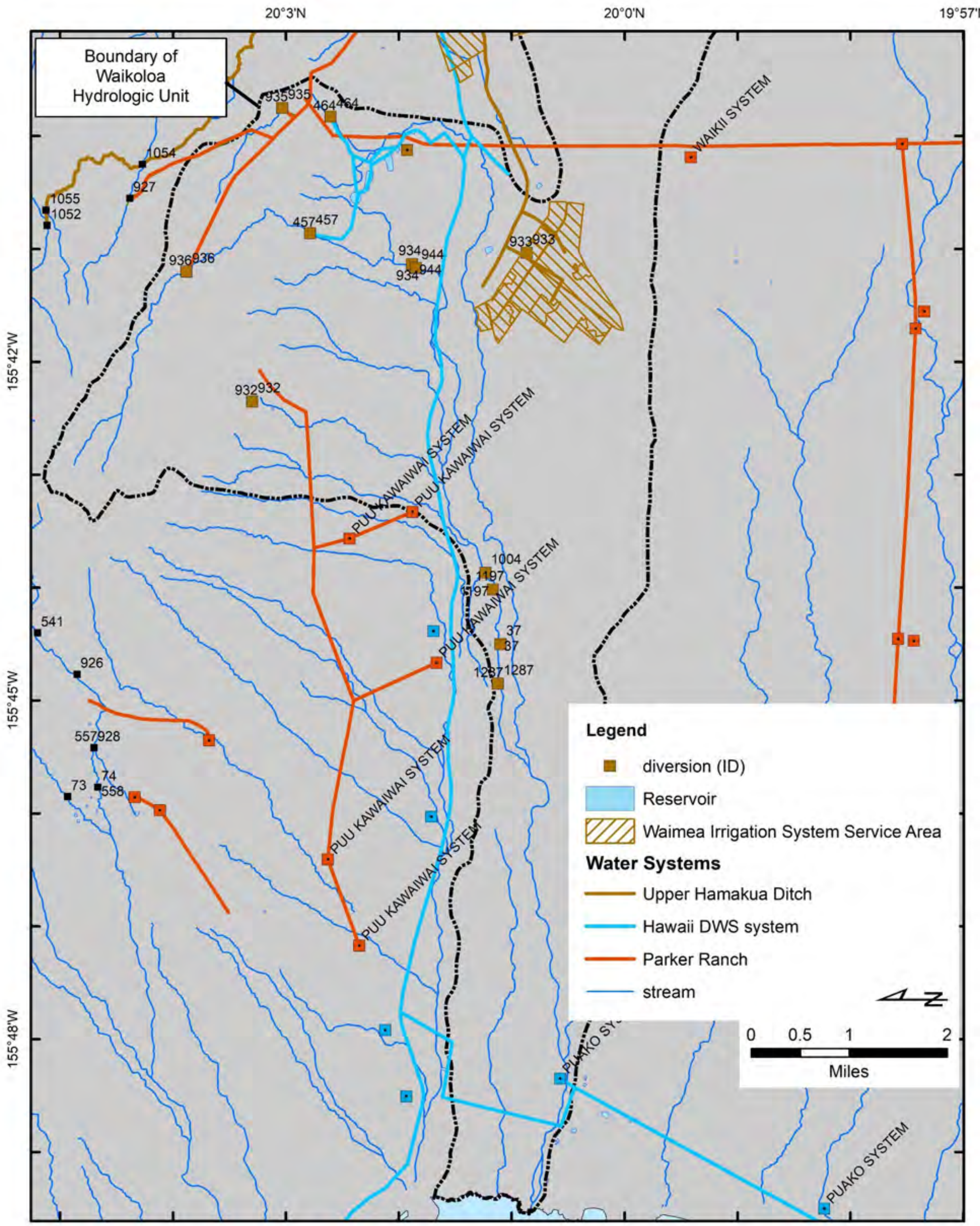


Table 14-1. Registered diversions in the Waikoloa hydrologic unit, Hawai'i.
[Source of photos are denoted at the end of each description; CWRM, Commission on Water Resource Management;Chevrons ( ) indicate general direction of natural water flow to and out of diversions; Arrows ( ) indicate direction of diverted surface water flow]

| Event ID | File Reference | Tax Map Key | Landowner | Active | Verified | Riparian | Rights Claim |
|---|---|---|---|---|---|---|---|
| REG.457 | Hawaii DWS | 6-5-001-011 | DHHL | Yes | Yes | No | Yes |

**Photos.** a) Diversion 257 from left bank during high flow; b & c) diversion dam from left bank; d) intake pipeline from diversion dam; e) downstream view of Kohākōhau Stream; f) upstream view of Kohākōhau Stream from dam (CWRM 01/13/2020)

a)

b)

c)

d)

e)

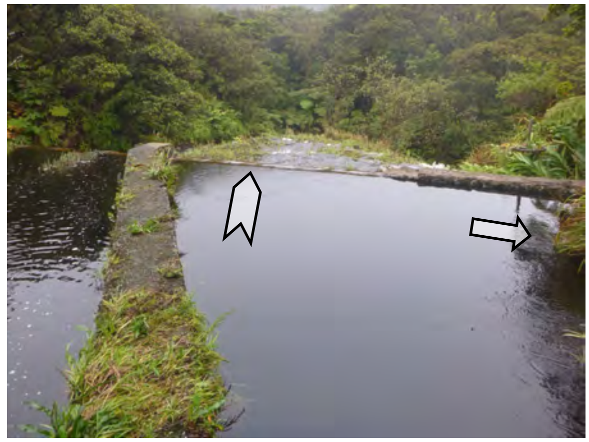
f)


Table 14-2. Continued.

| Event ID | File Reference | Tax Map Key | Landowner | Active | Verified | Riparian | Rights Claim |
|---|---|---|---|---|---|---|---|
| REG.464 | Hawaii DWS | 6-3-001-001 | PR Waiemi LLC | Yes | Yes | No | No |

**Photos.** a) Waikoloa Stream diversion at Marine Dam from right bank; b) downstream view of diversion dam; c) diversion dam from left bank; d) diversion dam from right bank; e) downstream view of Waikoloa Stream from diversion; f) upstream view of Waikoloa Stream from diversion (CWRM 01/13/2020)

a)

b)

c)

d)

e)

f)


Table 14-2. Continued.

| Event ID | File Reference | Tax Map Key | Landowner | Active | Verified | Riparian | Rights Claim |
|---|---|---|---|---|---|---|---|
| REG.936 | PARKER RANCH | 6-3-001-002 | State of Hawaii | Yes | Yes | No | Yes |

**Photos.** Upper Kohakohau Intake; max capacity 312.5 gpm (0.45 mgd) for livestock and dust control; a) Upstream view of diversion dam; b) diversion dam from left bank (1988); pipeline from diversion dam along left bank (CWRM 1/13/2020)

a)

b)

c)

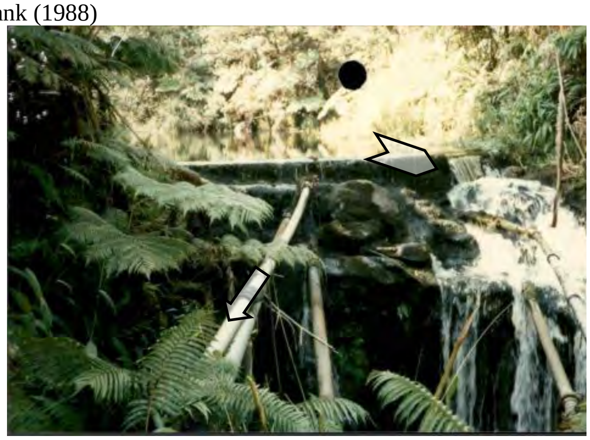
d)

Table 14-2. Continued.

| Event ID | File Reference | Tax Map Key | Landowner | Active | Verified | Riparian | Rights Claim |
|---|---|---|---|---|---|---|---|
| REG.935 | PARKER RANCH | 6-3-001-001 | PR Waiemi LLC | Yes | Yes | Yes | Yes |

**Photos.** Waikoloa Diversion Dam; max capacity 312.5 gpm (0.45 mgd) for livestock and dust control; 5 pipes, combined flow with Alakahi and Upper Kohakohau diversion dams; a) Upstream view of diversion dam; b) diversion dam from right bank (1988)

a)



b)

| Event ID | File Reference | Tax Map Key | Landowner | Active | Verified | Riparian | Rights Claim |
|---|---|---|---|---|---|---|---|
| REG.1197 | WALLACH K | 3-6-2-009-004 | | Yes | No | Yes | No |

**Photos.** a) Water pumped from intermittently-flowing Keanuiomano Stream via a 150 gpm pump is used for non-potable domestic supply and for irrigation of approximately 2.6 acres of nursery, windbreak, and lawn on 5.25 acres of land

a) b)

| Event ID | File Reference | Tax Map Key | Landowner | Active | Verified | Riparian | Rights Claim |
|---|---|---|---|---|---|---|---|
| REG.1004 | SCHULZE R | multiple | | Yes | No | Yes | No |

**Photos.** a) J. Spielman who owns parcel where diversion intake is located at TMK: (3) 6-2-007:009. Auwai then flows to Jardine WN property. Then auwai flows into the Kanehoa Subdivision. See also Registration for R Schulze who registered stream diversion, Ouli Auwai from Keanuiomano Stream for a group of 11 properties (Kanehoa Auwai Compact).

a) b)

Table 14-2. Continued.

| Event ID | File Reference | Tax Map Key | Landowner | Active | Verified | Riparian | Rights Claim |
|---|---|---|---|---|---|---|---|
| REG.37 | BALDWIN E | 3-6-2-009-018 | | Yes | No | Yes | No |

**Photos.** a) Two pipes from Keanuiomano Stream; water is diverted from stream during times of flow using two 6” pipes and stored in reservoirs for irrigation of 6 acres of citrus and fruit orchard and windbreak trees.

a) b)

c) d)

e)

## Current Agricultural Demands

The 2020 Department of Agriculture Baseline Agriculture Survey identifies the types of agriculture taking place on Hawaii Island (Figure 14-3). The current area utilized for agriculture and percent of the the Waikoloa hydrologic unit is listed in Table 14-3. Water from various sources is used for agriculture, including the Hawaii DWS South Kohala water system, the Upper Hāmākua Ditch, and the Parker Ranch water system.

Table 14-2. Crop category, total land area and percent of unit for agriculture in the Waikoloa hydrologic unit, Hawai‘i. (State of Hawaii Department of Agriculture, 2020)

| Crop Category | Total Land Area (mi$^2$) | Acres | Percent of Unit |
|---|---|---|---|
| Pasture | 36.255 | 332.8 | 70.5% |
| Diversified Crop | 0.52 | 6.4 | 1.0% |
| Flowers/Foliage/Landscape | 0.01 | 23,203.2 | <0.1% |

## Utilization of Important Agricultural Lands

In 1977, the Agricultural Lands of Importance to the State of Hawaii (ALISH) were completed by the State Department of Agriculture (HDOA), with the assistance of the Soil Conservation Service (SCS), U.S. Department of Agriculture, and the University of Hawai‘i College of Tropical Agriculture and Human Resources. Three classes of agriculturally important lands were established for Hawaii in conjunction with the SCS in an effort to inventory prime agricultural lands nationwide (Figure 14-5). Hawaii’s effort resulted in the classification system of lands as: 1) Prime agricultural land; 2) Unique agricultural land; and 3) Other important agricultural land. Each classification was based on specific criteria such as soil characteristics, slope, flood frequency, and water supply. The ALISH was intended to serve as a long-term planning guidance for land use decisions related to important agricultural lands. As agricultural commodities changed substantially with the closure of large-scale pineapple and sugarcane in the 1980s-2000s, the HDOA funded an updated baseline study of agricultural land use (ALUM) for 2020, for Hawai‘i.

The information is presented here to provide the Commission with present or potential noninstream use information. The Waikoloa hydrologic unit has 19.342 square miles of land designated as ALISH, with 1.027 square miles of unclassified lands, 2.666 square miles of prime agricultural lands, and 15.649 square miles of other agricultural lands (Figure 14-6, Table 14-5). However, much of this land is used as pasture. The UHD service area includes potential lands East and South of Waimea Town that are zoned agriculture but not fully utilized due to a lack of non-potable water supply.

Figure 14-2. 2020 Baseline Agricultural Land Use map for the Waikoloa hydrologic unit, Hawai'i.

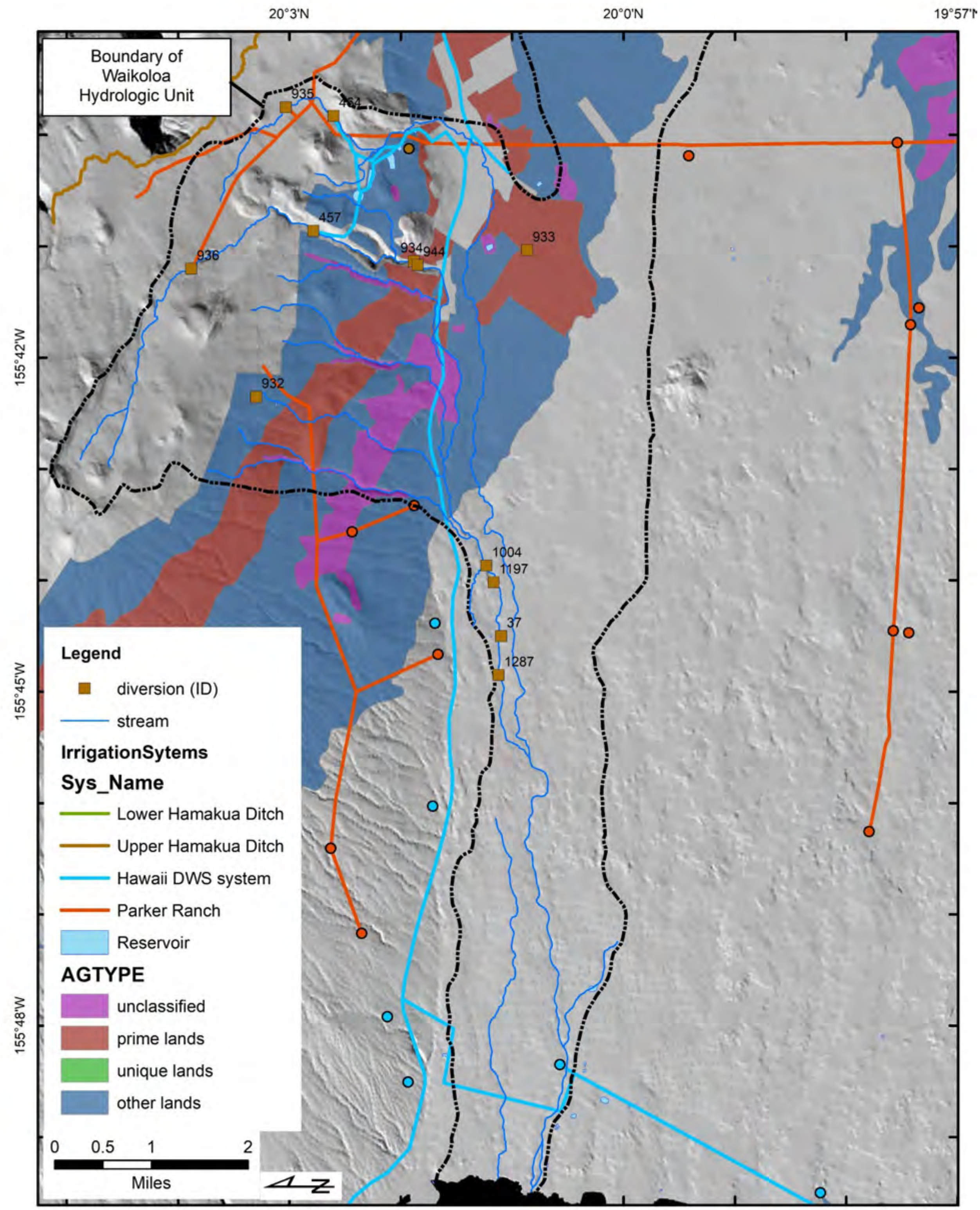


Table 14-3. Agricultural Lands of Importance to the State of Hawai‘i in the Waikoloa hydrologic unit, Hawai‘i.

| Type | Square miles | Acres |
|---|---|---|
| Prime land | 2.666 | 1706.24 |
| Unique land | 0 | 0 |
| Unclassified land | 1.027 | 657.28 |
| Other lands | 15.649 | 10,015.36 |

## Agriculture Use from Hawai‘i DWS South Kohala Water System

The Commission’s role in weighing instream and noninstream uses is dependent on balancing public trust uses with reasonable and beneficial uses of water. While the transfer of water from one hydrologic unit to another may add complexity to management decisions, the importance of the system to both agriculture and municipal water supply in Waimea town and surrounding communities in consideration of economic impacts must be weighted against the need to protect instream and other public trust uses of water. The Hawai‘i DWS South Kohala water system provides approximately 0.20 mgd of water for agricultural uses in the region (Table 13-2).

## Diverted Flow Through Non-Potable Water Systems: Parker Ranch Water System

The Parker Ranch non-potable water system diverts water from multiple streams and transmits the water via pipelines to Parker Ranch owned or leased lands on Mauna Kea above and below Waimea Town.

There are three primary intakes on the Alakai, Waikoloa, and Kohākōhau Streams. One intake on Hauani Stream was discontinued prior to the Registration deadline in 1989 following the passage of HRS 174C while three other diverions divert water from smaller springs on intermittent streams (Figure 14-5).

No continuous metering has been reported for the Parker Ranch system. However, a few historic values have been found in the literature as provided in Table 14-4.

Table 14-4. Historic measurements of water diverted by the Parker Ranch water system in cubic feet per second (million gallons per day). (Source: Davis and Yamanaga, 1963)

| location | date | Measurement |
|---|---|---|
| Kohākōhau diversion | 09/28/62 | 0.097 (0.063) |
| Alakahi diversion | 09/27/62 | 0.13 (0.084) |

## State of Hawai‘i Department of Agriculture Upper Hāmākua Ditch-Waimea Irrigation System

The State of Hawaii Department of Agriculture currently manages the Upper Hāmākua Ditch (UHD; also known as the Waimea Irrigation System). The UHD diverts streamflow from Kawainui, Kawaiki, Alakahi, and Waima streams in the Kohala Mountain Watershed Forest Reserve. The water is conveyed via lined and unlined ditches, tunnels, and flumes to the 60 MG Waimea Reservoir, located on DHHL property east of Waimea Town. While not all agricultural uses are considered public trust uses, all water use for the Department of Hawaiian Home Lands is considered a public trust use. The water is delivered to a series of reservoirs, which may be bypassed in part or in whole, and then delivered to various service areas.

Historically, the lands upon which the UHD arises constituted a part of the crown ‘ili of Pu‘ukapu, which is a portion of the larger ahupua‘a near Waimea. In 1913 a forest reserve was established in the mauka portion of Pu‘ukapu and later, when the ‘ili of Pu‘ukapu was put under the control of the Hawaiian Homes Commission Act of 1920, the forest reserve land was exempted and remained with the Territory/State. The ditch is entirely on state-owned land and from its construction in 1920 to 1948, was leased by Hawaiian Irrigation Company (HIC) to provide water for cane-fluming purposes, irrigation needs of diversified agriculture, and potable water needs of plantations along Hāmākua Coast. The HIC operated and maintained the ditch until 1948, when the Commissioner of Public Lands canceled the license at the request of the Hawaiian Homes Commission (Resolution No. 102, July 2, 1947). The state withheld auctioning off the lease in 1948 in anticipation of making large tracks of land in the vicinity of Waimea Town available for agriculture. The HHC assumed jurisdiction over the ditch system and was authorized, through Act 215, SLH 1947) to develop lands for homestead purposes in Waimea, utilizing the water of the UHD for irrigation. The DLNR Division of Water and Land Development (DOWALD) managed the system until DLNR's reorganization following the passage of the State Water Code (HRS 174C) and management of the system was transferred to the Department of Agriculture.

While USGS maintained a number of ditch monitoring stations over time, USGS station 16726000 was discontinued in 2004 and USGS station 16727000 Upper Hamakua Ditch ab Puukapu Reservoir was discontinued in 2000. Data from these stations are provided in Table 14-5. In 2022, CWRM staff began monitoring ditch flow at the former USGS 16726000 station for the DOA. The UHD is composed of a series of concrete lined ditches, partially lined, and unlined ditches, flumes, and tunnels. Since it's construction, the UHD has suffered from large seepage losses. Most of the seepage losses occur in unlined sections of the ditch that utilized stream channels to convey water downstream. Particularly in the Koiawe and Waima streams (Figure 14-5).

Today, the UHD services a modest region of South Kohala, focusing mostly on the distribution of water to the DHHL Pu‘ukapu farmlots, Pu‘ukapu agricultural development, and the Lalamilo agricultural lots (Figure 14-6). Monthly metered water use is graphed relative to localized rainfall conditions in Figure 14-4 and total end use for the system is provided in Table 14-6. Two reservoirs provide storage capacity to meet demand during drought, while one well (8- ), originally drilled for Hawaii DWS, could supplement surface water sources, however, groundwater pumping is cost-prohibitive. The Waimea Reservoir has a maximum storage of 61.6 MG and a normal storage of 57.3 MG. The larger Pu‘u Pulehu‘u Reservoir, built in 1910 and refurbished in 1991, has a maximum storage of 145 MG but has a normal storage of 110.1 MG. This reservoir is located on the Hāmākua side of the crest of the saddle in Waimea Town and therefore water must be pumped from the reservoir uphill to a holding tank before being used. The Lalamilo Reservoir, built in 1961, has a capacity of 4.5 MG and was used as the distribution reservoir with the opening of the Lalamilo Farm Lots.

Large landowners have historically supported the maintenance of plantation era water infrastructure. The presence of large landowners in the Waikoloa hydrologic unit that can help support investments in water delivery systems which benefit them is noteworthy (Figure 14-7).

Figure 14-3. Agricultural Lands of Importance to the State of Hawaiʻi (ALISH) for the Waikoloa hydrologic unit, Hawaiʻi. (Source: State of Hawaii, Office of Planning, 2020j)

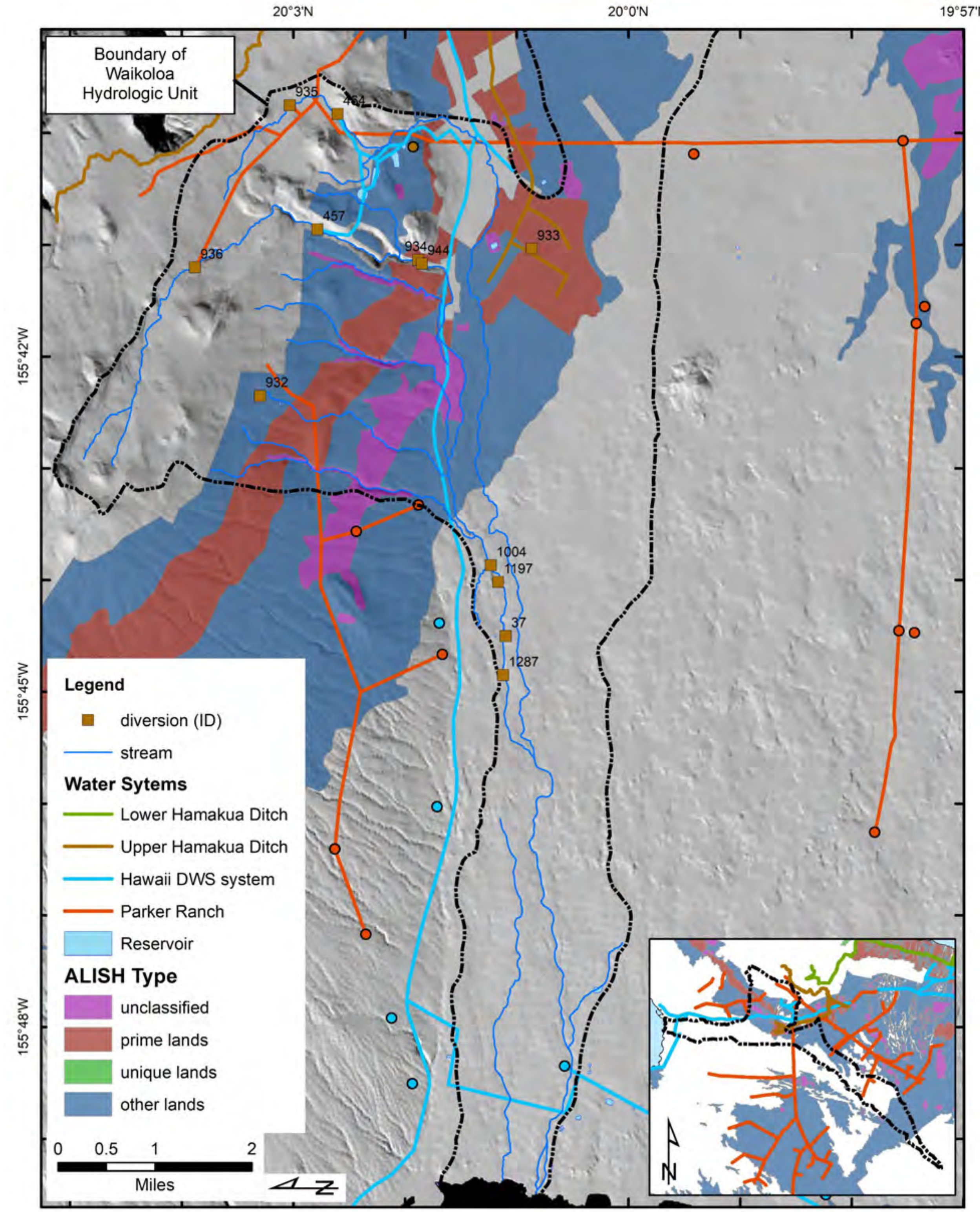


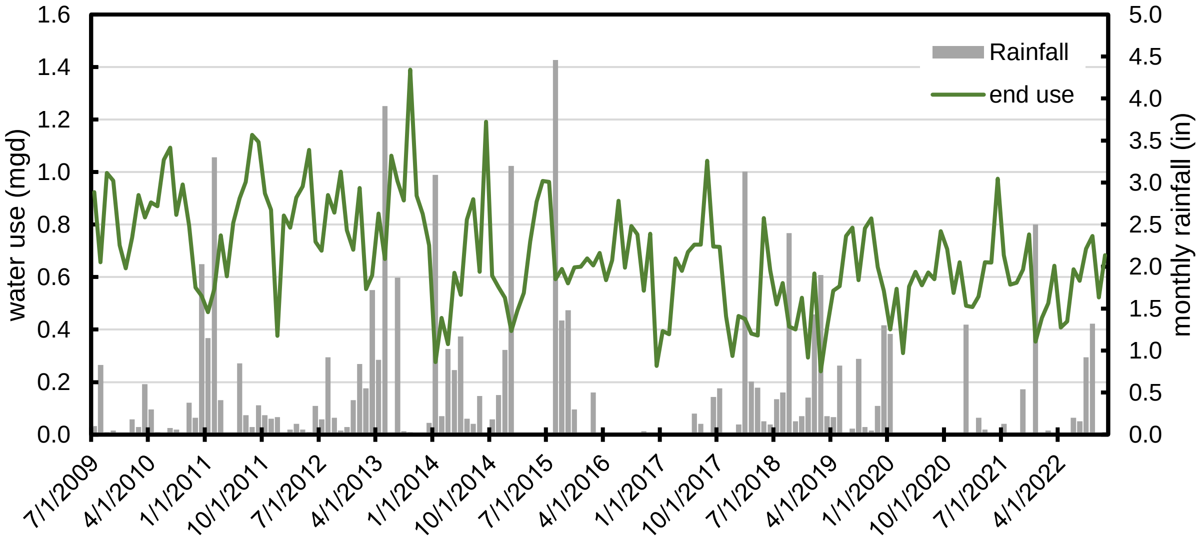
Table 14-5. Flow statistics in cubic feet per second (million gallons per day) for Upper Hāmākua Ditch at USGS stations, historic records, and recent reported total water use for the service area.

| station ID | stream name | Period of Record | Mean Daily Flow | discharge (Q) for a selected percentage (xx) discharge was equaled or exceeded | | | |
|---|---|---|---|---|---|---|---|
| | | | | $Q_{50}$ | $Q_{70}$ | $Q_{90}$ | $Q_{95}$ |
| 16720500 | Upper Hāmākua Ditch blw Kaiwiki Str | 1964-2002 | 7.4 (4.75) | 5.3 (3.43) | 2.2 (1.42) | 0.73 (0.47) | 0.45 (0.29) |
| 16724800 | Upper Hāmākua Ditch abv Alakahi Str | 1968-2000 | 5.3 (3.43) | 3.2 (2.07) | 0.89 (0.58) | 0.01 (0.006) | 0.00 (0.00) |
| 16726000 | Upper Hāmākua Ditch abv Waimea Res Div | 1974-1983, 1994-2004 | 9.4 (6.07) | 6.6 (4.26) | 2.8 (1.80) | 0.80 (0.52) | 0.37 (0.24) |
| 16727000 | Upper Hāmākua Ditch abv Puu Pulehu Res | 1977-2004 | 1.4 (0.91) | | | | |
| 8-182 | Total Metered End Use | 2009-2022 | 1.05 (0.68) | 1.02 (0.66) | 0.88 (0.57) | 0.63 (0.41) | 0.59 (0.38) |

Table 14-6. End use statistics (million gallons per day, mgd) for the Waimea Irrigation System (Upper Hāmākua Ditch) operated by the Department of Agriculture.

| Year | mean | median | maximum |
|---|---|---|---|
| 2009 | 0.816 | 0.823 | 0.996 |
| 2010 | 0.838 | 0.854 | 1.093 |
| 2011 | 0.788 | 0.832 | 1.142 |
| 2012 | 0.853 | 0.840 | 1.084 |
| 2013 | 0.866 | 0.867 | 1.39 |
| 2014 | 0.619 | 0.584 | 1.191 |
| 2015 | 0.669 | 0.634 | 0.966 |
| 2016 | 0.660 | 0.668 | 0.891 |
| 2017 | 0.620 | 0.684 | 1.043 |
| 2018 | 0.484 | 0.447 | 0.825 |
| 2019 | 0.609 | 0.601 | 0.823 |
| 2020 | 0.576 | 0.581 | 0.775 |
| 2021 | 0.614 | 0.604 | 0.975 |
| 2022 | 0.574 | 0.586 | 0.756 |
| ALL YEARS | 0.680 | 0.656 | 1.390 |

Figure 14-4. Mean daily metered end use from the Waimea Irrigation System and total monthly rainfall at SKN 191.4 Lalamilo Farm.




## Irrigation Needs of Diversified Agriculture

The State of Hawai‘i Department of Agriculture uses a baseline irrigation rate of 3,400 gallons per acre per day (gad) to calculate the irrigation water demand for diversified agriculture. While this average may be applicable across a broad range of soil and climate conditions using particular irrigation practices with some crops, it does not help in the estimation of the actual water demands for crops frown in the field.

The Commission funded the development of a GIS-based software program the utilizes the state of Irrigation Water Requirement Estimation Decision Support System, IWREDSS (State of Hawaii, Commission on Water Resource Management, 2015b) was developed by the College of Tropical Agriculture and Human Resources, University of Hawai‘i at Mānoa for the State of Hawai‘i. IWREDSS is an ArcGIS-based numerical simulation model that estimates irrigation requirements (IRR) and water budget components for different crops grown in the Hawaiian environment. The model accounts for different irrigation application systems (e.g., drip, sprinkler, flood), and water application practices (e.g., field capacity versus fixed depth). Model input parameters include rainfall, evaporation, soil water holding capacities, depth of water table, and various crop water management parameters including length of growing season, crop coefficient[1], rooting depth, and crop evapotranspiration.

[1] Crop coefficient is an empirically derived dimensionless number that relates potential evapotranspiration to the crop evapotranspiration. The coefficient is crop-specific.

Figure 14-5. Location and rate of seepage losses (in cfs per mile) based on seepage runs conducted by the US Geological Survey on December 10 and 11, 1963 for the Upper Hāmākua Ditch, Hawaiʻi.

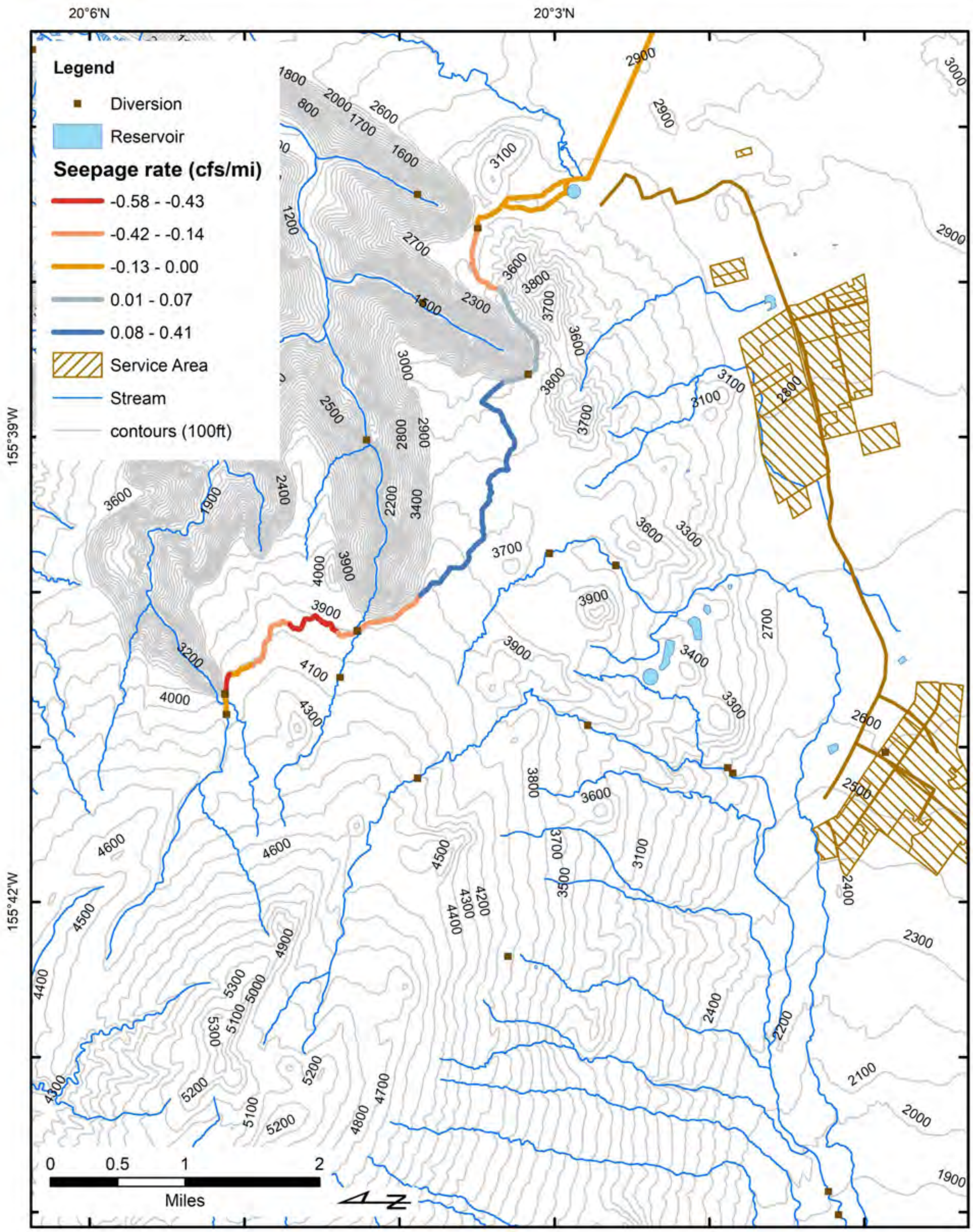


Figure 14-6. Major ditches, pipelines, reservoirs, tanks, and booster pumps with associated large landowners in the vicinity of the Upper Hāmākua Ditch (Waimea Irrigation System), Hawai'i DWS water system, and the Parker Ranch water system in the South Kohala Region, Hawai'i.

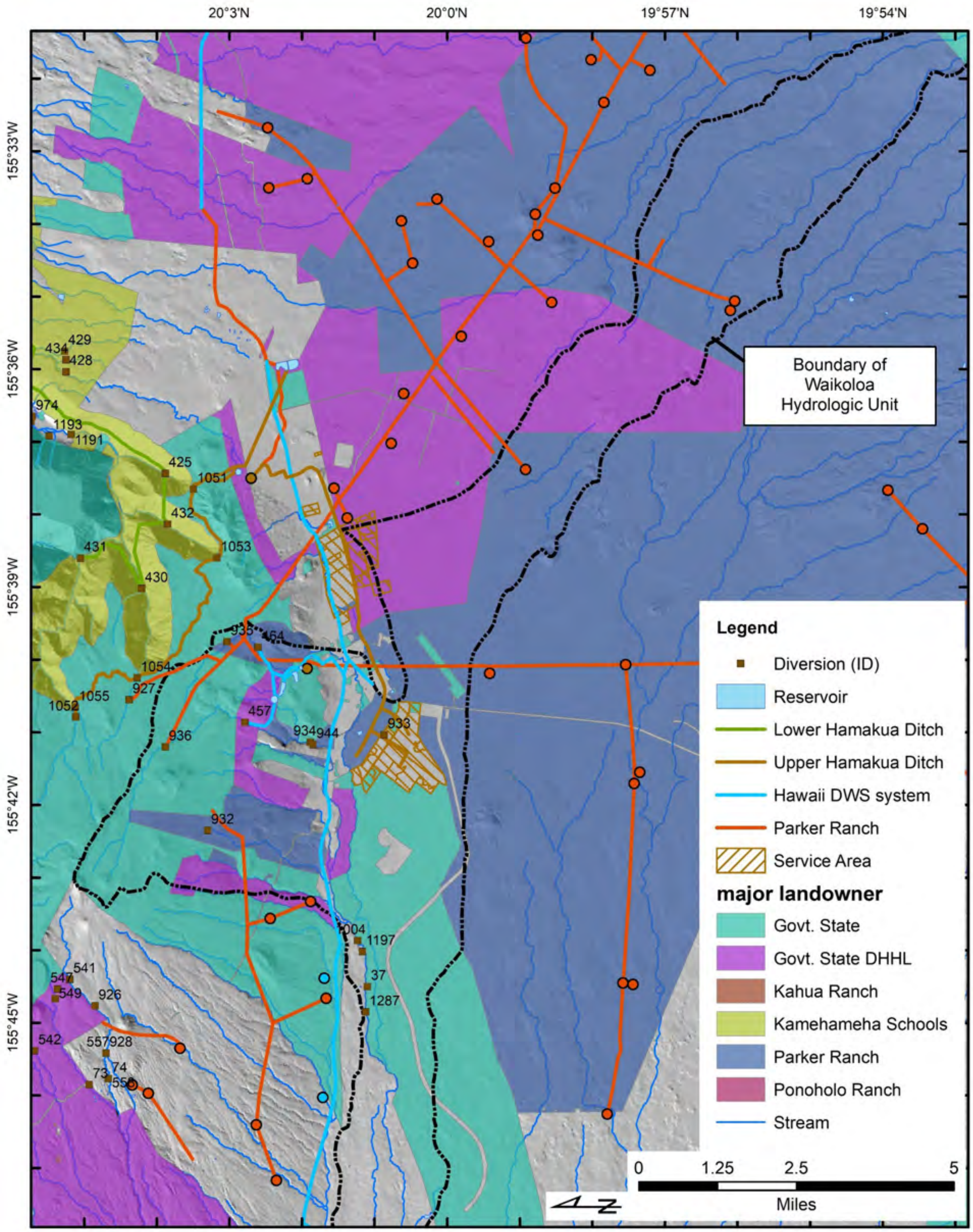
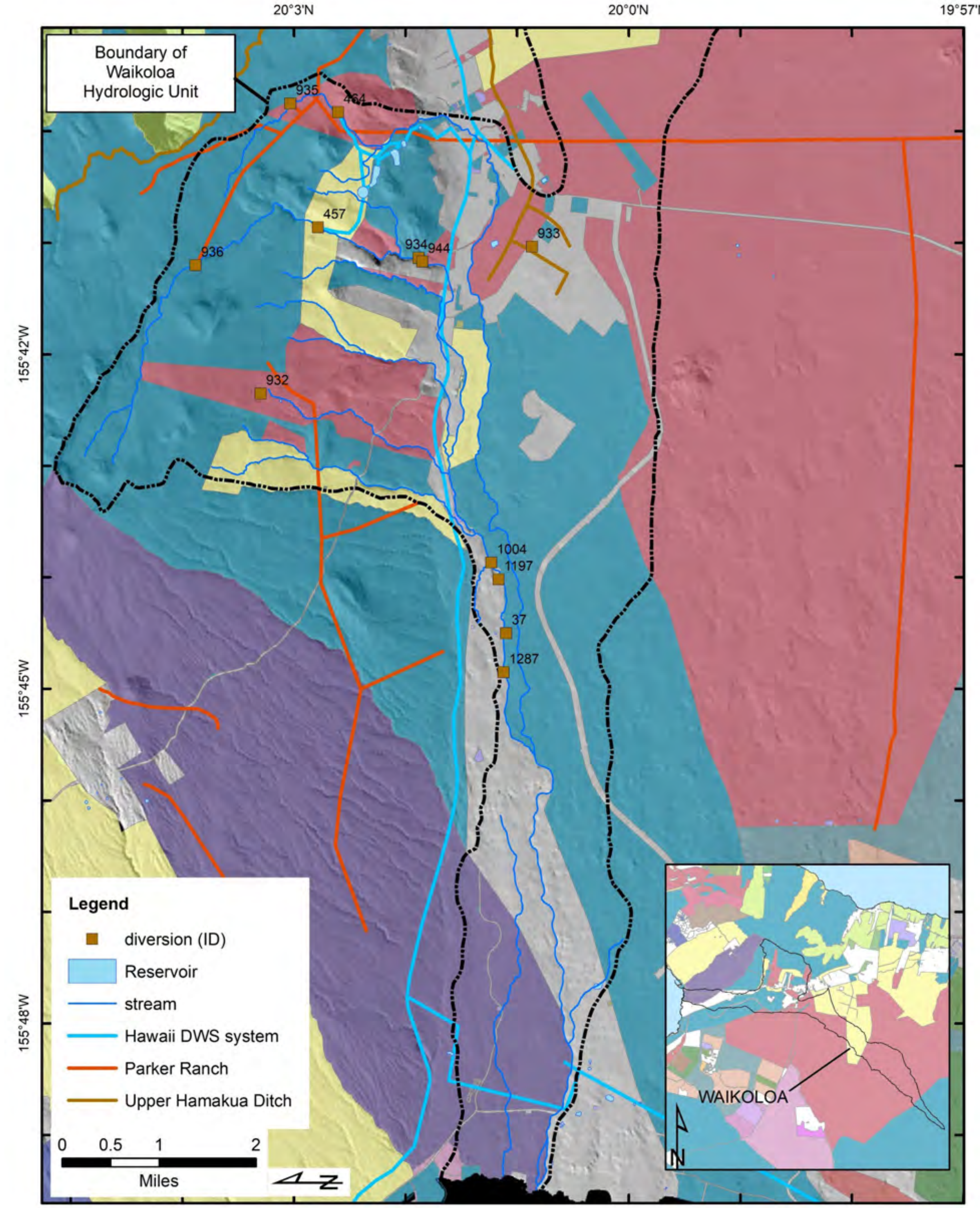


Figure 14-7. Large landowners in the Waikoloa hydrologic unit, Hawai'i.



Calibration and validation of the model was based on the crop water requirement data for different crops from the Hawaii region United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS) Handbook 38 (NRCS-USDA, 1996). Relative errors between the net irrigation requirements (NIR) estimated by the model and those estimated by NRCS range from less than 1 percent to a 26 percent overestimate. This difference may be attributed to the general nature of the technique NRCS used in estimating NIR. Results of the regression analysis indicate a good correlation ($R^2 = 0.97$) between the two techniques; however, the NIR calculations by NRCS were consistently 8 percent higher than those of the IWREDSS model. Overall, the model is an appropriate and practical tool that can be used to assess the IRR of crops in Hawaiʻi.

Understanding that water demand is highly site, weather, application, and crop dependent, IWREDSS can still provide a useful approximation of water needs. The simulation estimated that the IRR for various crops proposed for the central valley grown on TMK 3-6-4-038-008 (a DHHL parcel in the area) ranges from 708 to 1563 gallons per acre per day, depending on the crop (Table 14-7). The model calculates IRR based on long-term rainfall records available at the weather stations located nearest to the fields. Thus, the estimated IRR represents an average value for given drought scenarios as opposed to average or wet year conditions. However, the estimated IRR for the relative drought year frequencies could be extrapolated to represent the highest demand scenarios.

Table 14-7. Mean drip irrigation demand estimates for various crops grown in Waimea Town (TMK 364038008) based on IWREDSS scenarios modeled using the trickle drip irrigation method to field capacity given a 50 ft depth to water table and an SCS curve number of 64. Irrigation Requirement (IRR) value in gallons per acre per day.

| | | estimated irrigation demand (gallons/acre/day) for a given drought frequency | | | |
|---|---|---|---|---|---|
| crops | irrigation method | 1 in 2 (50%) | 1 in 5 (20%) | 1 in 10 (10%) | 1 in 20 (5%) |
| tomato | Trickle Drip | 864 | 1138 | 1279 | 1394 |
| peppers | Trickle Drip | 477 | 708 | 837 | 947 |
| sweet potatoes | Trickle Drip | 1248 | 1563 | 1720 | 1845 |
| pumpkin | Trickle Drip | 730 | 938 | 1044 | 1129 |
| dryland taro | Trickle Drip | 819 | 1013 | 1109 | 1185 |
| avocado | Trickle Drip | 424 | 726 | 913 | 1081 |

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# 16.0 Appendices

Appendix A  Waikoloa, Hawai‘i, Hawai‘i. June 2008. DAR Watershed Code: 85003
*State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources.*

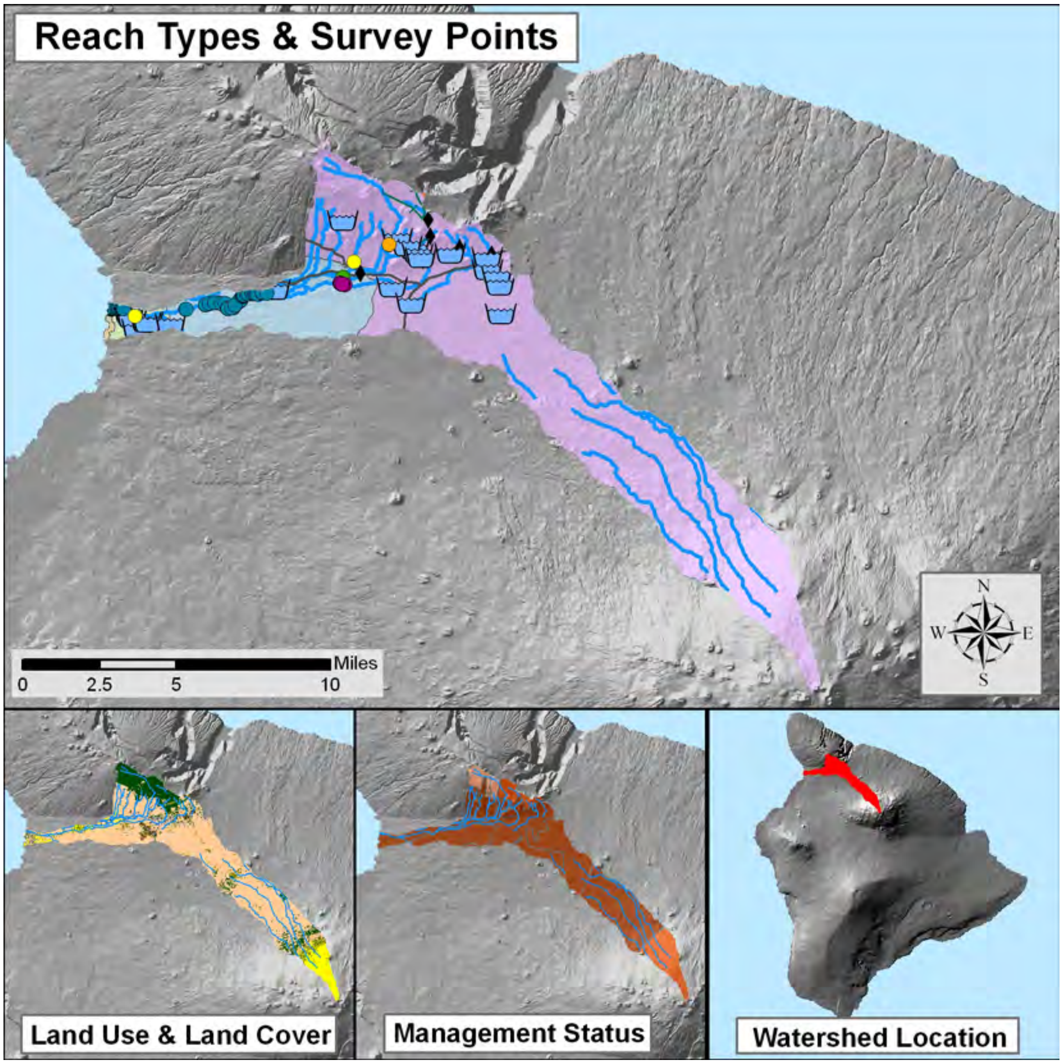
# APPENDIX A

## State of Hawai‘i, Department of Land and Natural Resources, Division of Aquatic Resources

## Atlas of Hawaiian Watersheds & Their Aquatic Resources Waikoloa, Hawai‘i

*DAR Watershed Code: 85003*

# Wai‘ula‘ula, Hawai‘i




## WATERSHED FEATURES

Wai‘ula‘ula watershed occurs on the island of Hawai‘i. The Hawaiian meaning of the name is unknown. The area of the watershed is 74.3 square mi (192.4 square km), with maximum elevation of 13609 ft (4148 m). The watershed's DAR cluster code is not yet determined. The percent of the watershed in the different land use districts is as follows: 74.3% agricultural, 20.5% conservation, 0.1% rural, and 5.1% urban.

**Land Stewardship: Percentage of the land in the watershed managed or controlled by the corresponding agency or entity. Note that this is not necessarily ownership.**

| Military | Federal | State | OHA | County | Nature Conservancy | Other Private |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 32.2 | 14.6 | 0.0 | 0.0 | 53.2 |

**Land Management Status: Percentage of the watershed in the categories of biodiversity protection and management created by the Hawaii GAP program.**

| Permanent Biodiversity Protection | Managed for Multiple Uses | Protected but Unmanaged | Unprotected |
|---|---|---|---|
| 0.0 | 4.3 | 14.7 | 81.0 |

**Land Use: Areas of the various categories of land use. These data are based on NOAA C-CAP remote sensing project.**

| | Percent | Square mi | Square km |
|---|---|---|---|
| High Intensity Developed | 0.7 | 0.51 | 1.31 |
| Low Intensity Developed | 2.7 | 2.00 | 5.19 |
| Cultivated | 0.7 | 0.50 | 1.31 |
| Grassland | 66.3 | 49.26 | 127.58 |
| Scrub/Shrub | 5.9 | 4.37 | 11.32 |
| Evergreen Forest | 15.2 | 11.26 | 29.15 |
| Palustrine Forested | 0.0 | 0.00 | 0.00 |
| Palustrine Scrub/Shrub | 0.0 | 0.00 | 0.00 |
| Palustrine Emergent | 0.0 | 0.00 | 0.00 |
| Estuarine Forested | 0.0 | 0.00 | 0.00 |
| Bare Land | 8.5 | 6.34 | 16.41 |
| Unconsolidated Shoreline | 0.0 | 0.00 | 0.00 |
| Water | 0.1 | 0.06 | 0.16 |
| Unclassified | 0.0 | 0.00 | 0.00 |

## STREAM FEATURES

Wai‘ula‘ula is a perennial stream. Total stream length is 95.5 mi (153.8 km). The terminal stream order is 3.

**Reach Type Percentages: The percentage of the stream's channel length in each of the reach type categories.**

| Estuary | Lower | Middle | Upper | Headwaters |
|---|---|---|---|---|
| 0.0 | 0.4 | 3.0 | 21.0 | 75.6 |

The following stream(s) occur in the watershed:

| | | | | |
|---|---|---|---|---|
| Hale‘aha | Hāloa | Keanu‘i‘omanō | Kohākōhau | Kuupahaa |
| Lamimaumau | Lanikepu | Mamaewa | Momoualoa | ‘O‘olāmakapehu |
| ‘Ōuli | Wai‘aka | Waikōloa | Wai‘ula‘ula | |

## BIOTIC SAMPLING EFFORT

Biotic samples were gathered in the following year(s):

1968 1990 1992 1994 1999 2000 2001

**Distribution of Biotic Sampling: The number of survey locations that were sampled in the various reach types.**

| Survey type | Estuary | Lower | Middle | Upper | Headwaters |
|---|---|---|---|---|---|
| Damselfly Surveys | 0 | 0 | 1 | 0 | 1 |
| DAR Point Quadrat | 0 | 26 | 41 | 129 | 0 |
| HDFG | 0 | 0 | 0 | 0 | 1 |
| Microhabitat Survey | 0 | 0 | 0 | 24 | 0 |
| Published Report | 0 | 0 | 0 | 1 | 0 |

## BIOTA INFORMATION

**Species List**

**Native Species**

| | |
|---|---|
| **Crustaceans** | *Macrobrachium grandimanus* |
| **Fish** | *Awaous guamensis* |
| | *Lentipes concolor* |
| | *Sicyopterus stimpsoni* |
| **Worms** | *Myzobdella lugubris* |

**Native Species**

| | |
|---|---|
| **Insects** | *Anax junius* |
| | *Anax strenuus* |
| | *Chironomus hawaiiensis* |
| | *Megalagrion sp.* |
| | *Orthocladius grimshawi* |
| | *Scatella clavipes* |
| | *Scatella sp.* |

**Introduced Species**

| | |
|---|---|
| **Amphibians** | *Bufo marinus* |
| | *Rana catesbiana* |
| | Ranid sp. |
| **Bryozoans** | *Plumatella repens* |
| **Crustaceans** | *Macrobrachium lar* |
| **Fish** | *Gambusia affinis* |
| | *Misgurnus anguillicaudatus* |
| | *Poecilia reticulata* |
| | Poeciliid sp. |
| **Worms** | *Camallanus cotti* |

**Introduced Species**

| | |
|---|---|
| **Insects** | *Cricotopus bicinctus* |
| | *Crocothemis servilia* |
| | *Enallagma civile* |
| | *Ischnura posita* |
| | *Ischnura ramburi* |
| | *Orthemis ferruginea* |
| | *Pantala flavescens* |
| | *Rhantus gutticollis* |

**Species Size Data: Species size (inches) observed in DAR Point Quadrat Surveys.**

| Scientific Name | Status | Minimum Size | Maximum Size | Average Size |
|---|---|---|---|---|
| *Bufo marinus* | Introduced | 0.5 | 4 | 0.9 |
| *Rana catesbiana* | Introduced | 5 | 5 | 5.0 |
| Ranid sp. | Introduced | 0.5 | 0.75 | 0.5 |
| *Plumatella repens* | Introduced | 0.75 | 0.75 | 0.8 |
| *Macrobrachium grandimanus* | Endemic | 0.5 | 2 | 1.2 |
| *Macrobrachium lar* | Introduced | 1 | 4 | 2.2 |
| *Lentipes concolor* | Endemic | 1.5 | 3.5 | 2.2 |
| *Sicyopterus stimpsoni* | Endemic | 2.25 | 5 | 3.5 |
| *Awaous guamensis* | Indigenous | 1 | 7 | 2.4 |
| *Gambusia affinis* | Introduced | 0.5 | 2 | 0.9 |

| | | | | |
|---|---|---|---|---|
| *Misgurnus anguillicaudatus* | Introduced | 2 | 6 | 3.4 |
| *Poecilia reticulata* | Introduced | 0.5 | 2 | 0.9 |
| Poeciliid sp. | Introduced | 0.5 | 2 | 1.0 |
| *Anax strenuus* | Endemic | 0.75 | 1 | 0.9 |
| *Megalagrion sp.* | Endemic | 0.75 | 0.75 | 0.8 |

**Average Density: The densities (#/square yard) for species observed in DAR Point Quadrat Surveys averaged over all sample dates in each reach type.**

| Scientific Name | Status | Estuary | Low | Mid | Upper | Headwaters |
|---|---|---|---|---|---|---|
| *Anax strenuus* | Endemic | | | | 0.06 | |
| *Lentipes concolor* | Endemic | | | | 0.88 | |
| *Sicyopterus stimpsoni* | Endemic | | 0.19 | 0.06 | | |
| *Awaous guamensis* | Indigenous | | 1.32 | 0.41 | 0.74 | |
| *Bufo marinus* | Introduced | | 1.51 | 0.18 | 0.03 | |
| *Gambusia affinis* | Introduced | | 13.1 | 0.09 | 1.74 | |
| *Macrobrachium lar* | Introduced | | 1.13 | 0.18 | 0.12 | |
| *Misgurnus anguillicaudatus* | Introduced | | | 0.03 | 0.38 | |
| *Poecilia reticulata* | Introduced | | 0.57 | | | |
| Poeciliid sp. | Introduced | | 5.65 | 0.03 | 0.32 | |
| Ranid sp. | Introduced | | 9.42 | | | |

**Species Distributions: Presence (P) of species in different stream reaches.**

| Scientific Name | Status | Estuary | Lower | Middle | Upper | Headwaters |
|---|---|---|---|---|---|---|
| *Macrobrachium grandimanus* | Endemic | | P | | | |
| *Lentipes concolor* | Endemic | | | | P | |
| *Sicyopterus stimpsoni* | Endemic | | P | P | P | |
| *Anax strenuus* | Endemic | | | | P | |
| *Chironomus hawaiiensis* | Endemic | | | | P | |
| *Megalagrion sp.* | Endemic | | | P | P | |
| *Orthocladius grimshawi* | Endemic | | | | P | |
| *Scatella clavipes* | Endemic | | | | P | |
| *Awaous guamensis* | Indigenous | | P | P | P | |
| *Anax junius* | Indigenous | | | | P | |
| *Scatella sp.* | Indigenous | | | | P | |
| *Bufo marinus* | Introduced | | P | P | P | |
| *Rana catesbiana* | Introduced | | | | P | |
| Ranid sp. | Introduced | | P | | | |
| *Plumatella repens* | Introduced | | | P | | |
| *Macrobrachium lar* | Introduced | | P | P | P | |
| *Gambusia affinis* | Introduced | | P | P | P | |
| *Misgurnus anguillicaudatus* | Introduced | | | P | P | |
| *Poecilia reticulata* | Introduced | | P | | P | |
| Poeciliid sp. | Introduced | | P | P | P | |

| | | | | |
|---|---|---|---|---|
| *Cricotopus bicinctus* | Introduced | | P | |
| *Crocothemis servilia* | Introduced | | P | |
| *Enallagma civile* | Introduced | P | P | |
| *Ischnura posita* | Introduced | | | P |
| *Ischnura ramburi* | Introduced | P | | |
| *Orthemis ferruginea* | Introduced | | P | |
| *Pantala flavescens* | Introduced | | P | |
| *Rhantus gutticollis* | Introduced | | P | |

## HISTORIC RANKINGS

**Historic Rankings: These are rankings of streams from historical studies. "Yes" means the stream was considered worthy of protection by that method. Some methods include non-biotic data in their determination. See Atlas Key for details.**

Multi-Attribute Prioritization of Streams - Potential Heritage Streams (1998): No

Hawaii Stream Assessment Rank (1990): not ranked

U.S. Fish and Wildlife Service High Quality Stream (1988): No

The Nature Conservancy- Priority Aquatic Sites (1985): No

National Park Service - Nationwide Rivers Inventory (1982): No

**Current DAR Decision Rule Status: The following criteria are used by DAR to consider the biotic importance of streams. "Yes" means that watershed has that quality.**

| Native Insect Diversity > 19 spp. | Native Macrofauna Diversity > 5 spp. | Absence of Priority 1 Introduced |
|---|---|---|
| No | No | No |
| **Abundance of Any Native Species** | **Presence of Candidate Endangered Species** | **Endangered Newcomb's Snail Habitat** |
| No | No | No |

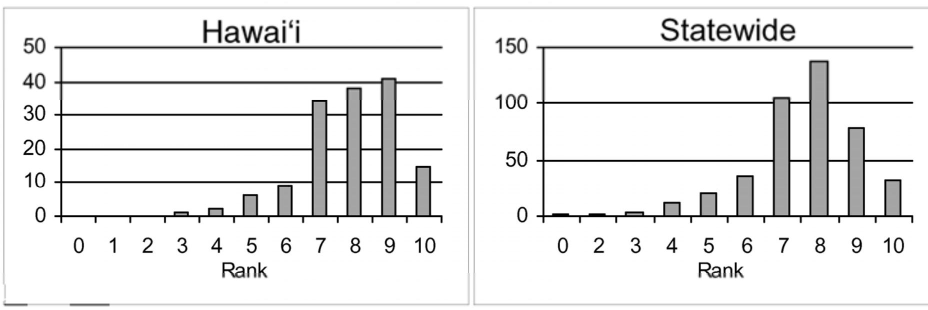
## CURRENT WATERSHED AND STREAM RATINGS

The current watershed and stream ratings are based on the data contained in the DAR Aquatic Surveys Database. The ratings provide the score for the individual watershed or stream, the distribution of ratings for that island, and the distribution of ratings statewide. This allows a better understanding of the meaning of a particular ranking and how it compares to other streams. The ratings are standardized to range from 0 to 10 (0 is lowest and 10 is highest rating) for each variable and the totals are also standardized so that the rating is not the average of each component rating. These ratings are subject to change as more data are entered into the DAR Aquatic Surveys Database and can be automatically recalculated as the data improve. In addition to the ratings, we have also provided an estimate of the confidence level of the ratings. This is called rating strength. The higher the rating strength the more likely the data and rankings represent the actual condition of the watershed, stream, and aquatic biota.

## WATERSHED RATING: Wai‘ula‘ula, Hawai‘i

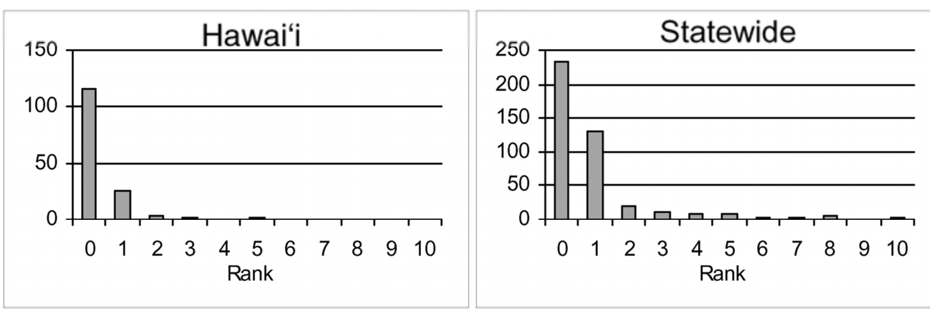
Land Cover Rating: Rating is based on a scoring sytem where in general forested lands score positively and developed lands score negatively.

Watershed Rating
7



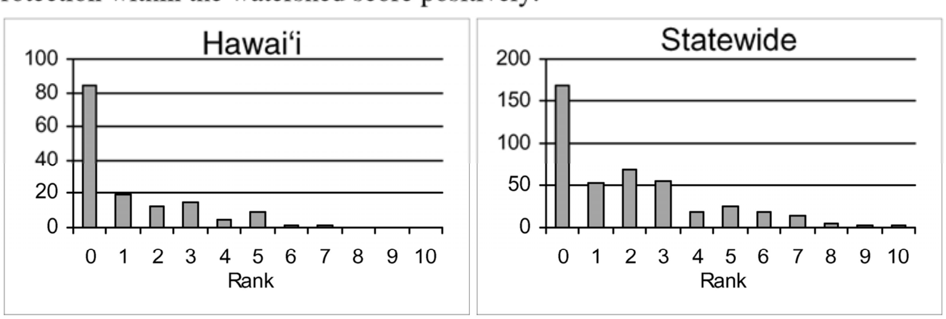

Shallow Waters Rating: Rating is based on a combination of the extent of estuarine and shallow marine areas associated with the watershed and stream.

Watershed Rating
1




Stewardship Rating: Rating is based on a scoring system where higher levels of land and biodiversity protection within the watershed score positively.

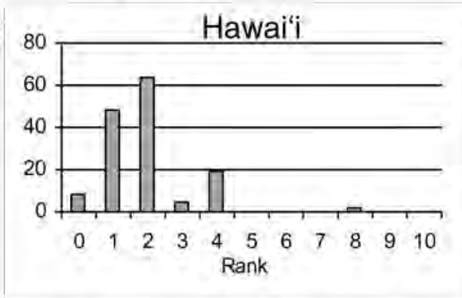
Watershed Rating
1

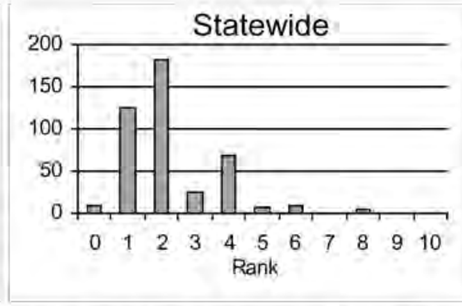


## WATERSHED RATING (Cont): Wai'ula'ula, Hawai'i

Size Rating: Rating is based on the watershed area and total stream length. Larger watersheds and streams score more positively.

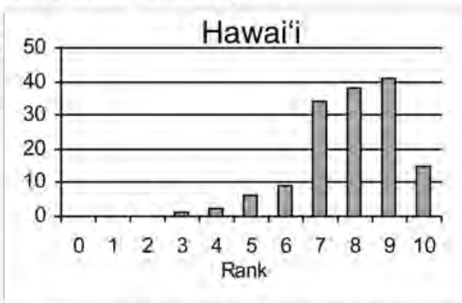
Watershed Rating
4

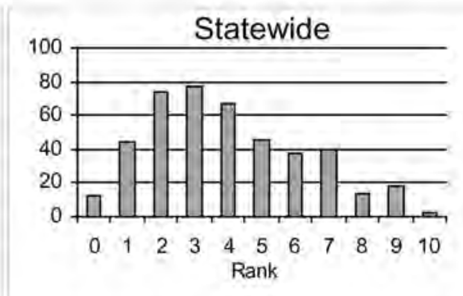



Wetness Rating: Rating is based on the average annual rainfall within the watershed. Higher rainfall totals score more positively.

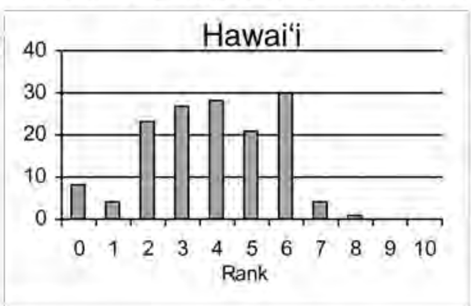
Watershed Rating
1

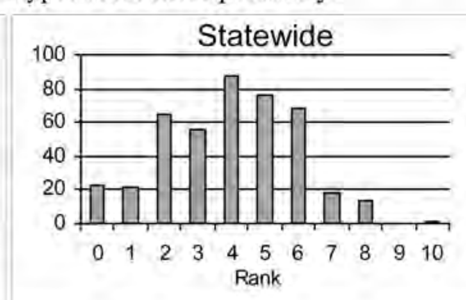



Reach Diversity Rating: Rating is based on the types and amounts of different stream reaches available in the watershed. More area in different reach types score more positively.

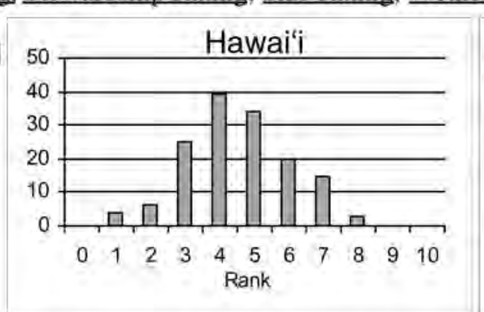
Watershed Rating
6

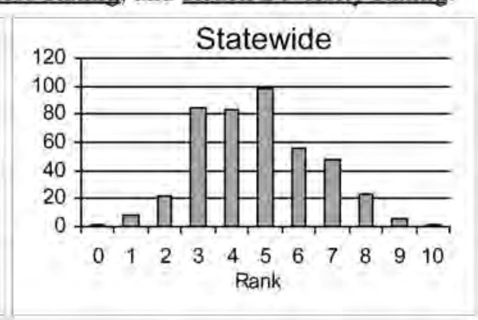



Total Watershed Rating: Rating is based on combination of Land Cover Rating, Shallow Waters Rating, Stewardship Rating, Size Rating, Wetness Rating, and Reach Diversity Rating.

Watershed Rating
5



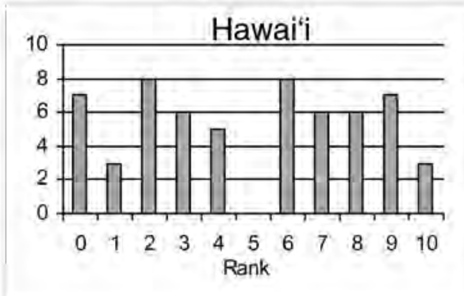



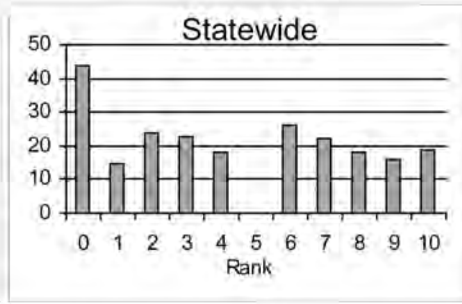
## BIOLOGICAL RATING: Wai‘ula‘ula, Hawai‘i

Native Species Rating: Rating is based on the number of native species observed in the watershed.

Stream Rating

4

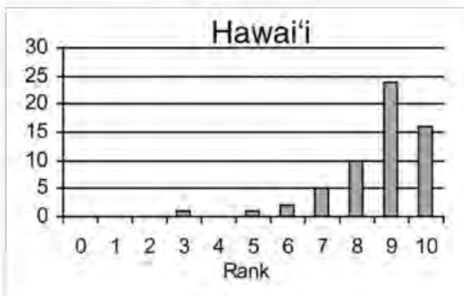


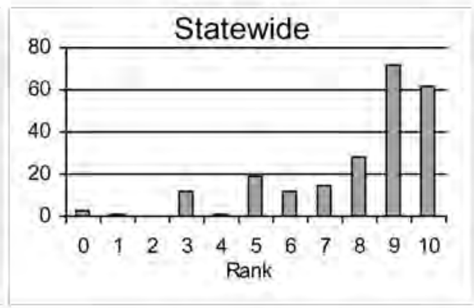




Introduced Genera Rating: Rating is based on the number of introduced genera observed in the watershed.

Stream Rating

6

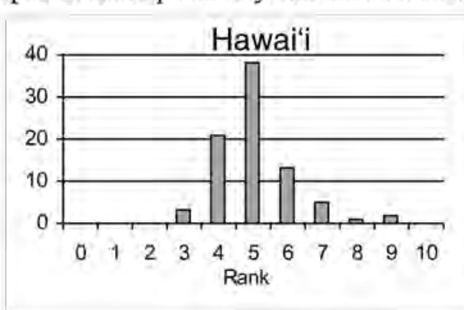


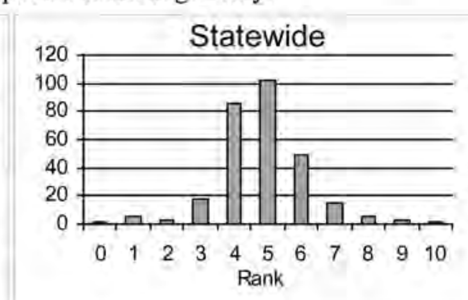




All Species' Score Rating: Rating is based on the Hawaii Stream Assessment scoring system where native species score positively and introduced species score negatively.

Stream Rating

3

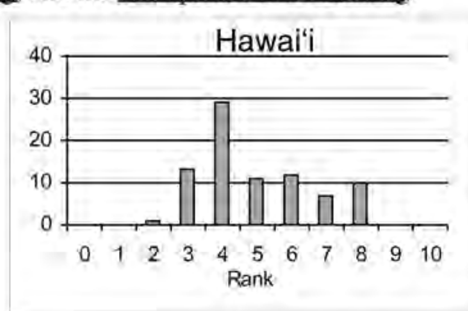


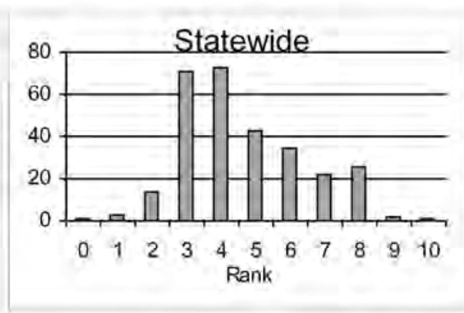




Total Biological Rating: Rating is the combination of the Native Species Rating, Introduced Genera Rating, and the All Species' Score Rating.

Stream Rating

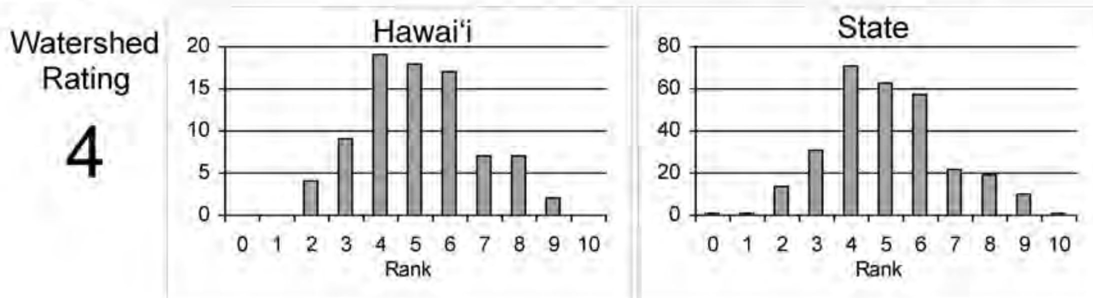
3



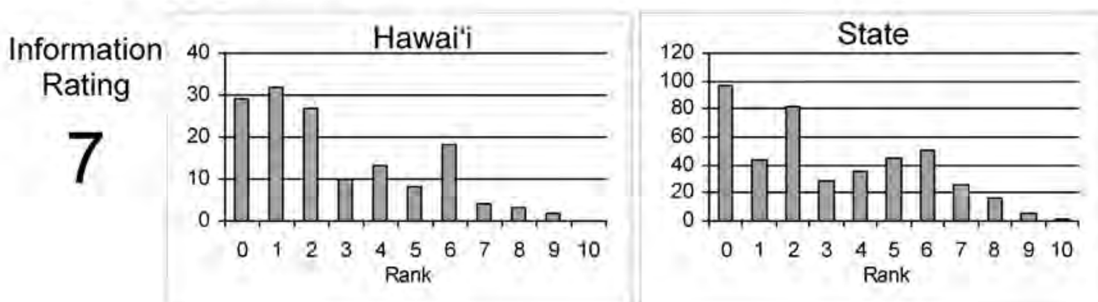
## OVERALL RATING: Wai‘ula‘ula, Hawai‘i

Overall Rating: Rating is a combination of the Total Watershed Rating and the Total Biological Rating.




## RATING STRENGTH: Wai‘ula‘ula, Hawai‘i

Rating Strength: Represents an estimate of the overall study effort in the stream and is a combination of the number of studies, number of different reaches surveyed, and the number of different survey types.

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