Instream Flow Standard Assessment Report

Island of Oahu
Hydrologic Units 3071
Kaupuni

June 2020 **DRAFT PR-2020-03**

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

COVER
Satallite image of Kaupuni hydrologic units with the Kaupuni stream flowing into Pokai Bay, Oahu [Google Earth, 2015].

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)
DWS	Department of Water Supply (County of Maui)
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
KLM	Kaanapali Land Management Company
LCA	Land Commission Award
LUC	Land Use Commission (State of Hawaii)
MECO	Maui Electric Company
MF	multi-family residential
mgd	million gallons per day
Mgal/d	million gallons per day
mi	mile
MLP	Maui Land & Pineapple
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 Kaupuni is located on the leeward side of the island of Oahu (Figure 1-3). The hydrologic unit includes the ahupuaa of Kaupuni in the Moku of Waianae. The Kaupuni hydrologic unit is 9.2 square miles on the western flank of the Waianae Mountain Range and Mt Kaala, which was part of the former Waianae caldera that included Lualualei Valley. The Kaupuni watershed is 8.35 square miles and includes the Kaupuni Stream and its tributiaries as well as the Waianae Stream. Mean annual precipitation for Kaupuni is 37.3 inches. The Kaupuni watershed ranges from a maximum elevation of 3,940 feet to sea level, with a mean basin elevation of 1030 feet and a mean basin slope of 42.9 percent (Figures 1-4 and 1-5). Forty-three percent of the basin has a slope greater than 30 percent. Many small streams start at the back of the amphitheater-shaped watershed featuring the high cliffs of the Waianae Range, which were generated by the southeast to northwest oriented rift zone, and opens into the broader Waianae Valley. The lava flows of the shield building Waianae Volcanics phase and are characterized by high porosity and transmissivity. Numerous vertical dikes are found along the rift zone and along the interfluve with limited distribution in the lateral margins and the upper reaches of Waianae Valley are situated in the marginal dike zone. Where incision has exposed these dikes, spring flow emenates, supporting continual surface flow. The shield-building phase from the Waianae Volcano ended approximately 3 million years ago with erosion and subsidence modifying the original volcano. As Waianae Valley formed, eroded sediments filled the valley floor.

The longest flow path in Kaupuni is 6.35 miles in length, traversing in a southwesternly direction from its headwaters to Pokai Bay. Multiple volcanic ridges extend in a northeast to southwest direction as remnents of the last eruption event following a massive submarine slump which altered the movement of magma within the volcano. Kaupuni Valley includes Kanewai, Honua, Kalalua, and Hiu streams that begin as spring flow from incised dike structures. Mt Kaala, the tallest point on Oahu and its high elevation bog environment, forms a small portion of the Kaupuni hydrologic unit and makes a minor contribution to surface flow. Landcover in the Kaupuni hydrologic units is dominated by non-native scrub and grassland, with upper elevations consisting mostly of non-native evergreen forest while the lower elevations support urban development. The higher elevation portions of the hydrologic unit are made up of conservation land owned by the Department of Land and Natural Resources or the Honolulu Board of Water Supply (HBWS), with other lands owned by the Department of Hawaiian Home Lands. Watershed landcover and stewardship are rated poorly, with few native species living above the lowest estuarine reaches. The census designated place of Waianae is located along the coast with a total population of 10,506 people (U.S. Census Bureau Office of Planning 2011). There is one highway that passes through Kaupuni between Makaha and Nanakuli (Figure 1-6). Numerous development tunnels were built during the 1920s to support the agricultural water needs of the area or during the 1940s and 1950s for municipal use. While most of them became unproductive over time, four are still actively used by the HBWS for municipal water supply. The largest tunnel, named the Waianae Tunnel by HBWS and commonly referred to as the Kunesh Tunnel, is over 10,000 feet long at an elevation of 418 feet. This tunnel alters groundwater flow from higher elevation springs and tunnels.

Current Instream Flow Standard

The current interim instream flow standard (IFS) for Kaupuni Stream was established by way of Hawaii Administrative Rules (HAR) §13-169-44, which, in pertinent part, reads as follows:

> Interim instream flow standard for Leeward Oahu. The Interim Instream Flow Standard for all streams on Leeward Oahu, as adopted by the commission on water resource management on October 19, 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 December 10, 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 Hawaii 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 Oahu streams, as well as other streams statewide. The Hawaii 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.

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."

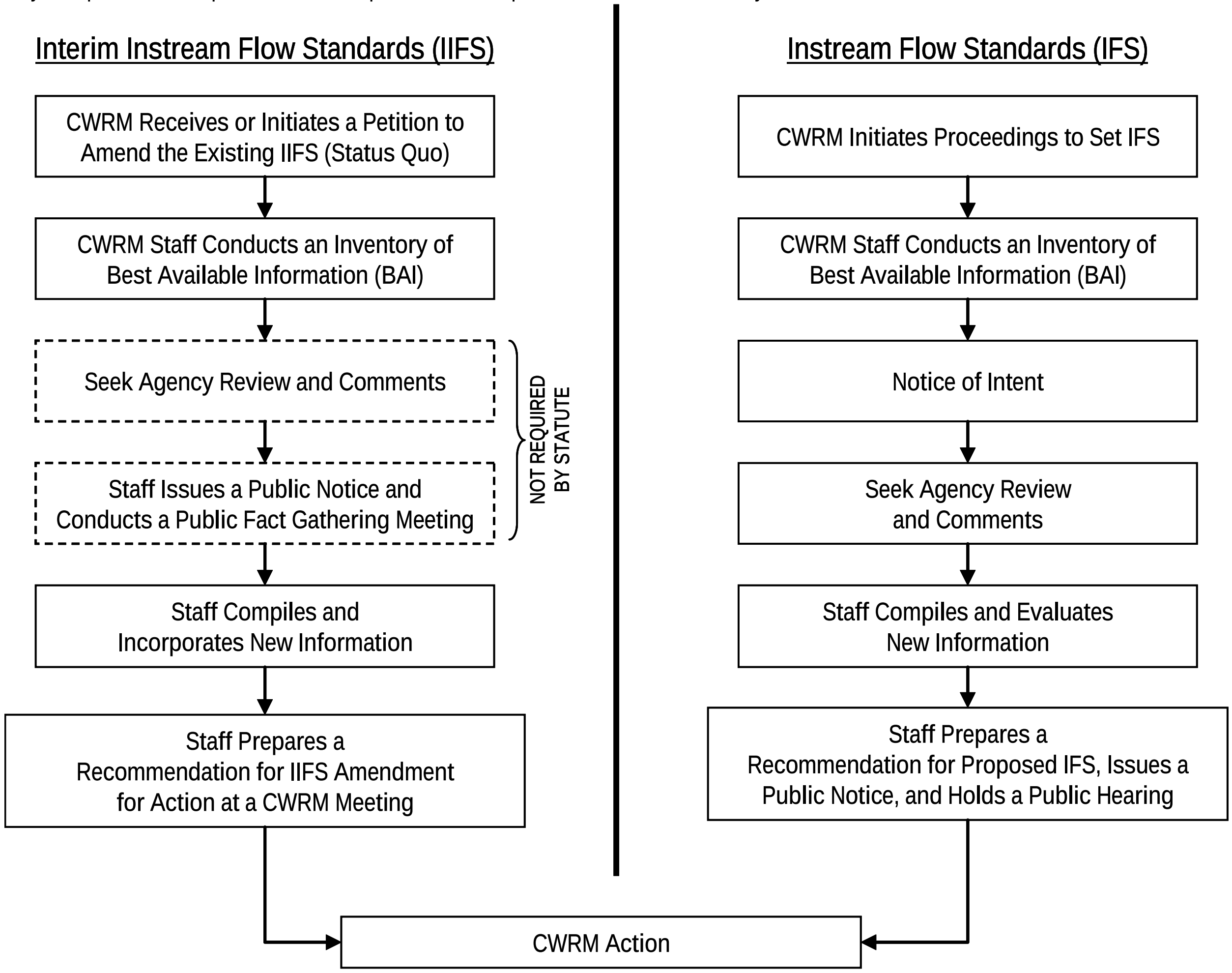
Figure 1-1. Information to consider in setting measurable instream flow standards.

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.

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.



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.

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. World View 2 satellite imagery of the Kaupuni hydrologic unit and streams on Oahu, Hawaii. (Source: State of Hawaii, Planning Department, 2004; State of Hawaii, Commission on Water Resource Management, 2015c)

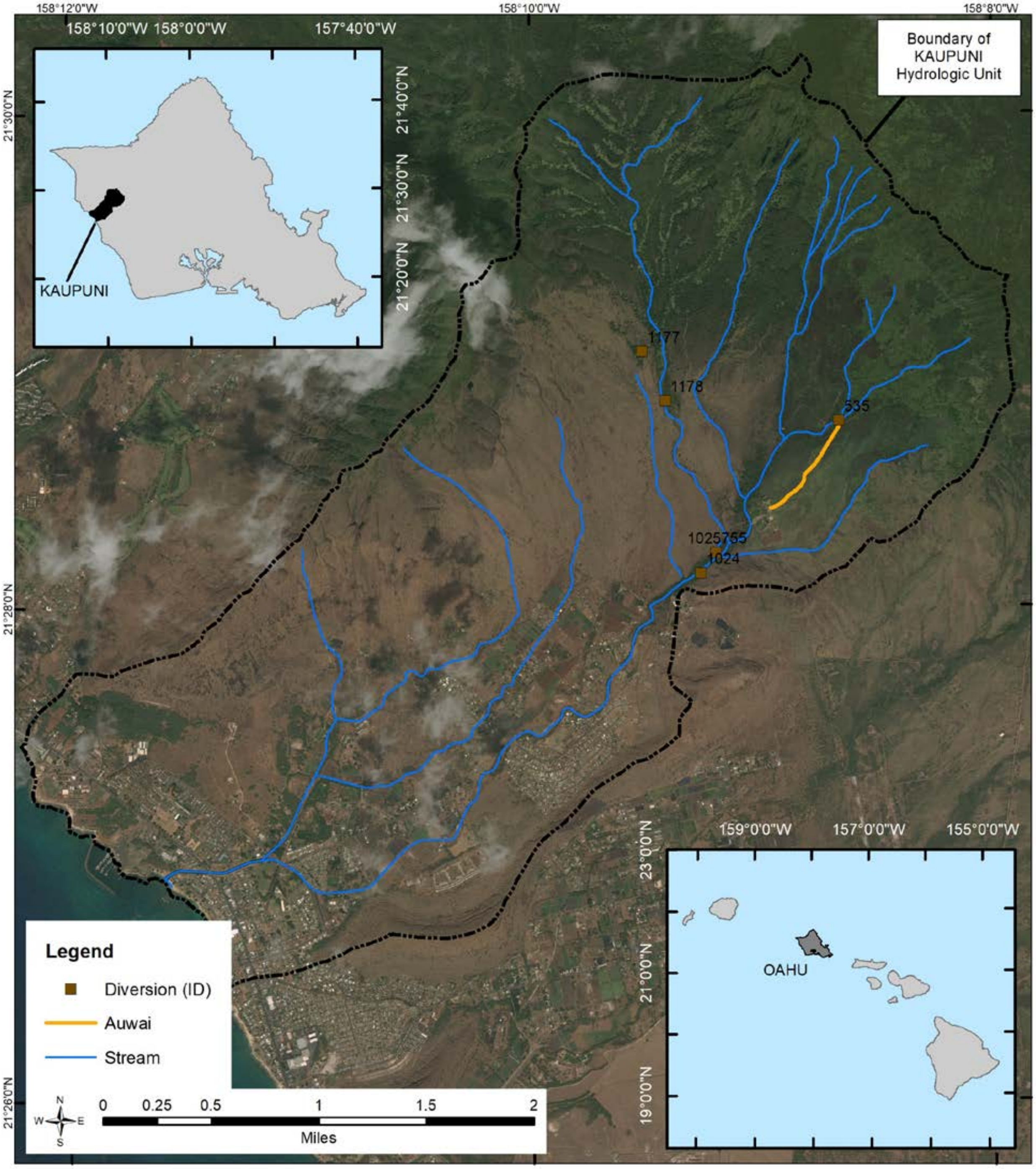


Figure 1-4. Elevation range and contours of the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2004e; U.S. Geological Survey, 2001)

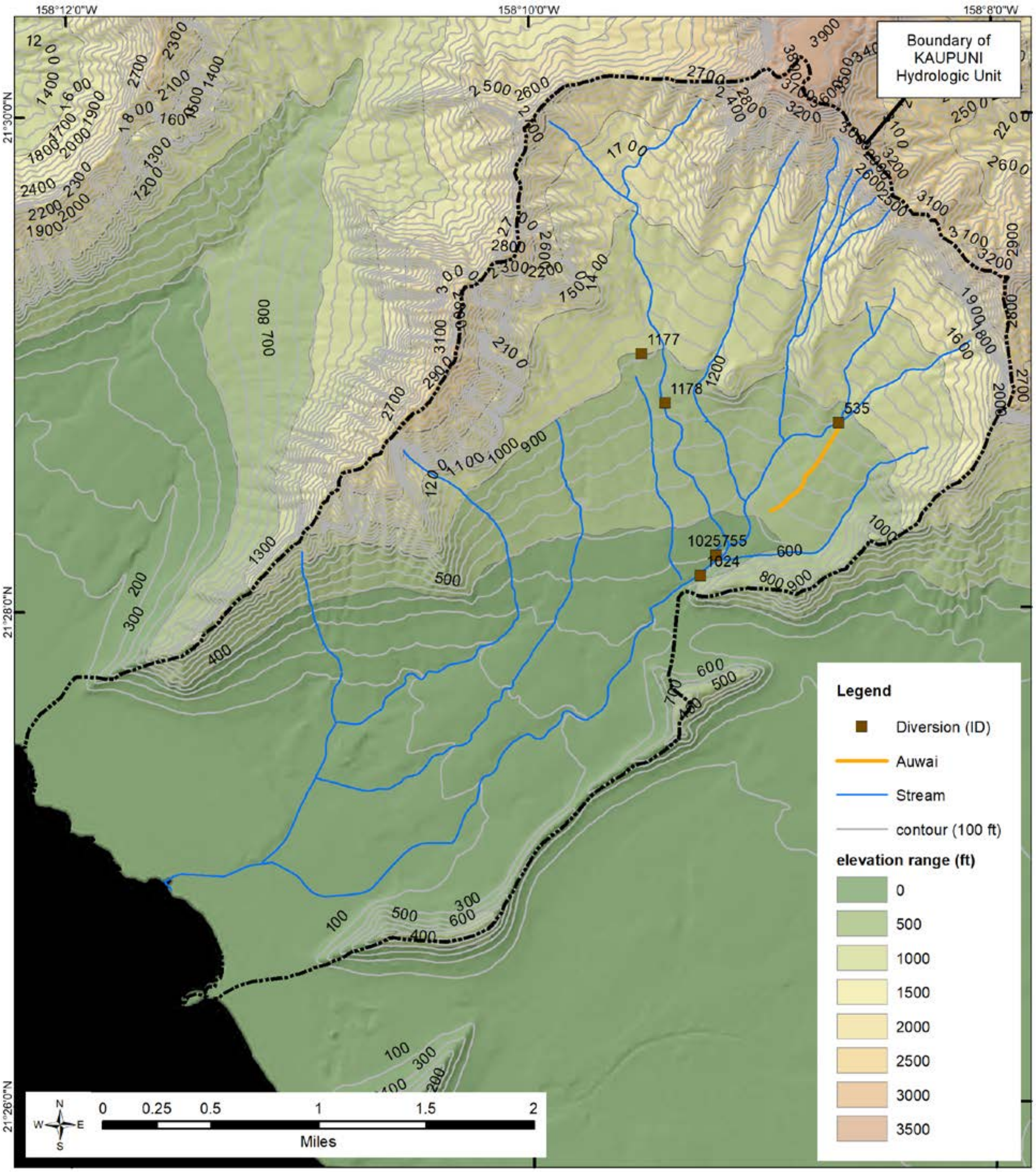


Figure 1-5. USGS topographic map of Kaupuni hydrologic unit, Oahu. (Source: U.S. Geological Survey, 1996)

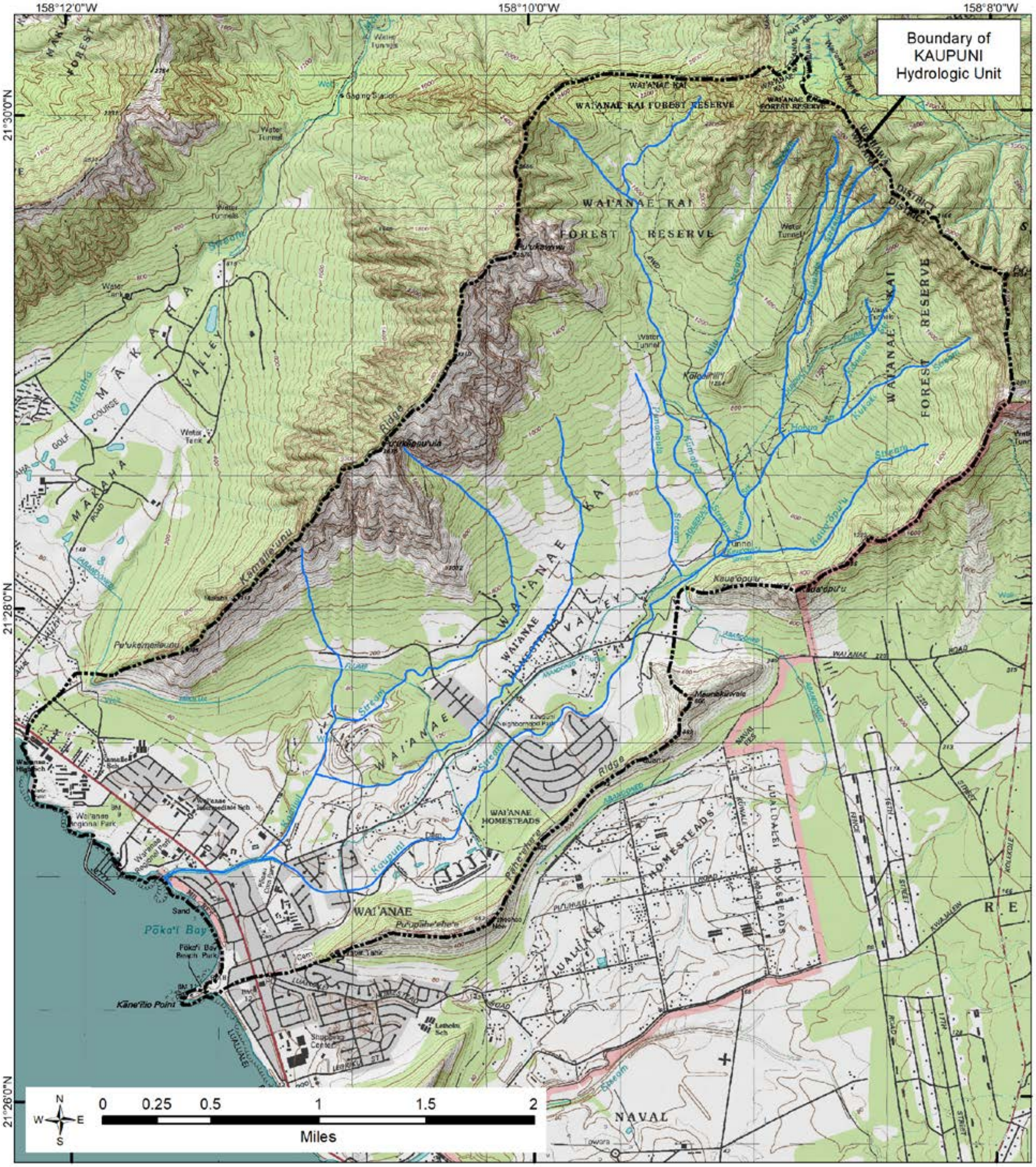
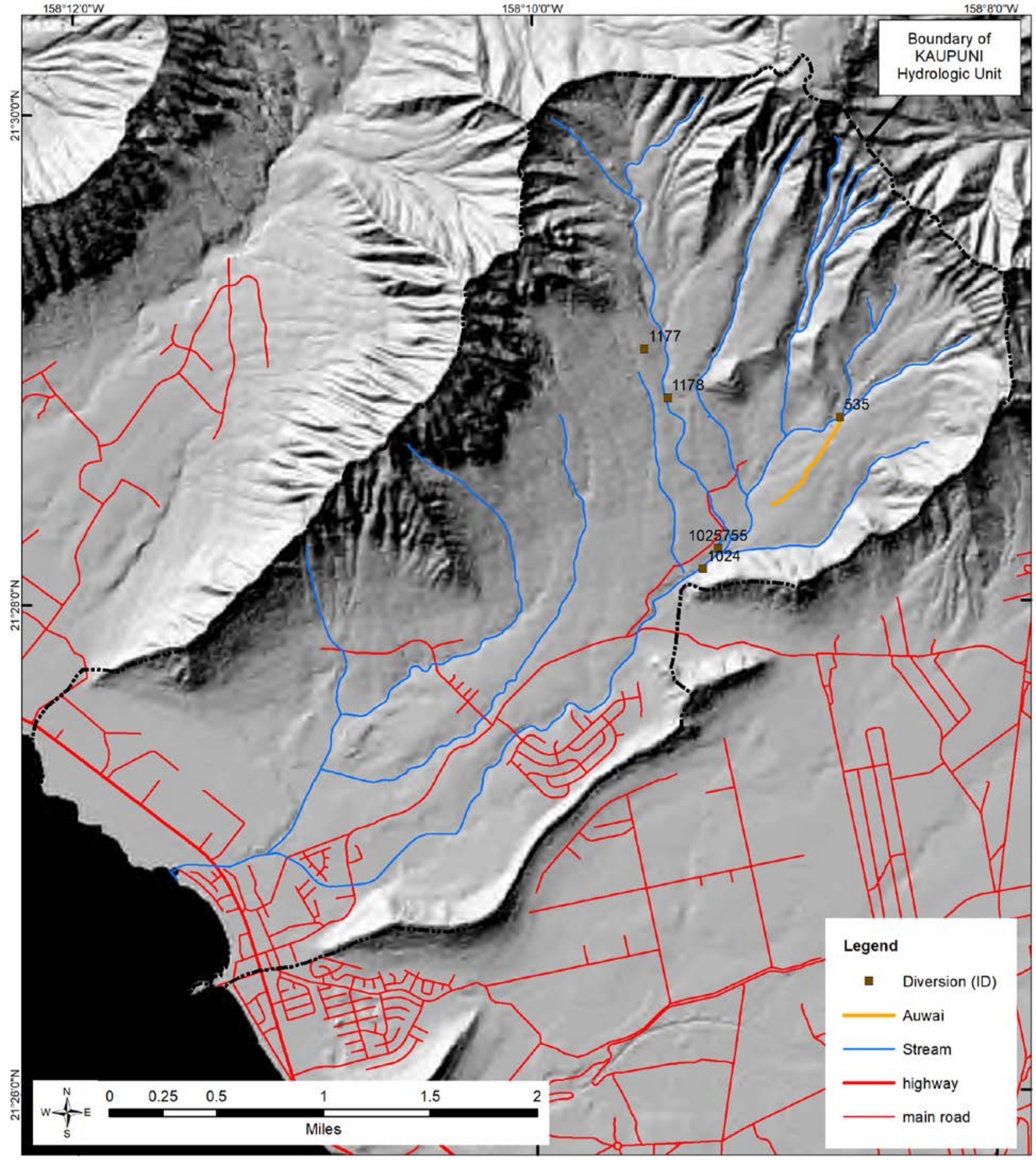


Figure 1-6. Major and minor roads for the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning 2020)



2.0 Unit Characteristics

Geology

The island of Oahu was built by the coalescence of two shield volcanoes: the Waianae volcano on the western side and the Koolau volcano on the eastern side (Stearns, 1946). The Waianae volcano became dormant before the Koolau volcano, resulting in Koolau lava flows overtopping the eroded remains of the eastern facing slopes of the Waianae volcano. The former caldera of the Waianae volcano, centered in what is now Lualualei Valley, extended into Waianae Valley, with a well-defined rift zone extending to the northwest. A poorly defined rift zone is oriented to the northeast, while to the south of the caldera boundary, dike formations are less parallel and more radial. The principal shield-building phase of the Waianae Volcano is dominated by tholeiitic olivine basalt in the Lualualei Member of the Waianae Volcanics (approximately 3.9-3.55 million years old). Lualualei lavas are mainly exposed near Puu Heleakala and Puu o Hulu on the south side of Lualualei Valley, beyond the caldera boundary fault. At later shield-building stages which comprise the Kamaileunu member of the Waianae Volcanics (approximately 3.55-3.06 million years old), there is increasing variability in the composition of lava flows. One intercaldera eruption produced the Mauna Kuwale flow which now forms the interflueve between Waianae and Lualualei, with Kamaileunu basalts overlain by augite-hypersthene tholeiitic andesite and two additional flows of hornblende-biotite-hypersthene rhyodacite. Lower basalts are exposed with clear dikes and sills cutting through the sequence. A sequence of eruptions filled the caldera during this period.

Following the shield-building phase, the “alkali cap” of the Waianae volcano was produced by the Palehua member of the Waianae Volcanics (3.06-2.98 million years ago). These flows represent eruptions along the northwest and southeast trending rift zones. Before the end, the Waianae volcano returned to a brief basaltic eruption of the Kolekole Volcanics, extending from the young cones and flows at the southern end of the Waianae Range, Kolekole Pass area, and to Mt. Kaala, Pahole, and Kuaokala regions to the north. The end of the Palehua Volcanics Series is marked by a major erosional event called the submarine Waianae slump resulting in shifts in magma distribution within the volcano.

The permeability of volcanic rocks varies depending on the type of rock, amount of weathering, and the thickness. Most volcanic rocks on Oahu are typical of Hawaiian basalts, described as “microlithic or porphyritic igneous rock of a lava flow or minor intrusion, often vesicular or amygdaloidal and composed essentially of plagioclase, and pyroxene, with or without interstitial glass.” (Holmes 1920). If olivine is present, then the rock is termied olivine-basalt and most of the rocks on Oahu contain olivine phenocrysts. The lava flows range in thickness from 1 to 400 feet, but are usually less than 75 feet thick (Stearns and Vaksvik, 1935). Such lava flows can support large amounts of basal and high-elevation (both perched and dike-confined) groundwater. The subaerial, dike free shield-building igneous rocks comprise most lava flows and are generally highly permeable, with hydraulic conductivity ranging from hundreds to thousands of feet per day (Mink and Lau, 1980). As a result, the horizontal water table gradient is fairly low (~1 foot per mile).

By contrast, in regions where dikes intrude the lava flows, horizontal movement is impeded, limiting the overall permeability. Many lava flows on Oahu are fed by magma that rose through vertical cracks which then solidified to form dikes. The dikes impound rain water infiltrating down from the high elevation forest, changing the direction of flow from seaward (i.e., downslope) to a perpendicular direction (i.e., parallel with the dike complex), creating high-elevation water bodies that discharge into other complexes, into the basal aquifer, or into streams where incision has exposed the dike complex. The transmissivity of these dike structures tend to range from 2,000 to 13,000 gallons per day per foot as compared to 1.4 to 4.0 million gallons per day per foot in dike-free aquifer zones (Ferris et al., 1962). The most appreciable dike complexes arc around the Waianae caldera. The location of dikes, and especially of dike complexes (many, closely spaced dikes), control the movement of groundwater in the Waianae region (Stearns, 1946).

The Kaupuni hydrologic unit is located on the leeward side of the Waianae mountain range, just north of the former Waianae caldera. Waianae Valley is eroded into the western flank of the Mt. Kaala. The lava flows of the shield building Waianae Volcanics phase originated from the caldera or the rift zones and are characterized by high porosity and transmissivity (Visher and Mink, 1969). Numerous vertical dikes are found along the rift zone and along the interfluve, with limited distribution in the lateral margins. The upper reaches of Waianae Valley are situated in the marginal dike zone. Where incision has exposed these dikes, spring flow emenates, supporting continual surface flow. The shield-building phase from the Waianae Volcano ended approximately 3 million years ago with erosion and subsidence modifying the original volcano. As Waianae Valley formed, eroded sediments filled the valley floor.

The Kaupuni watershed and stream network are typical of leeward facing watersheds, with steep upper reaches draining amphitheater-shaped valleys forming narrow valleys among hilly terrain in the middle reaches. As the streams reach less sloping, lower-elevation areas they produced broader alluvial fans. The main rocks in this region consist of older alluvium, lava flows, sand and gravel, and beach deposits. The generalized surface geology of the Kaupuni hydrologic unit is depicted in Figure 2-1 and Table 2-1.

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

Name	Rock Type	Area (mi^2)	Percent of Unit
Older alluvium	Sand and gravel	4.824	51.94%
Waianae Volcanics	Talus breccia, Lava flows, Mauna Kuwale rhyodacite, Icelandite vent deposits	2.942	31.68%
Lagoon and reef deposits	Limestone and mudstone	0.920	9.91%
Alluvium	Sand and gravel	0.523	5.63%
Kolekole Volcanics	Lava flows	0.052	0.56%
Beach deposits	Beach deposits	0.027	0.29%

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 Kaupuni hydrologic unit, soils are dominated by rock land, stony land, and lualualei groups (Table 2-2). Soils are predominantly in the Group D hydrologic unit (45.4%) with a high content of clay loam, silty clay loam, or clay, resulting in a high runoff potential. Group C soils (36.7%) make up the second the largest contributor, while Group B soils (17.4%) consisting of silty loam or loam with moderate infiltration rates are moderately permeable with slow to medium runoff and a slight to moderate erosion hazard (U.S. Department of Agriculture, National Resource Conservation Service, 1986). Finally, Group A soils (0.3%) with high infiltration rates are composed of sandy or sandy loam soils make up the rest. Hydrologic soils groups for the Kaupuni hydrologic unit are identified in Figure 2-2.

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

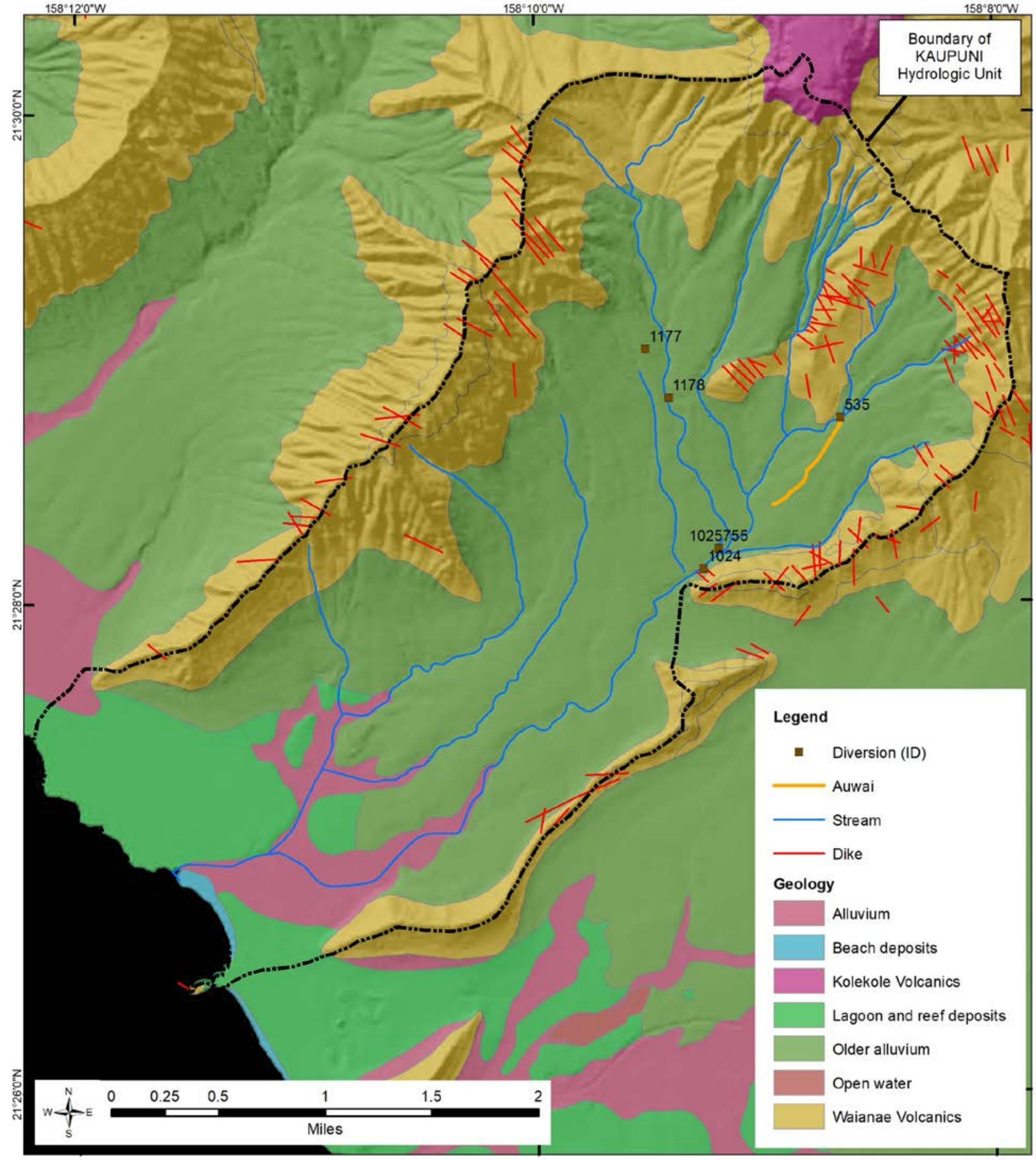


Table 2-2. Area and percentage of soil types for the Kaupuni hydrologic unit, Oahu. (Source: Soil Survey Saff, 2020)

Soil Series Unit	Hydrologic Soil Group	Area (mi^2)	Percent (%)
Rock land	D	4.662	25.08%
Stony land	C	4.514	24.29%
Lualualei	D	2.712	14.59%
Tropohumults	C	1.98	10.65%
Stony steep land	B	1.148	6.18%
Pulehu	B	1.144	6.16%
Coral outcrop	D	1.028	5.53%
Ewa	B	0.866	4.66%
Hanalei	C	0.324	1.74%
Mokuleia	B	0.08	0.43%
Beaches	A	0.064	0.34%
Keaau	D	0.028	0.15%
Water > 40 acres		0.024	0.13%
Alakai	D	0.012	0.06%

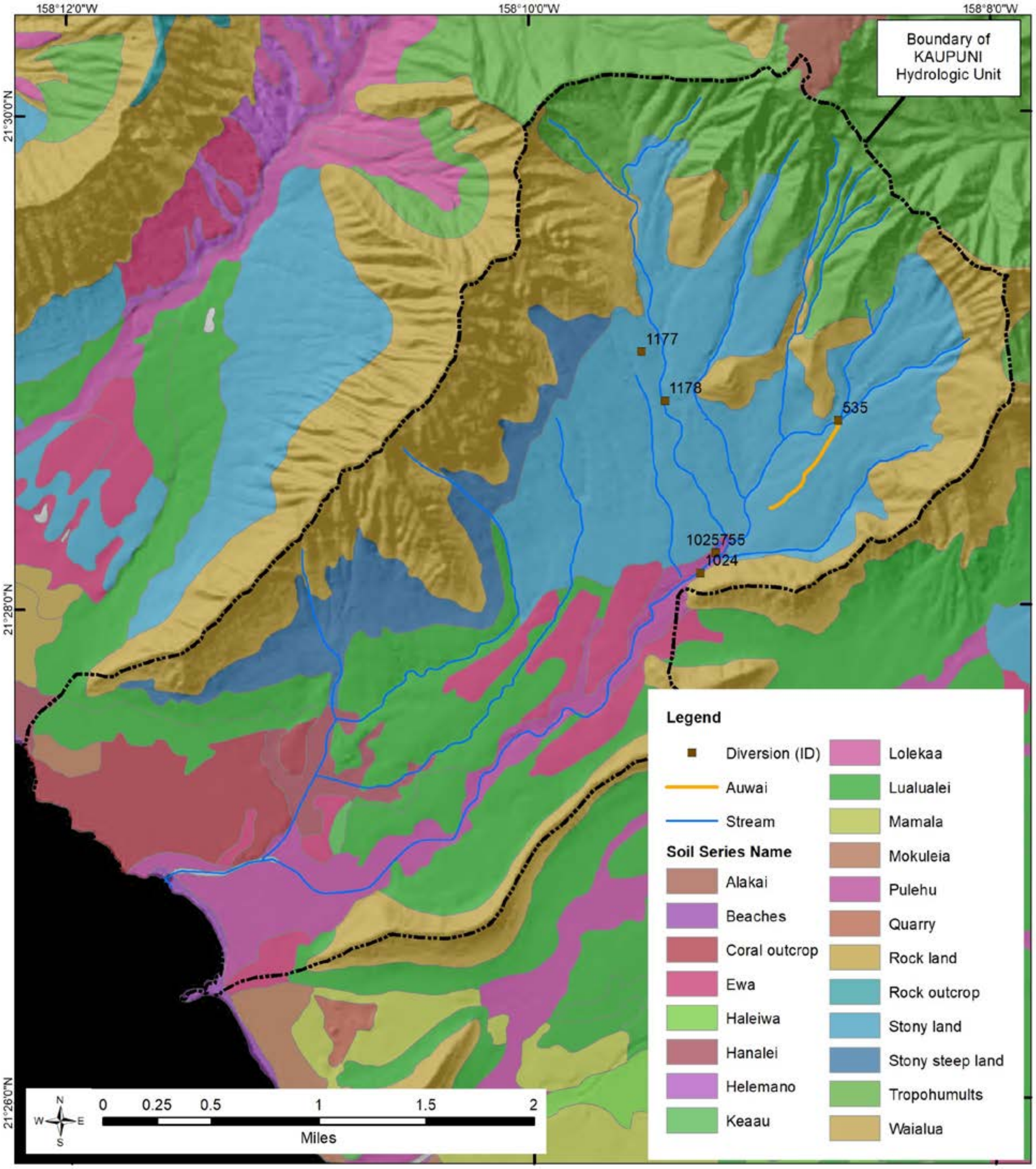
Rainfall

The Koolau and Waianae Mountains are the driving force affecting the distribution of rainfall on Oahu, with rainfall affected by the orographic[1] 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 occurs below the elevation where cloud height is restricted by the temperature inversion (Scholl 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 (Engott et al., 2017). Above this 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).

[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.

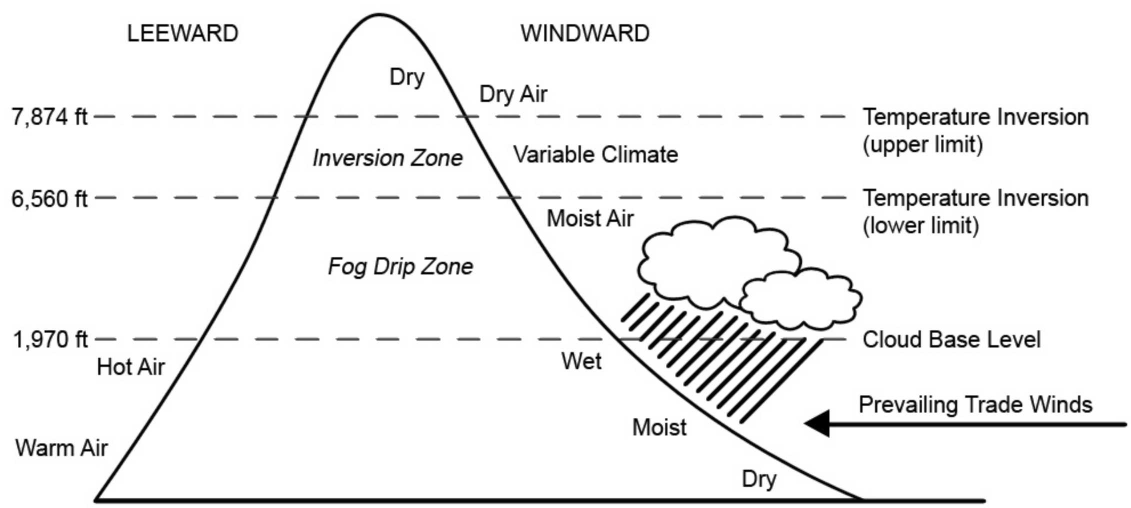
Figure 2-2. Soil series classification of the Kaupuni hydrologic unit, Oahu. (Source: Soil Survey Staff, 2020)



A majority of the mountains in Hawaii 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. Mt. Kaala is the tallest peak (4,025 feet a.s.l) in the Waianae range, situated along the cliffs of Waianae Valley and influences rainfall due to its position in the trade winds. 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. The position of the peak lies in the cloudy layer below the trade wind inversion resulting in substantial rainfall in the region. Mean annual rainfall measured in Waianae Valley (station 802; elevation 330 feet; active from 1930-1968) was 26.4 inches and measured at Mt Kaala (station 844; 4015 feet; active from 1932-present) is 81.5 inches (Giambelluca et al. 2013). The fog drip zone on the windward side of islands extends from the cloud base level at 1,970 feet to the lower limit of the most frequent temperature inversion base height at 6,560 feet (Giambelluca and Nullet, 1992).

The Kaupuni hydrologic unit is situated on the leeward side of the Waianae Mountains and as such receives little orographic rainfall, although the orographic rainfall on the windward side contributes to higher rainfall in the upper elevations as the winds blow precipitation across the peak (Figure 2-4). The high spatial variability in rainfall is evident by the large variation in mean annual rainfall across the hydrologic unit. For the whole hydrologic unit, mean annual rainfall averages 40.6 inches, ranging from 21.4 to 73.4 inches. Above 2000 ft, rainfall is highest during the months of November to February, where the mean monthly rainfall varies from 6.65 to 8.95 inches (Table 2-3).

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



Shade (1999) used the monthly fog drip to rainfall ratios for the windward slopes of Mauna Loa on the Island of Hawaii (Table 2-3) to calculate fog drip contribution to the water-budget in windward East Maui. The fog drip to rainfall ratios were estimated using: 1) the fog drip zone boundaries for East Maui (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 Hawaii (Juvik and Nullet, 1995). This method was used to determine the contribution of fog drip in the Kaupuni 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 12.9 percent of Kaupuni (1.202 square miles) lies in the fog drip zone based on elevations greater than 2000 feet. The total contribution from fog drip to the annual water budget of the upper elevations based on percent of fog drig from monthly rainfall is about 23.7 percent (19.16 inches versus 80.82 inches) of the upper (>2,000 ft) watershed, assuming the same ratios apply here (Table 2-3). The total estimated mean annual contribution of fog drip to the Kaupuni hydrologic unit is about 160.62 millon gallons or about 0.44 mgd.

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 Kaupuni Hydrologic Unit based on elevations greater than 2000 feet and equivalent ratios.

Month	Ratio (%)	Mean Rainfall (in)	Contribution (in)
January	13	8.95	1.16
February	13	6.65	0.86
March	13	5.67	0.74
April	27	4.19	1.13
May	27	3.44	0.93
June	27	2.48	0.67
July	67	2.75	1.84
August	67	3.37	2.26
September	67	3.55	2.38
October	40	5.55	2.22
November	40	6.89	2.76
December	27	8.17	2.21

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. In the Kaupuni hydrologic unit, average annual solar radiation ranged from 160.2 to to 210.9 W/m^2 per day (Figure 2-5). It is greatest at the coast and decreases toward the uplands, where cloud cover is more of an influence (Giambelluca et al., 2014).

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

[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.

evaporation rates are generally associated with greater net radiation, high wind speed and surface temperature, and lower humidity.

Potential evapotranspiration (PET) is the reate of water lost to the atmosphere when 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 Hawaii 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 Hawaii, evaporation generally decreases with increasing elevation below the temperature inversion[4] and the cloud layer (Figure 2-6). 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 Hawaii. 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. The PET in Kaupuni (Figure 2-6) averages 125.9 inches and ranges from 71.1 to 254.7 inches (Giambelluca et al. 2014). Annual actual evapotranspiration for the Kaupuni hydrologic unit ranges from 23.3 inches to 46.7 inches per year, with an average of 27.2 inches per year.

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.

[4] Temperature inversion is when temperature increases with elevation.

Figure 2-4. Mean annual rainfall and zone of fog drip in the Kaupuni hydrologic unit, Oahu. (Source: Giambelluca et al., 2013)

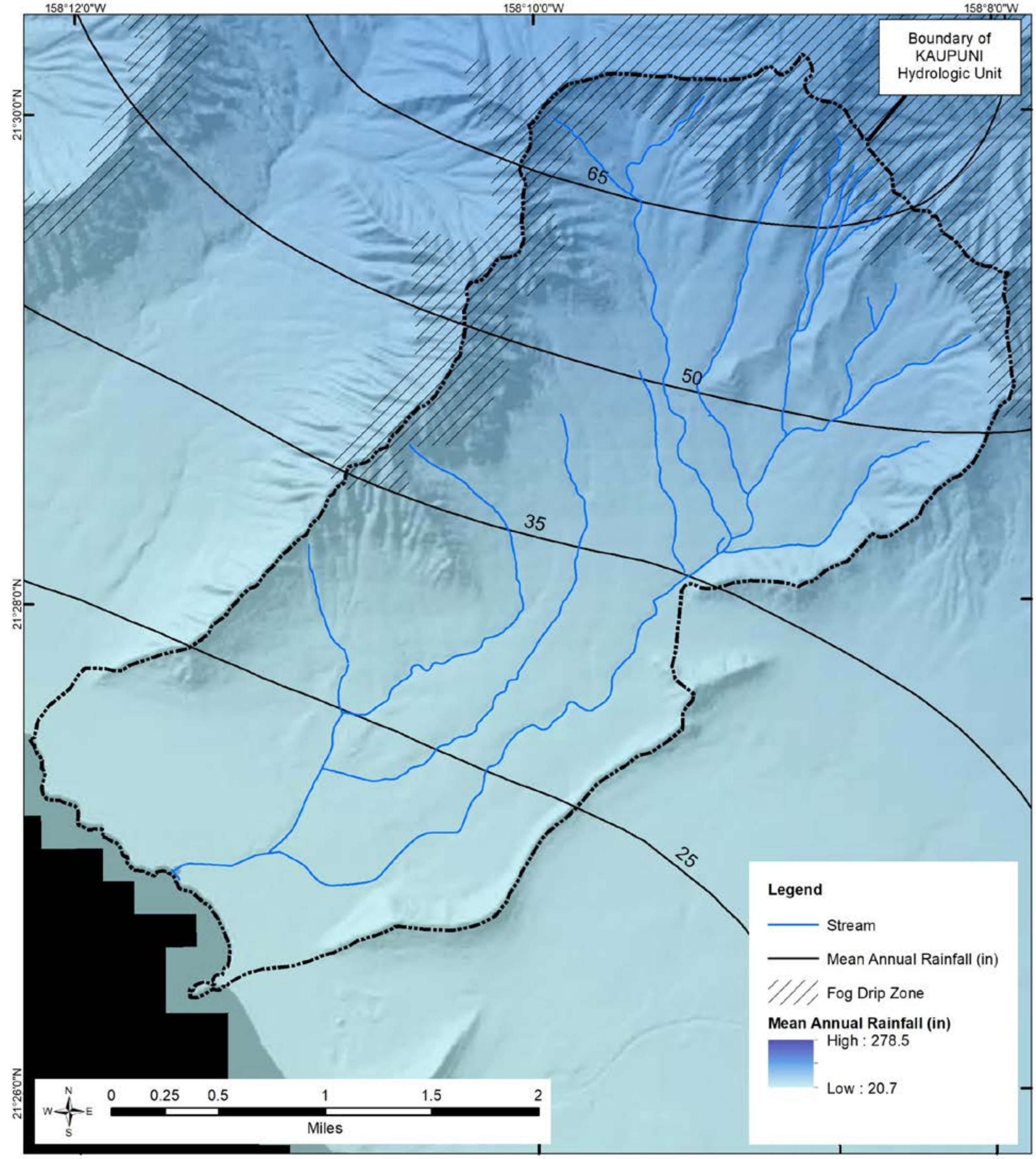


Figure 2-5. Mean annual solar radiation of the Kaupuni hydrologic unit, Oahu. (Source: Giambelluc et al., 2014)

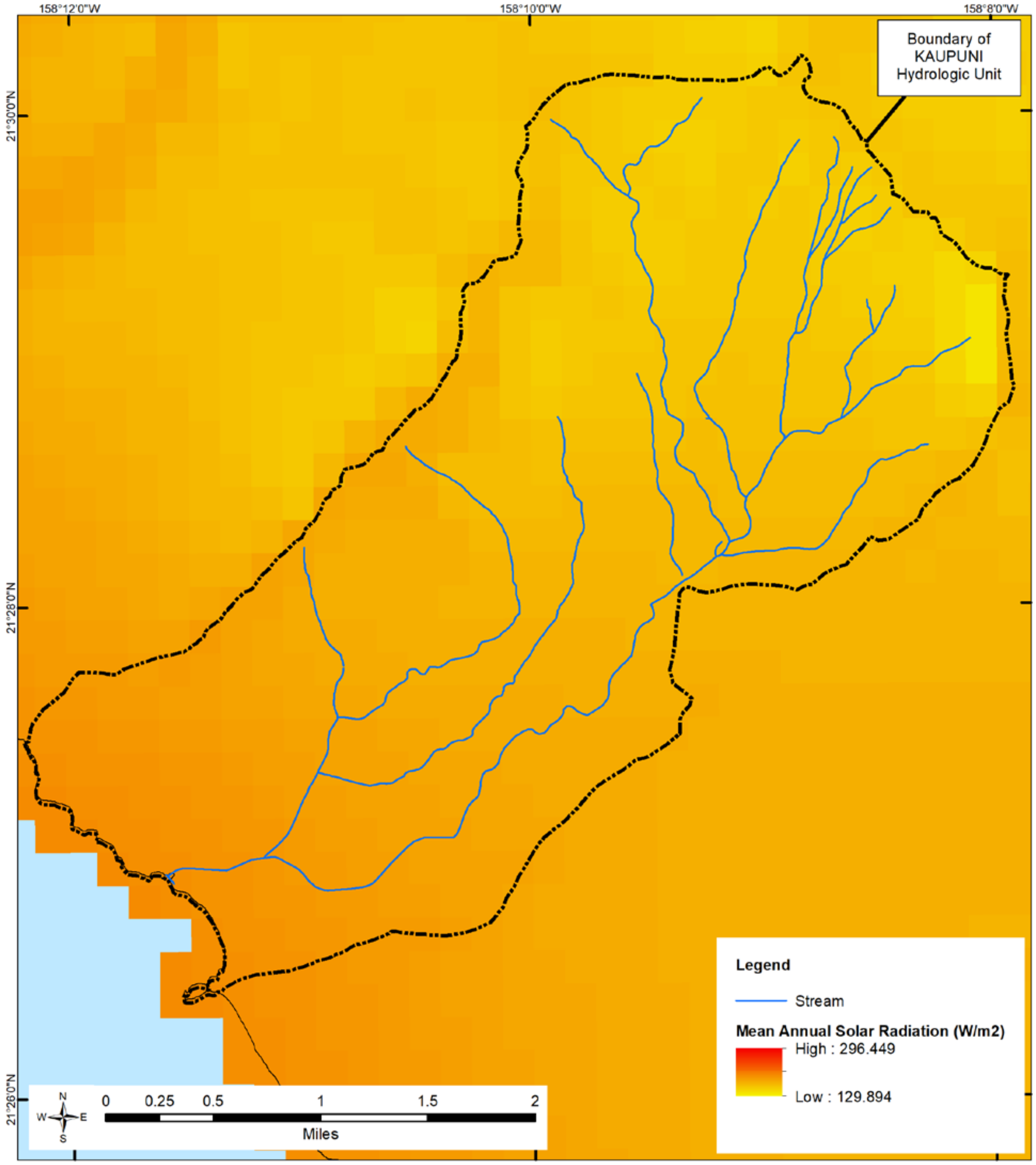
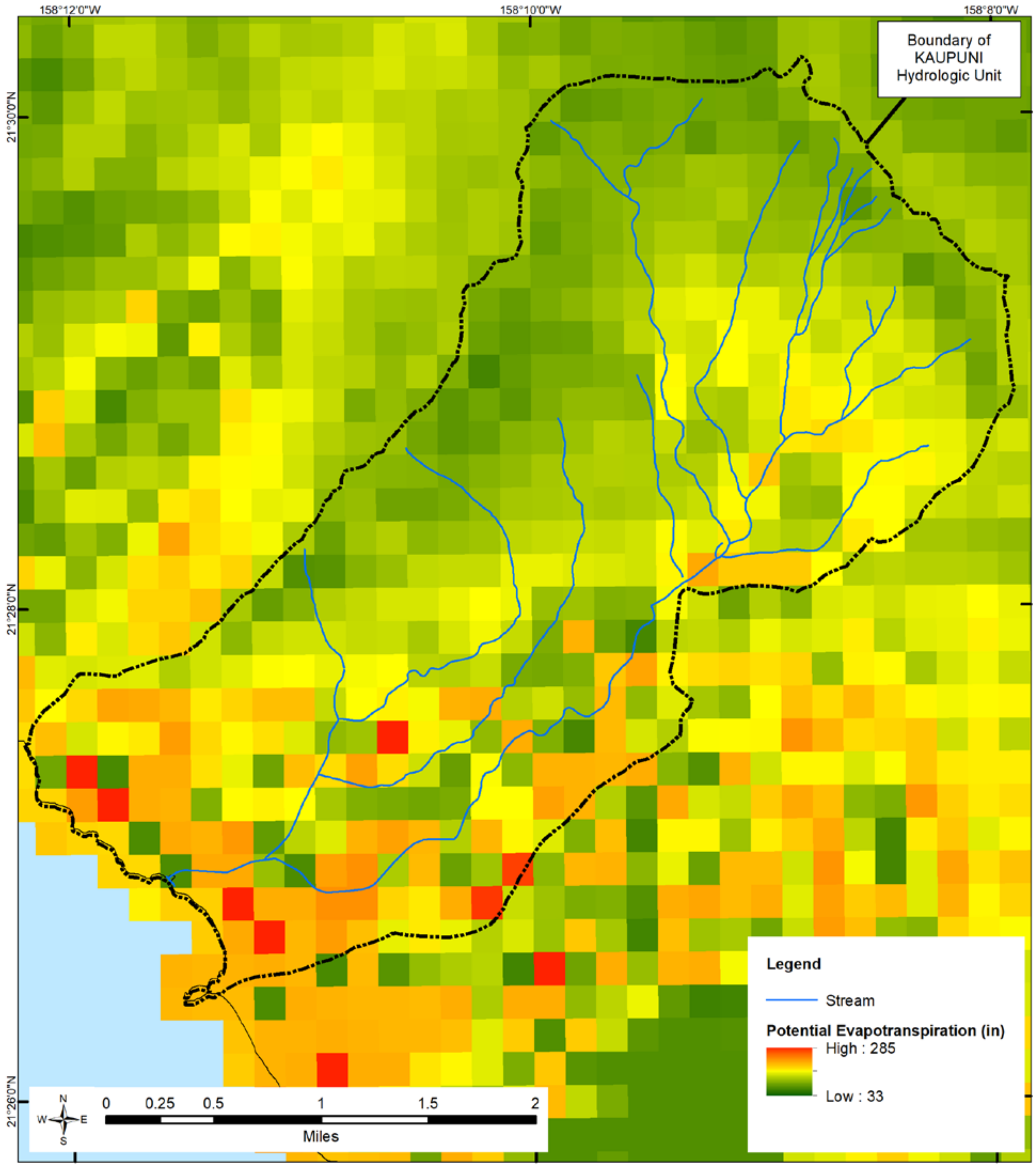


Figure 2-6. Mean annual potential evapotranspiration (Penman-Monteith method) for Kaupuni hydrologic unit, Oahu. (Source: Giambelluca et al., 2014)



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, 44.8 percent of the land in Kaupuni (4.171 square miles) was designated as agriculture and 44.6 percent of the land (3.919 square miles) as conservation (State of Hawaii, Office of Planning, 2015d). Only a small portion of the hydrologic unit is designated as urban (0.975 square miles, 10.5 percent) and none as rural (Figure 2-7).

Land Cover

Land cover for the hydrologic units of Kaupuni 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 Kaupuni, e.g., forest, shrub, developed areas, and wetlands (Table 2-4, Figure 2-8). 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 2-9).

Based on the two land cover classification systems, the land cover of Kaupuni consists mainly of urban development and evergreen forest, grassland, and scrub areas dominated by alien vegetation. There is minimal wetland and little native vegetation in the unit.

The land cover maps (Figures 2-8, 2-9) provide a general representation of the land cover types in the Kaupuni hydrologic unit. 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 with reference to the cultivation of commercial crops. At small scales, there may be land cover types (e.g., crop cultivation) that is not pick up by the satellites such as tropical flowers, dryland (and some wetland) taro, sweet potato, banana, and papaya.

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 Hawaii. 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 Hawaii 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 Kaupuni hydrologic unit, Oahu. (Source: National Oceanographic and Atmospheric Agency, 2015)

Land Cover	Description	Area (mi^2)	Percent of Unit
Evergreen Forest	Areas where more than 67% of the trees remain green throughout the year	3.542	38.0%
Grassland	Natural and managed herbaceous cover	2.643	28.4%
Scrub	Areas dominated by woody vegetation less than 6 meters in height	1.258	13.5%
Low Intensity Developed	Constructed surface with substantial amounts of vegetated surface	0.700	7.5%
Medium Intensity Developed	Areas with a mixture of constructed materials and substantial amounts of vegetation	0.460	4.9%
Developed Open Space	Areas mostly managed grasses or low-lying vegetation planted for recreation, erosion control, or aesthetic purposes	0.316	3.4%
High Intensity Developed	Contains significant land area covered by concrete, asphalt and other constructed materials with less than 20% vegetation	0.194	2.1%
Cultivated	Areas intensely managed for the production of annual crops	0.107	1.2%
Bare Land		0.049	0.5%
Water		0.031	0.3%
Palustrine Forested Wetland	Included tidal and nontidal wetlands dominated by woody vegetation 5 meters in height or more	0.009	0.1%
Palustrine Emergent Wetland	Includes tidal and nontidal wetlands dominated by persistent emergent vascular plants, mosses or lichens	0.006	0.1%
Unconsolidated shore		0.001	0.01%

Peak floods in Kaupuni have been monitored at one location in the watershed (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 Kaupuni Stream at the Farrington Highway near the mouth are estimated as 555, 1410, 2300, 5340, 7140 cfs, respectively. 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 most of the urbanized areas of Kaupuni hydrologic unit as Flood-risk Zone X, with an area of minimal flood hazard or reduced flood risk due to a levee (Figure 2-10). Approximately 7.57 square miles (81.3%) is designated Flood Zone D, where there are possible but undetermined flood hazards. Another 1.525 square miles (16.4%) is designated Flood Zone X as an area of minimal flood hazard and 0.098 square miles (1.05%) designated as flood zone AE with a 1% chance of flooding floodplains or shallow flooding due to ponding (Figure 2-10).

Table 2-5. HI-GAP land cover classes and area distribution for the combined Kaupuni hydrologic unit, Oahu. (Source: HI-GAP, 2005)

Land Cover	Area (mi^2)	Percent of Unit
Alien Shrubland	2.315	24.87%
Alien Grassland	1.803	19.37%
Alien Forest	1.639	17.61%
Developed, Low Intensity	1.277	13.71%
Kiawe Forest and Shrubland	0.705	7.57%
Cultivated Cropland	0.628	6.75%
Mixed Native-Alien Forest	0.574	6.16%
Developed, High Intensity	0.139	1.49%
Ohia Forest	0.082	0.88%
Very Sparse Vegetation to Unvegetated	0.050	0.53%
Open Ohia Forest	0.032	0.34%
Closed Ohia Forest	0.020	0.22%
Uluhe Shrubland	0.011	0.12%
Undefined	0.010	0.11%
Native Wet Cliff Vegetation	0.010	0.10%
Open Water	0.010	0.10%
Uncharacterized Shrubland	0.004	0.04%
Mixed Native-Alien Shrubs and Grasses	0.001	0.01%

Table 2-6. The magnitude of peak flows with specific recurrence intervals based on measured peaks flows at select monitoring locations in the Kaupuni hydrologic unit, Oahu. (Source: USGS, 2020)

station ID	station name	period of record	peak flood magnitudes (cfs) 2-year	5-year	10-year	50-year	100-year
16211800	Kaupuni Str at alt 374 ft	1961-2004	197	840	1650	4700	6540

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.

Figure 2-7. State land use district boundaries of the Kaupuni hydrologic unit, Oahu (Source: State of Hawaii, Office of Planning, 2015d).

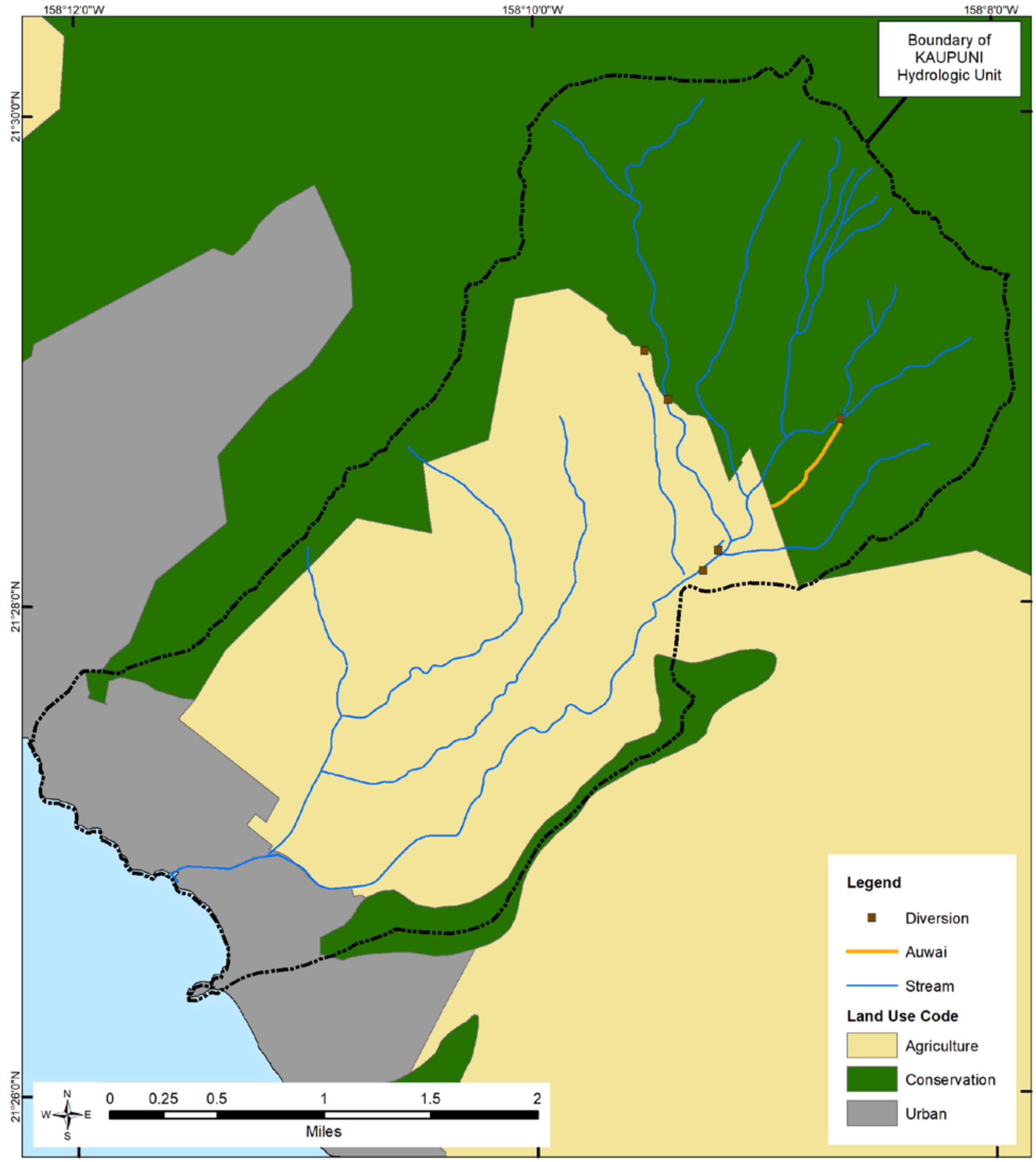


Figure 2-8. C-CAP land cover of the Kaupuni hydrologic unit, Oahu. (Source: NOAA, 2005).

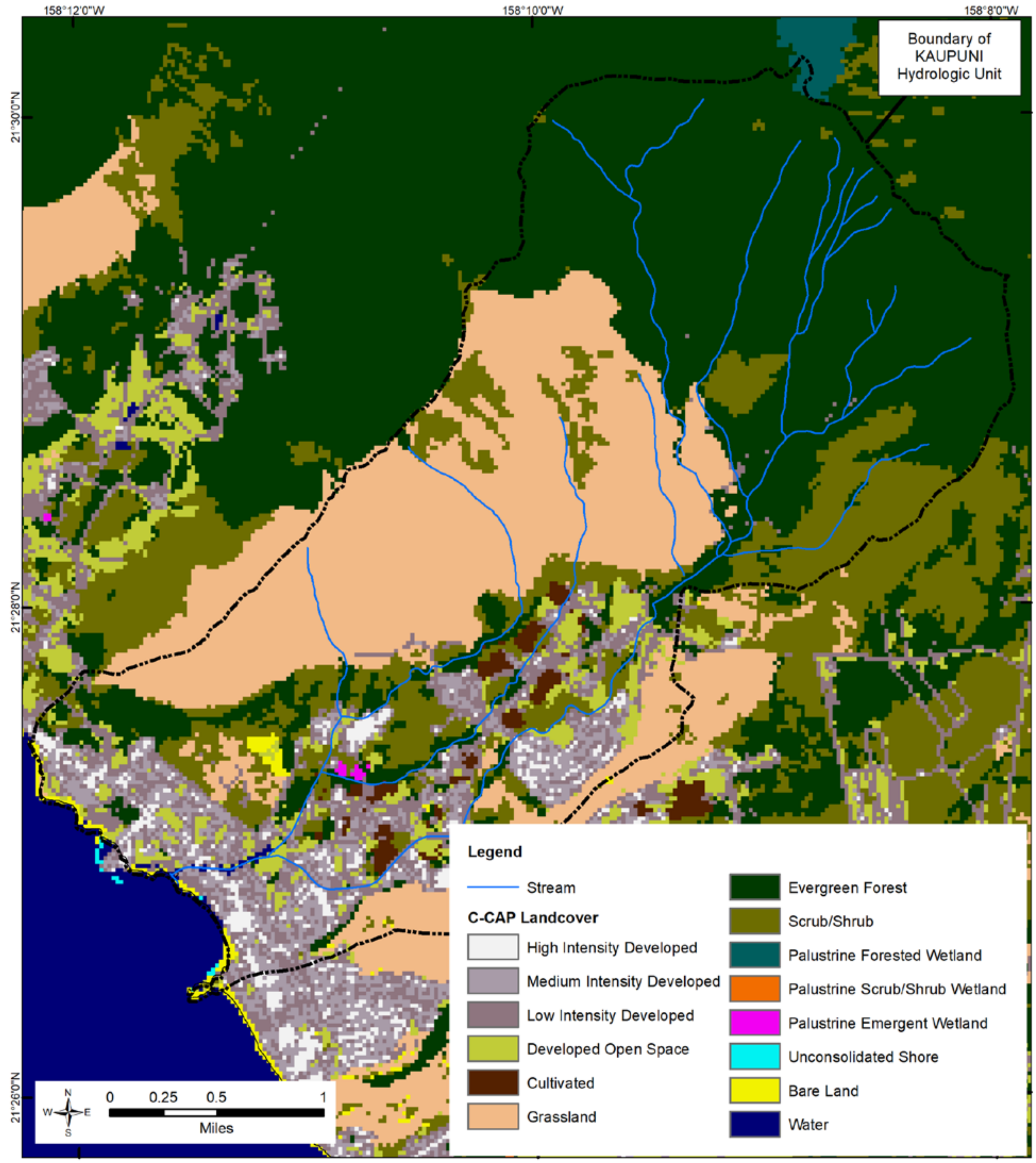
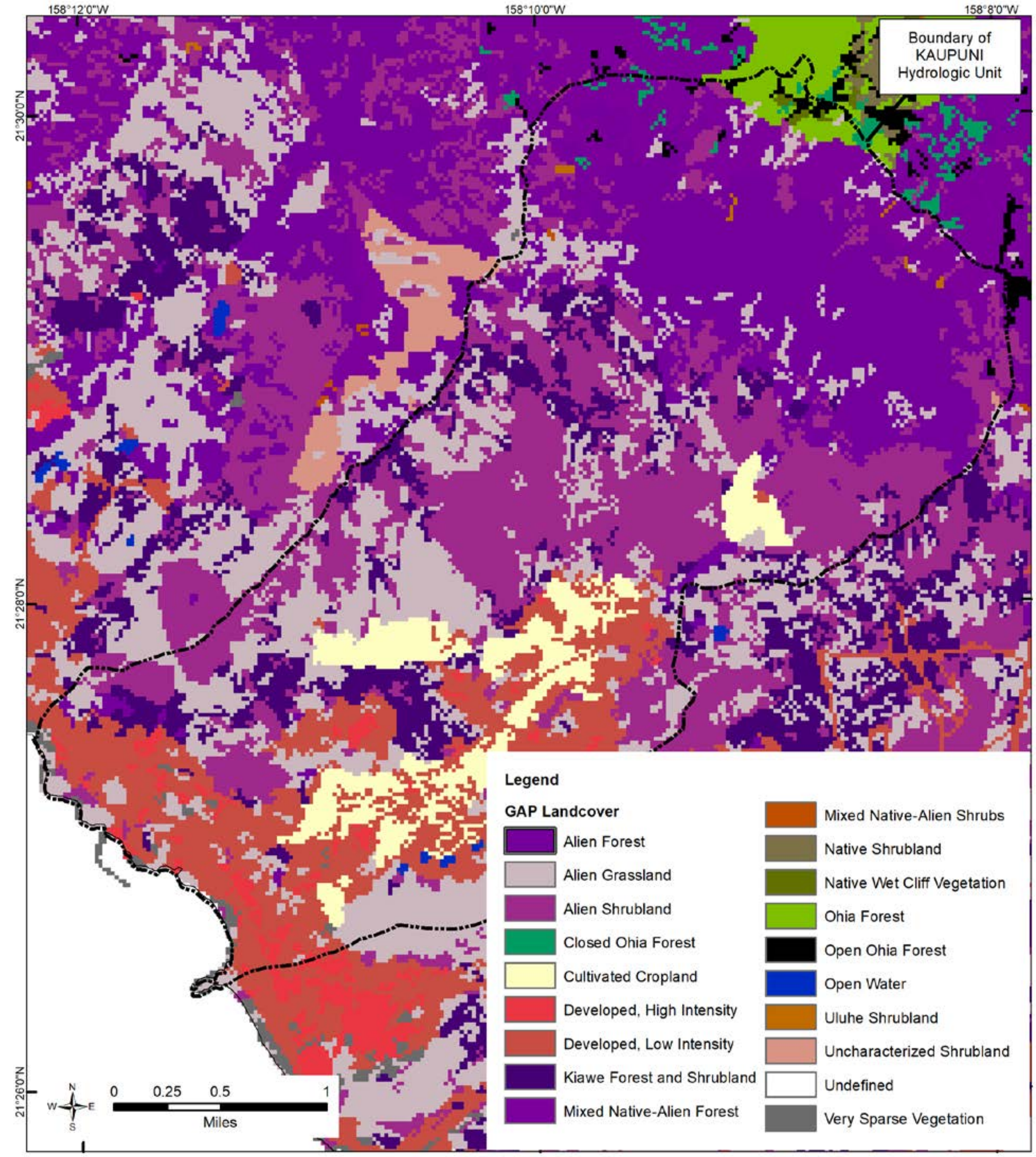


Figure 2-9. Hawaii GAP land cover classes of the Kaupuni hydrologic unit, Oahu (Source: USGS, 2001).



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 groundwater 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.

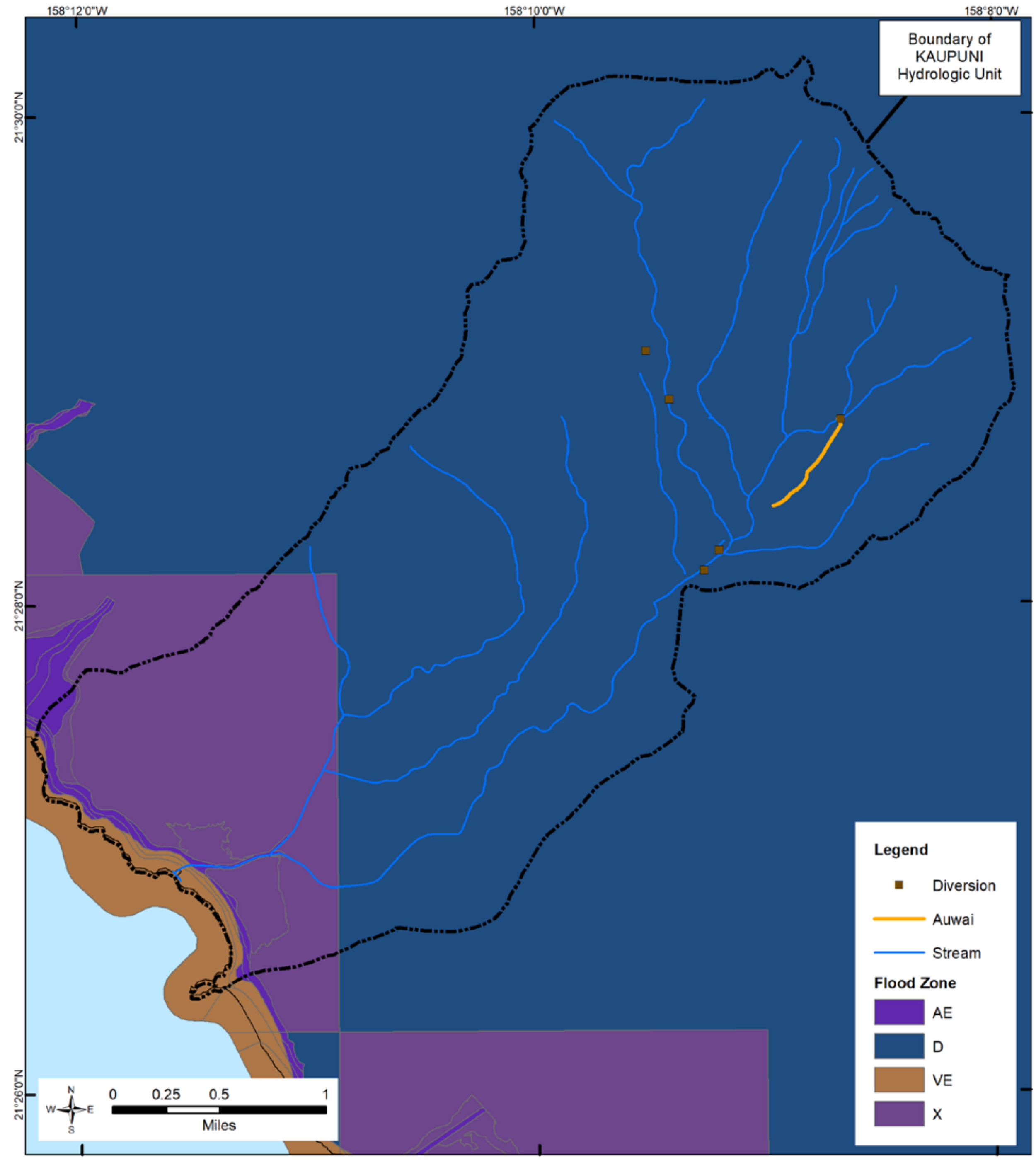
Droughts have affected the islands throughout Hawaii's recorded history. The most severe events of the recent past years are associated with the El Niño phenomenon. In January 1998, the National Weather Service's network of 73 rain gauges throughout the State did not record a single above-normal rainfall, 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.

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 Hawaii. It quantifies rainfall deficit for different time periods, i.e. 3 months and 12 months. Results of the study for Oahu are summarized in Table 2-7. Based on the 12-month SPI, the Central Oahu regions have the greatest risk to drought impact on Oahu because of its dependence on surface water sources, limited rainfall, or relatively high drought frequency and high population density. The growing population in the already densely populated area further stresses the water supply. Flow in Kaupuni Stream may decline during low rainfall periods (hydrological drought), although the Kaupuni watershed is not considered vulnerable to drought. There is an increase in wildland fire risk due to drought in the Kaupuni hydrologic unit, with dry invasive grasses or trees prone to wildfire.

Table 2-7. Drought risk areas for Oahu. (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	Central Oahu (Mililani/Waipio)	Central Oahu	Ewa, Haleiwa
Agriculture and Commerce	Central Oahu (Kunia to Helemano)	Central Oahu (Kunia)	North of Helemano
Environment, Public Health and Safety	Central Oahu (Mililani)	Central Oahu (Mililani and Kunia)	Waipio / Pearl City

Figure 2-10. FEMA flood zone regions in the Kaupuni hydrologic unit, Oahu (Source: Federal Emergency Management Agency, 2014).



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 aquifers and streams in the Kaupuni hydrologic unit.

Streams in Hawaii

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 Hawaii 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 groundwater is unlikely. Another way that groundwater 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. This can discharge groundwater onto the land surface, directly into the stream, or into the ocean. Figure 3-1 and Figure 3-2 illustrate how valley incision exposes a high-level, dike-confined water, a perched water body, or basal groundwater sources that contribute directly to streamflow.

The USGS has maintained a variety of continuous gaging stations over time (Figure 3-8). These stations have monitored the regulated flow of water in Kaupuni Stream (station 16211800) or the flow of water in ditches (stations 16211850). Historic flow data from these stations are available in Table 3-1. Thelocation of these stations is provided in Figure 3-11.

Table 3-1. Selected streamflow parameters and duration discharge exceedance values for the given period of record in the Kaupuni hydrologic unit, Oahu, Hawaii. (Source: USGS 2020)
[Flows are in cubic feet per second (million gallons per day]

station ID	station name	period of record	mean daily flow	14-day low flow	discharge (Q) for a selected percentage ($_{xx}$) discharge was equaled or exceeded			
					Q_{50}	Q_{70}	Q_{90}	Q_{95}
16211800	Kaupuni Str at alt 374 ft	1960-1972	1.13 (0.73)	0.00 (0.00)	0.25 (0.16)	0.11 (0.07)	0.00 (0.00)	0.00 (0.00)
16211850	Puea Mauka Ditch	1960-1967	0.58 (0.37)	0.26 (0.17)	0.50 (0.32)	0.45 (0.29)	0.31 (0.20)	0.31 (0.20)

Figure 3-1. Conceptual models of the occurance and flow of groundwater. (A) General model for Oahu with the low-permeability caprock composed of coastal-lain sediments and rejuvenated volcanic rocks. (B) Young shiled volcano with no confining caprock before dikes have been exposed by erosion. (Source: Izuka et al., 2018)

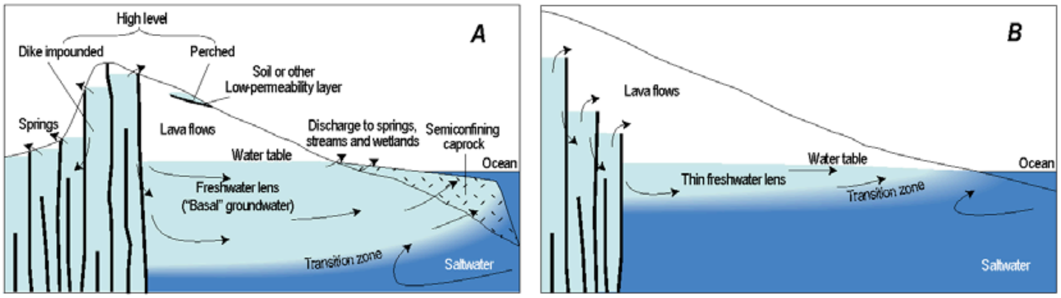
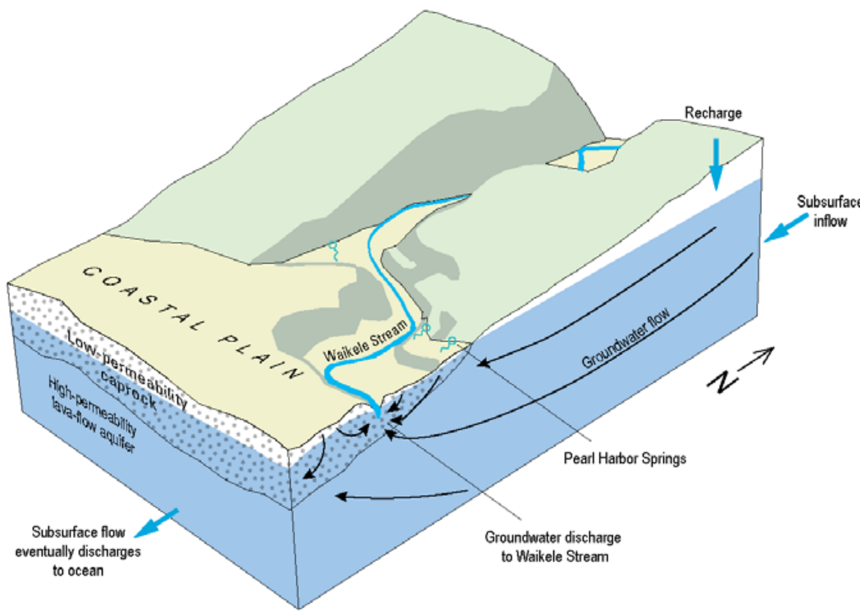


Figure 3-2. Models of the relation between groundwater discharge in and near semi-confining caprock overlying the high permeability lava flow on Oahu. (Source: Izuka et al., 2018).



Groundwater

Groundwater is an important component of streamflow as it constitutes the base flow[1] 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.

[1] 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).

In Hawaii, 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. 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 Oahu, dikes impound water to as high as 2,000 feet above mean sea level (Nichols et al. 1996). 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 (Engott et al., 2017). 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. By contrast, in breccia deposits, the water-bearing properties are dependent on the degree of weathering and cementation. Lava flows of the Waianae Volcanic Series are generally thin, tholeiitic shield-stage lavas that are subdivided into well-defined areas by geohydrologic barriers. In some areas a caprock of sedimentary deposits overlies and confines the aquifers. The Waianae rift zone on Oahu separated the central region with it's three groundwater flow systems (north-central system, Schofield Plateau, and south-central system) from the western exterior flow system (Nichols et al. 1996). The Waianae Volcano's Kolekole Volcanics and Waianae Volcanics have hydraulic conductivities of 500-5,000 feet per day in dike-free lava, but as low as 1-500 ft per day in dike complexes and breccia (Takasaki and mink, 1982).

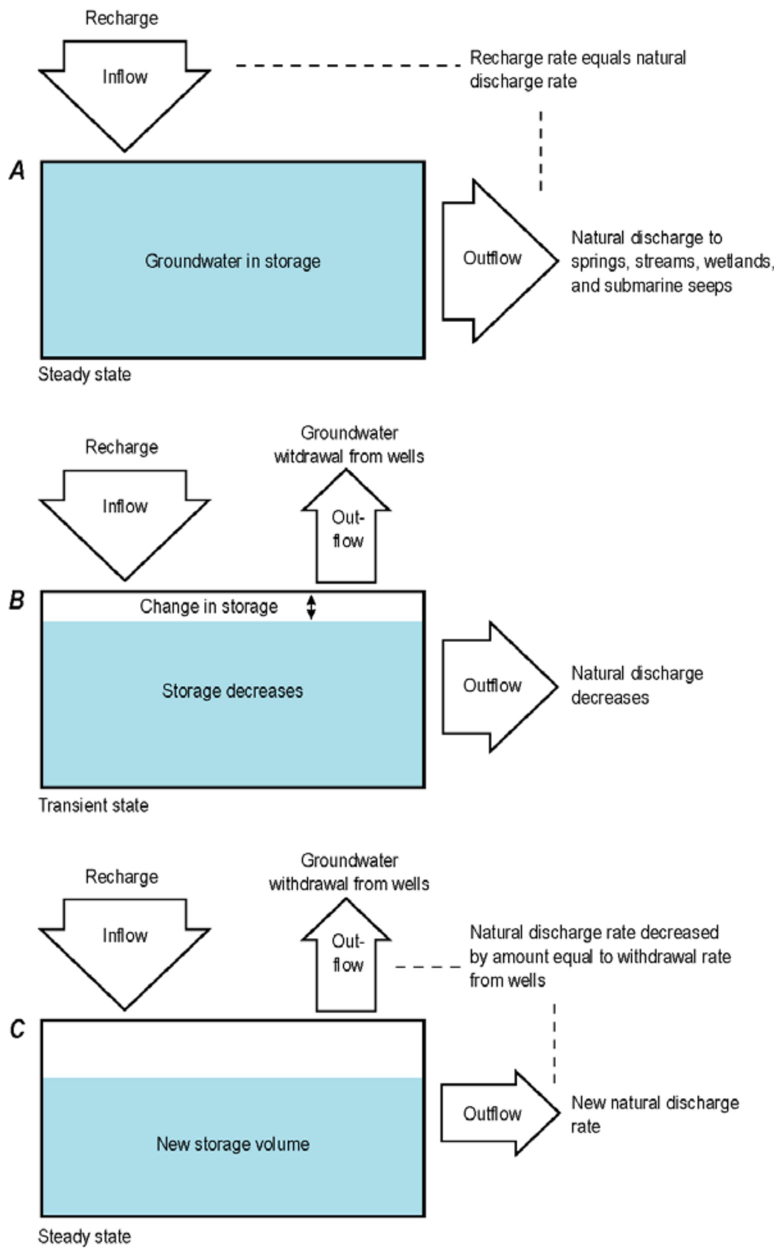
The Waianae Range lies in the rainshadow of the Koolau Range and as such, receives much less precipitation than the Koolau Range from tradewind showers. A general overview of the groundwater occurrence, movement, and interactions with surface water in this area is described in Nichols et al. (1996) and Engott et al. (2017) and illustrated in Figure 3-3. The geology of Waianae Valley is a heterogeneous composition of rocks from various volcanic events with the basalt subdivided into three members (Stearns and Vaksvick, 1935). The lower member is composed of pahoehoe basalt ranging from dense to vesicular of high permeability, interlaced with low permeable interconnected dikes. There is a distinct angular unconformity between the lower and middle member but no unconformity between the middle and upper member. Due to the low permeability dikes, there is substantial lateral movement of groundwater in the upper elevations of the valley which commonly discharges into streams and has been developed by constructing horizontal tunnels.

Wells in the Kaupuni Hydrologic Unit

The Waianae Aquifer System is located in the Waianae Aquifer Sector on the leeward side of Oahu and includes the surface water hydrologic unit of Kaupuni. Other aquifer systems in the sector include Keaau, Makaha, Lualualei, and Nanakuli. The 2019 update to the Water Resources Protection Plan revised the sustainable yield of the Waianae Aquifer Sector based on updated information from 16 mgd to 13 mgd (State of Hawaii, 2019). From 2010 to 2019, the Honolulu Board of Water Supply (HBWS) mean pumpage from the aquifer sector was 10.27 mgd, with a median of 10.20 mgd, and a maximum of 14.44 mgd. The total installed pump capacity in the Waianae aquifer system is 4.766 mgd, but does not include the flow from development tunnels, with a total of 74 wells. The location of wells in the Kaupuni hydrologic unit are depicted in Figure 3-7 and detailed information for each well is specified in Table 3-2.

Total monthly pumpage from the Waianae aquifer system by the HBWS is provided in Figure 3-4 and summarized in Tables 3-3. Some of the high elevation groundwater withdrawls in Kaupuni are from development tunnels used by the (HBWS). The HBWS water distribution system delivers water to hydrologic units in the Waianae Sector from areas outside of the area (e.g., Pearl Harbor Aquifer Sector).

Figure 3-3. Conceptual diagram of generalized groundwater movement on Oahu for A) steady state before groundwater withdrawal; B) transiet state before equilibrium during withdrawal; C) stead state following equilibrium with groundwater withdrawal. (Source: Engott et al., 2015)



The HBWS Waianae Valley (Kunesh) Development Tunnel is a 10,300 feet long tunnel that withdrawals water at an elevation of 418 feet. The first 6,300 feet were built in 1948 and then extended to 10,300 feet in 1950. The tunnel cuts through 2,000 feet of alluvium and then 8,100 feet of basalt in the Waianae volcanic series, with 70 dikes mapped. As a result of tunnel construction, the higher elevation dike compartments, which supplied water to streams and development tunnels in the mauka areas, were drained of much of their water (Figure 3-8).

Table 3-2. Information of wells located in the Waianae Aquifer System (Source: State of Hawaii, Commission on Water Resource Management, 2020c).
[elevation values indicate feet above mean sea level; depth values indicate feet below ground elevation; -- indicates value is unknown; BWS = Board of Water Supply; ABD = abandoned; ABNLOS = abandoned lost; DON = domestic, DOA = Department of Agriculture; IRR = irrigation; IRRGC = golf course irrigation; MUNCO = municipal county; OBS = observation; SL = sealed; UNU = unused]

Well number	Well Name	Well Owner	Year drilled	Use	Ground elevation (feet)	Well depth (feet) or Tunnel Length (feet)	Installed pump capacity (mgd)
2710-002	Waianae	Mountain View Dairy, Inc	1958	IRR	48	80	--
2710-003	Waianae	Daniel Vancil	--	UNU	--	49	0.432
2710-004	Waianae Kai II	Mountain View Dairy, Inc	1988	UNU	102	150	--
2710-005	Toledo Dairy	David A & Carol J Souza Trust	1946	DOM	--	--	0.216
2710-006	Dug Well 3	Mountain View Dairy, Inc	1946	IRR	--	37	--
2710-007	Nitta	Jan Uesato	1955	IRR	--	54	0.072
2710-008	Schmidt 2006	Sunset Acres Joint Venture	2008	DOM	--	295	0.014
2711-001	Waianae	C & C Honolulu	1939	UNU	4	101	--
2711-002	Waianae	Ho Chinn	1950	UNU	24	42	--
2711-003	Waianae	USGS	1960	ABNLOS	12	210	--
2711-004	Waianae	USGS	1960	ABNLOS	12	30	--
2711-005	Hawaii Baptist	Stanley Togikawa	1985	UNU	--	30	--
2711-007	Waianae Kai 1	Mountain View Dairy, Inc	1988	UNU	110	30	--
2711-008	Dug Well 1	Makaha Valley, Inc	1946	AGRCP	--	32	--
2711-009	Dug Well 6	Makaha Valley, Inc	1946	UNU	30	44	--
2711-010	Gamulo	Marion S. Imaoka Trust	1954	IRR	--	50	--
2712-001	Waianae	Waianae Development	1919	AGRCP	30	180	--
2712-030	Kamaile 2	Honolulu BWS	1976	MUNCO	34	164	0.864
2712-031	Kamaile 1	Honolulu BWS	1976	MUNCO	51	182	--
2712-032	Waianae	SOH Dept of Education	1991	AGRAQ	8	51	0.216
2809-001	Waianae Valley	Honolulu BWS	1941	ABNLOS	353		
2809-002	Waianae Valley	Honolulu BWS	1942	OBS	681		
2809-003	Waianae Valley	Honolulu BWS	1942	UNU	664		
2809-004	Waianae Valley	Honolulu BWS	1942	UNU	664		
2809-005	Waianae Valley	House of Finance Inc.	1945	AGRLI	303		
2809-006	Waianae Tunnel	Honolulu BWS	1950	MUNCO	418	10,300	n/a
2809-007	Waianae Tunnel 18	Waianae Plantation	--	UNU	--	84	--
2810-001	Waianae Valley	Xian Huang	1945	UNU	293	355	0.216
2810-002	Waianae III-1	Honolulu BWS	1980	MUNCO	416	670	0.720
2810-003	Waianae III-2	Honolulu BWS	1990	MUNCO	416	782	0.720

Table 3-2. continued.

Well number	Well Name	Well Owner	Year drilled	Use	Ground elevation (feet)	Well depth (feet) or Tunnel Length (feet)	Installed pump capacity (mgd)
2908-001	Waianae Tunnel 1	Honolulu BWS	--	ABN	1,425	63	--
2908-002	Waianae Tunnel 2	Honolulu BWS	--	ABN	1,426	--	--
2908-003	Waianae Tunnel 6	Honolulu BWS	--	ABN	1,525	696	--
2908-004	Waianae Tunnel 6A	Honolulu BWS	--	ABN	1,485	198	--
2908-005	Waianae Tunnel 7	Honolulu BWS	--	ABN	1,409	15	--
2908-006	Waianae Tunnel 8	Honolulu BWS	--	ABN	1,385	350	--
2908-007	Waianae Tunnel 9	Honolulu BWS	--	ABN	1,010	360	--
2908-008	Waianae Tunnel 11	Honolulu BWS	--	ABN	1,370	388	--
2908-009	Waianae Tunnel 14	Honolulu BWS	--	ABN	1,709	397	--
2908-010	Waianae Tunnel 15	Honolulu BWS	--	MUNCO	1,399	310	--
2908-011	Waianae Tunnel 19	Honolulu BWS	1933	MUNCO	1,515	560	--
2908-012	Waianae Tunnel 3	Waianae Plantation	--	UNU	1,545	10	--
2908-013	Waianae Tunnel 4	Waianae Plantation	--	UNU	1,575	144	--
2909-001	Waianae Tunnel 16	Honolulu BWS	--	ABN	1,075	297	--
2909-002	Waianae I	Honolulu BWS	1981	MUNCO	1,152	980	0.288
2909-003	Waianae II	Honolulu BWS	1985	MUNCO	1,339	1,000	1.008
2909-004	Waianae Tunnel 17	Honolulu BWS	--	ABNLOS	1,200	--	--

Table 3-3. Groundwater pumpage from source wells for the Honolulu Board of Water Supply from the Waianae Aquifer System from 2000 to 2019. (Note: -- value is unknown , n/a = not applicable) [Flows iin million gallons per day, mgd]

well ID	well name	Pump capacity (mgd)	average monthly pumpage (mgd)	median monthly pumpage (mgd)	maximum monthly pumpage (mgd)
2909-002	Waianae I	0.288	0.089	0.066	0.379
2909-003	Waianae II	1.008	0.589	0.636	0.963
2908-003	Waianae Tunnel 6[2]	n/a	0.000	0.000	0.000
2908-010	Waianae Tunnel 15[1]	n/a	0.312	0.311	0.651
2908-011	Waianae Tunnel 19[2]	n/a	0.000	0.000	0.000
2810-002	Waianae III-1	0.720	0.250	0.278	0.740
2810-003	Waianae III-2	0.720	0.000	0.000	0.000
2712-030	Kamaile 2	0.864	0.197	0.156	0.837
2712-031	Kamaile 1	--	0.000	0.000	0.000
2809-003	Waianae Valley	--	0.000	0.000	0.000
2809-006	Waianae Tunnel	n/a	1.432	1.459	1.466
	Total =	3.6	2.869	2.906	5.036

[1]data available only from 2013-2020
[2]included with Tunnel 15 as battery prior to 2013 (data not shown)

The HBWS mauka battery of development tunnels which they rely upon for potable water supply (tunnels 6,15, and 19) are connected to a transmission pipeline. However, since 2013, water has been released below tunnel 19 and the junction between tunnel 6 and tunnel 19 needs repair, leaving only water from tunnel 15 currently utilized. Prior to 2014, the median, mean, and maximum reported flow from this battery was 0.587 mgd, 0.582 mgd, and 1.085 mgd, respectively (Figure 3-5).

Figure 3-4. Total reported monthly pumpage (million gallons per day, mgd) and 12-month moving average for Honolulu Board of Water Supply (BWS) wells and development tunnels in the Waianae aquifer system, Oahu. (Source: Source: State of Hawaii, Commission on Water Resource Management, 2020c).

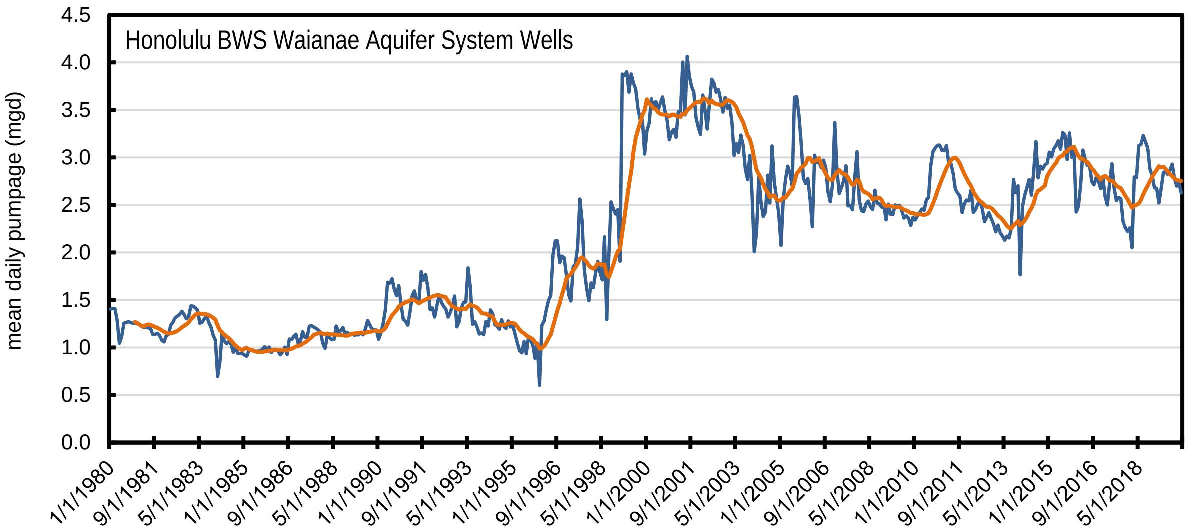
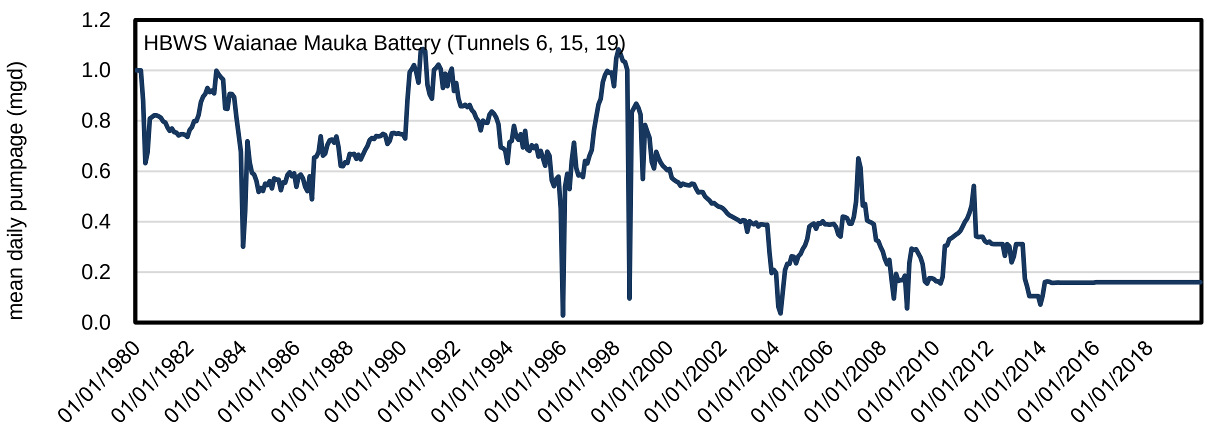


Figure 3-5. Mean groundwater pumpage (million gallons per day, mgd) from wells and development tunnels operated by the Honolulu Board of Water Supply in the Waianae Hydrologic unit. (Source: State of Hawaii, Commission on Water Resource Management, 2020c) [Note: starting in 2014, only water from Tunnel 15 has been utilized due to break in transmission pipeline]



Groundwater Pumping and Salinity Levels

Of growing concern is the impact of increased groundwater pumpage on ground water salinity. As pumpage draws down the less dense freshwater lens, brachish groundwater from the transition zone will mix, increasing the salinity (and thus chloride content) of the freshwater lens. Freshwater is water with a chloride content of less that 250 parts per million (ppm), or 1.3% of the chloride content of seawater. Hydrologists with the USGS and CWRM monitor the elevation of the freshwater lense, the transition zone to brachish water, and the elevation of sea water in deep monitoring wells across the state. In the Waianae Aquifer System, the HBWS reports chlorides for wells that are being actively pumped on a monthly basis, although there are often lapses in reporting (Figure 3-6). Chloride levels have remained relatively steady over the last 20 years from the HBWS wells, although there has been a concerning increase in well 3-2810-002 during recent months coinciding with increased pumpage.

Figure 3-6. Mean monthly pumpage (million gallons per day, mgd) and reported chloride (parts per million, ppm) for three Honolulu Board of Water Supply production wells in the Waianae Aquifer System, Oahu.

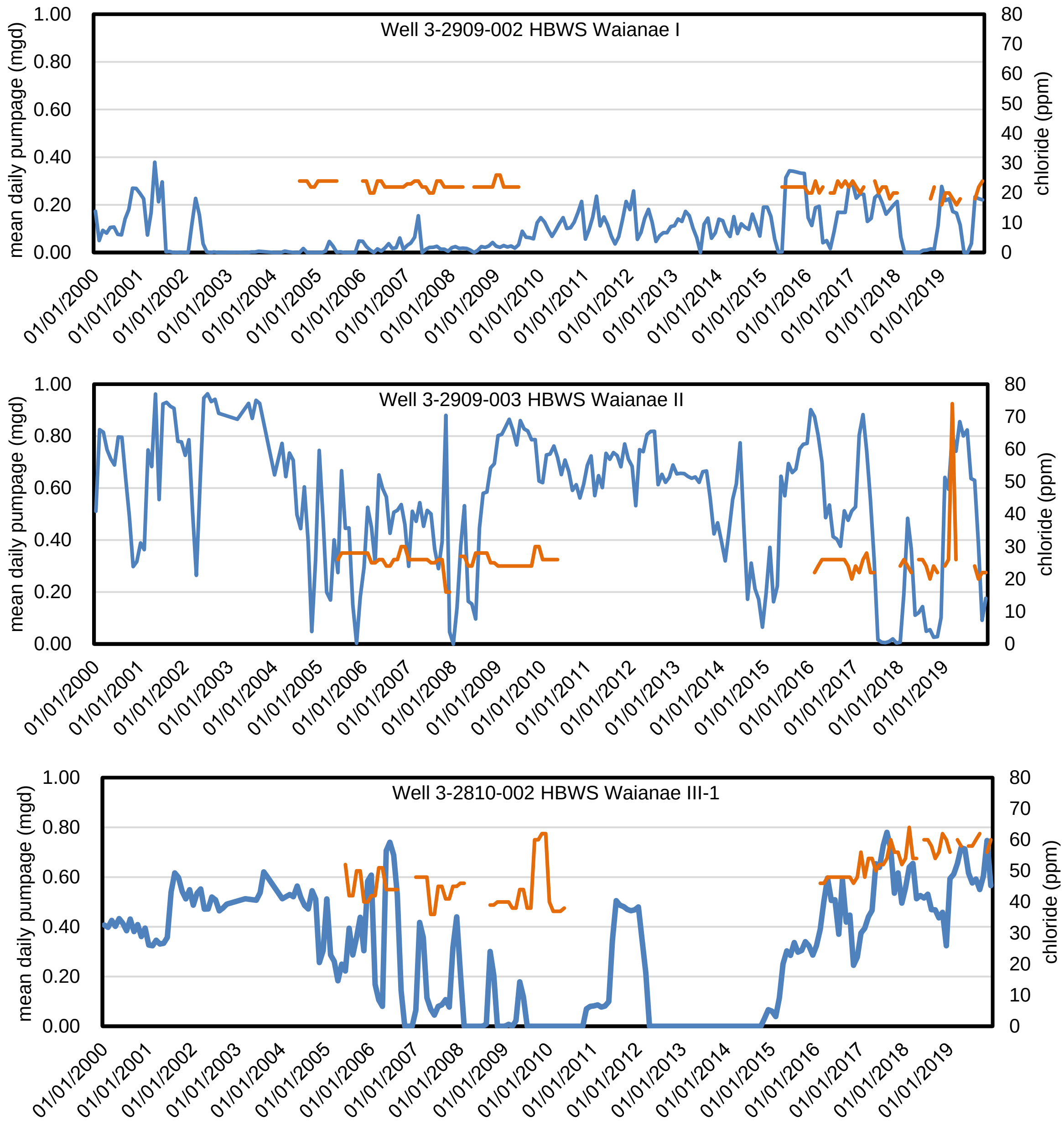


Figure 3-7. Well locations by well type and well numbers in the Kaupuni hydrologic unit, in the Waianae aquifer sector, Oahu. (Source: State of Hawaii, Commission on Water Resource Management, 2018c).

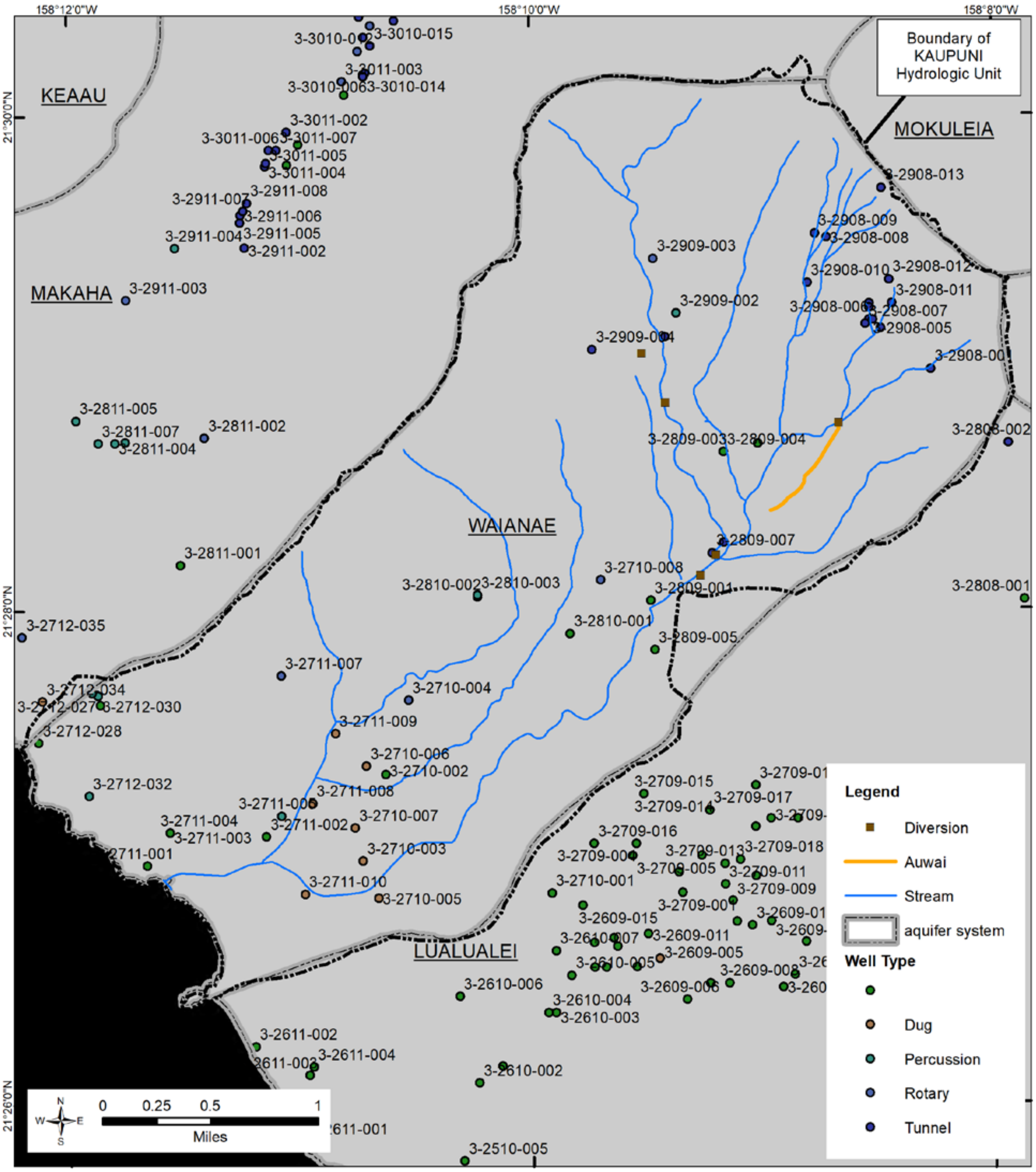
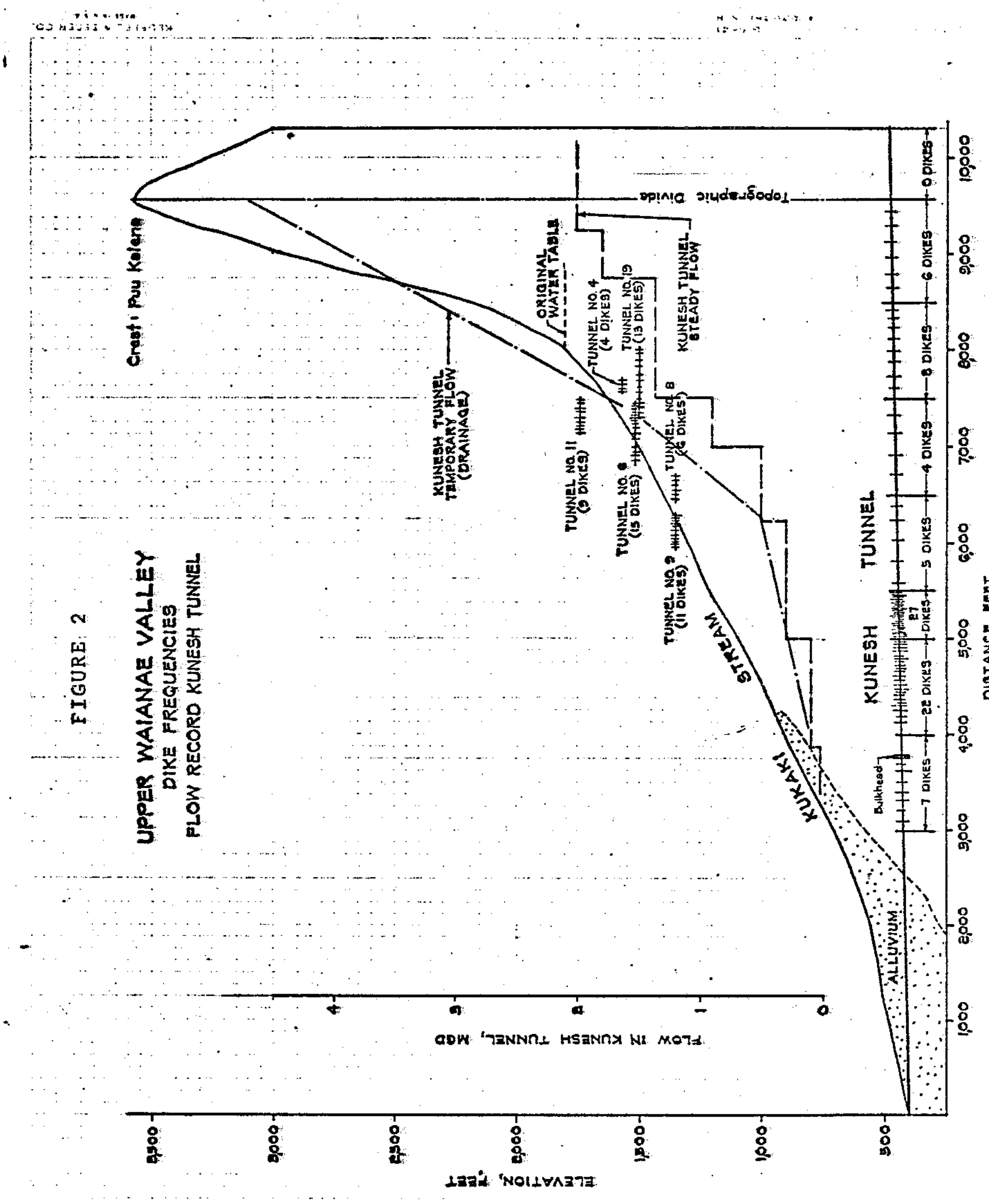


Figure 3-8. Distribution of dikes in the Kunesh Tunnel and in some of the upper Waianae Valley tunnels. (Source: Mink 1978)

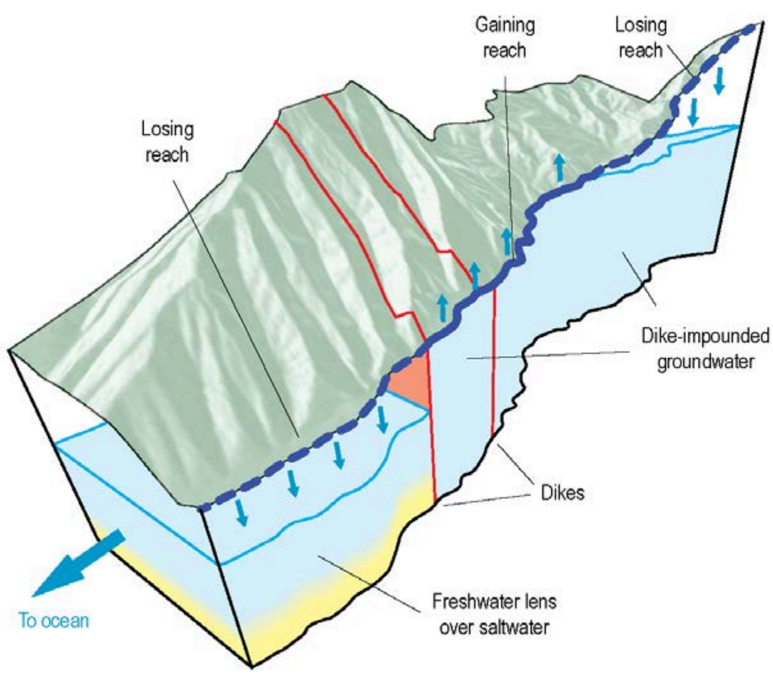


Streamflow Characteristics

Streams in Hawaii can either gain or lose water at different locations depending on the hydrogeologic conditions. 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 groundwater either at or below the water table. This can discharge groundwater onto the land surface, directly into the stream, or into the ocean. A stream gains water when the aquifer (either basal or high-elevation) is incised by the stream channel. Figure 3-9 illustrates a valley that has been incised through erosion, exposing a high-level water table and resulting in groundwater discharges that contribute directly to streamflow.

Streamflow conditions have been monitored continuously in the Kaupuni hydrologic unit on the Kanewai tributary at the 1000 ft elevation from 2016 to 2020 by CWRM (Figure 3-10). Mean daily flow for this period was 0.59 mgd, with a median (Q_{50}) flow of 0.56 mgd, a baseflow (Q_{70}) of 0.49 mgd, and a low flow (Q_{90}) of 0.42 mgd. The stability of the low flow values in Kanewai Stream are primarily driven by the release of water from Tunnel 19 (well 3-2908-011) by the HBWS and the groundwater seepage from abandoned development tunnels and springs along the stream course. There is substantial groundwater discharge from the high-elevation dike complexes which contribute to the baseflow of most streams in this region.

Figure 3-9. Depiction of the groundwater table along the stream course in Waianae Valley in relation to dike-impounded groundwater and losing reaches. (Source: Izuka et al., 2018)



Tributaries to Kaupuni Stream gains streamflow via groundwater seepage as it flows from mauka to makai in the upper elevations. As the stream transitions from the Waianae Volcanics basalt zone to alluvium, it begins to lose water. Figure 3-10 depicts the mean daily stream flow in Kaupuni Stream from 2016 to 2020 and Table 3-5 provides the annual and seasonal mean daily flow for this period.

Figure 3-10. Mean daily flow in Kanewai Stream at 1000 ft elevation (CWRM station 3-101) Kaupuni hydrologic unit, Oahu.

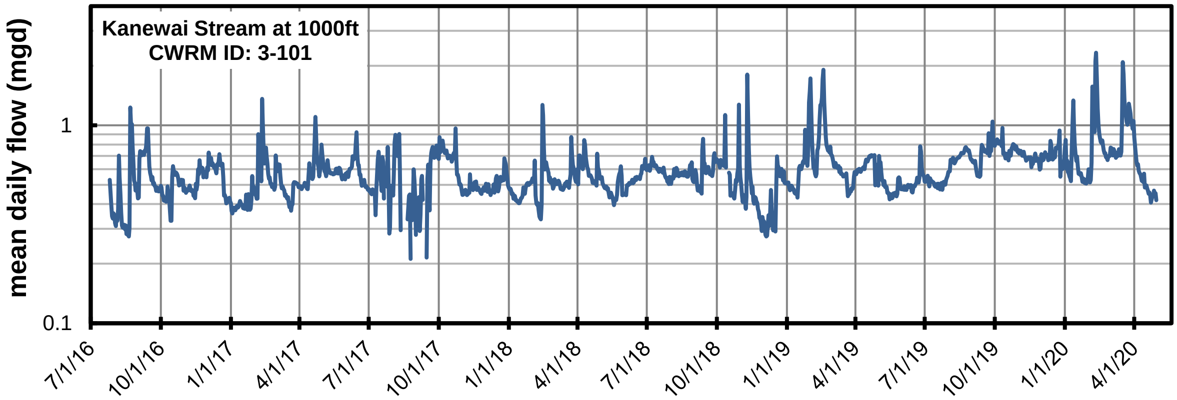


Table 3-4. Mean annual (±standard deviation) and seasonal flow statistics (in million gallons per day, mgd) for Kanewai Stream at 1000 ft elevation (CWRM 3-101) in the Kaupuni hydrologic unit, Oahu

	Mean Annual Flow (mgd)	Wet season (Nov-May)	Dry Season (Jun-Oct)
Kanewai Stream at 1000ft	0.59 (±0.20)	0.61 (±0.24)	0.58 (±0.14)

Seepage Gains and Losses

Point measurements of surface flow were made at various times throughout the Kaupuni hydrologic unit (Figure 3-12). These "seepage" measurements are used to quantify the gains and losses of streamflow due to interactions with the groundwater system. Many measurements were made from the early 1940s to late 1950s by the USGS, and again recently by CWRM staff. Using the upstream and downstream measurements, and the length of stream channel between the measurements, estimates of gains and losses of streamflow can be calculated. Overall, Kaupuni Stream is gaining flow in the upper elevations (>1200 feet a.s.l.) from spring flow and development tunnel leakage, then there is a losing reach at mid-elevations to about the lower elevation of the forest line (1200-940 feet a.s.l.). From here it is gaining again until the stream reaches about an elevation of 450 feet (Figure 3-12). Total natural streamflow gains and losses are difficult to quantify due to the presence of abandoned development tunnels and the consequences of the Waianae (Kunesh) tunnel (well 3-2809-006).

Long-term trends in flow

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 Oahu, there is a substantial area that has experienced a significant decline in annual and seasonal rainfall in the northern Koolau Mountains from 1920 to 2012, and for most of the island from 1983-2012 (Figure 3-13). There are no nearby long-term gaging station monitoring natural flow, although the Makaha Stream gage (station 16211600) which has been active continuously from

1959 to present day. Mean daily flow at station 16211600 is affected by groundwater development, but still provides an indication of existing conditions in a nearby hydrologic unit (Figure 3-14).

The USGS examined the long-term trends and variations in streamflow on the islands of Hawaii, Maui, Molokai, Oahu, and Kauai, 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 3-14 illustrates the results of the study for 7 long-term gaging stations around the islands. According to the analysis, 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 ground water contribution to streams.

Figure 3-11. USGS and CWRM gaging stations in streams in and near the Kaupuni hydrologic unit, Oahu (Source: USGS, 2020).

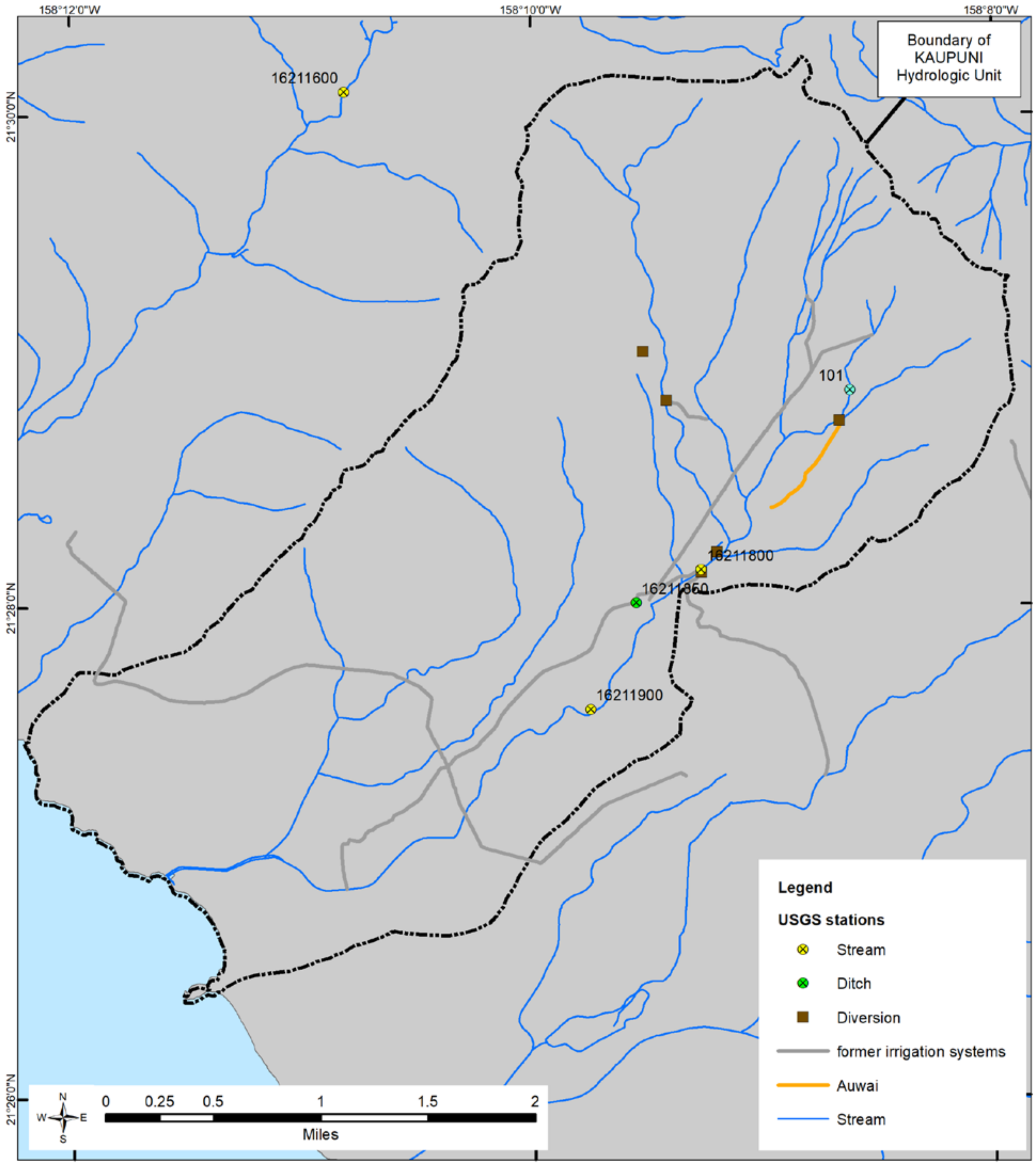


Figure 3-12. Seepage run results from point measurements in the Kaupuni hydrologic unit, Oahu.

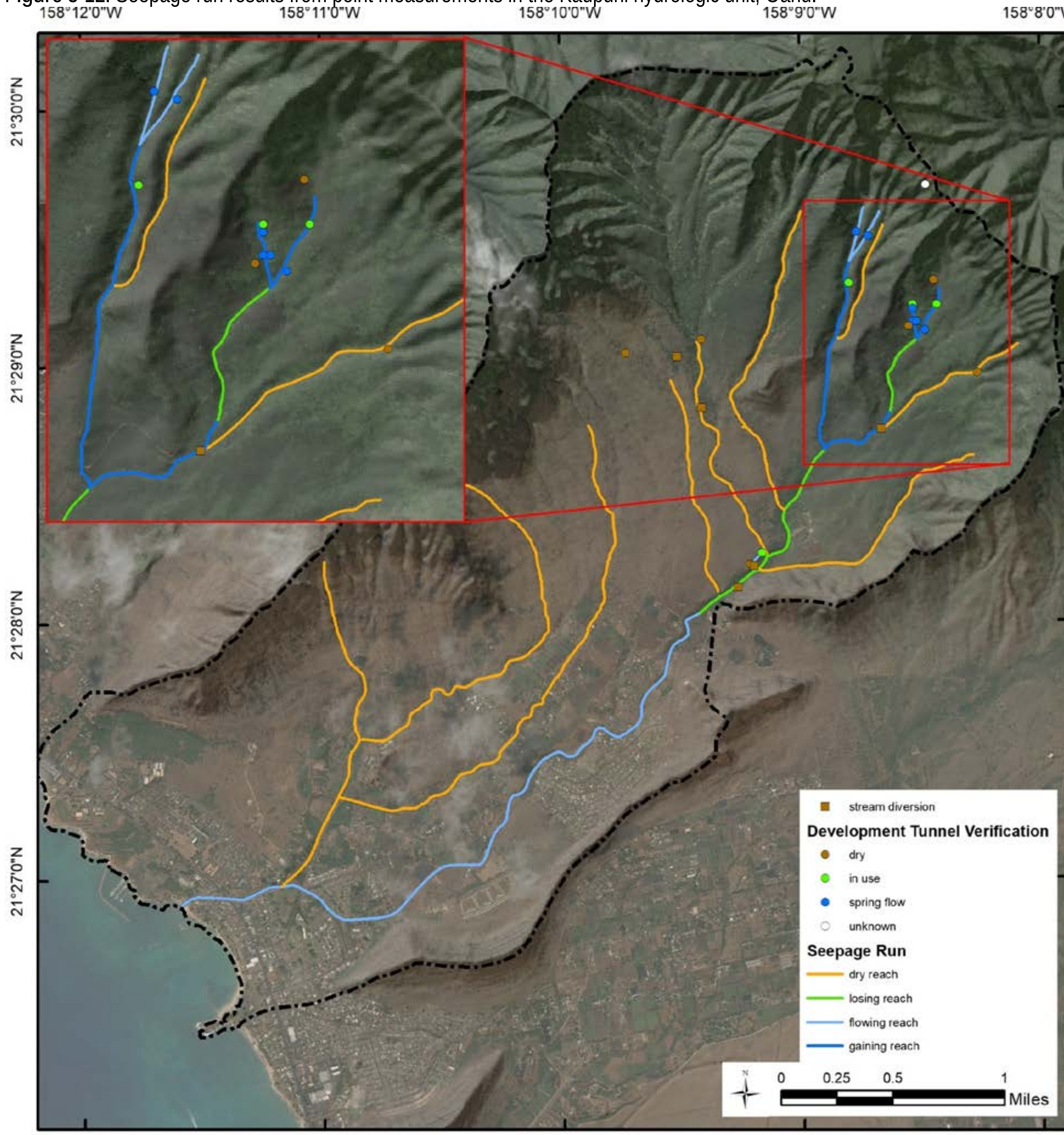


Figure 3-13. Annual, wet season (Nov-Apr) and dry season (May-Oct) rainfall trends for the 1920-2012 (A) and 1983-2012 (B) periods, Oahu. Hashed line areas represent significant trend over the period.
(with permission from Frazier and Giambelluca, 2017)

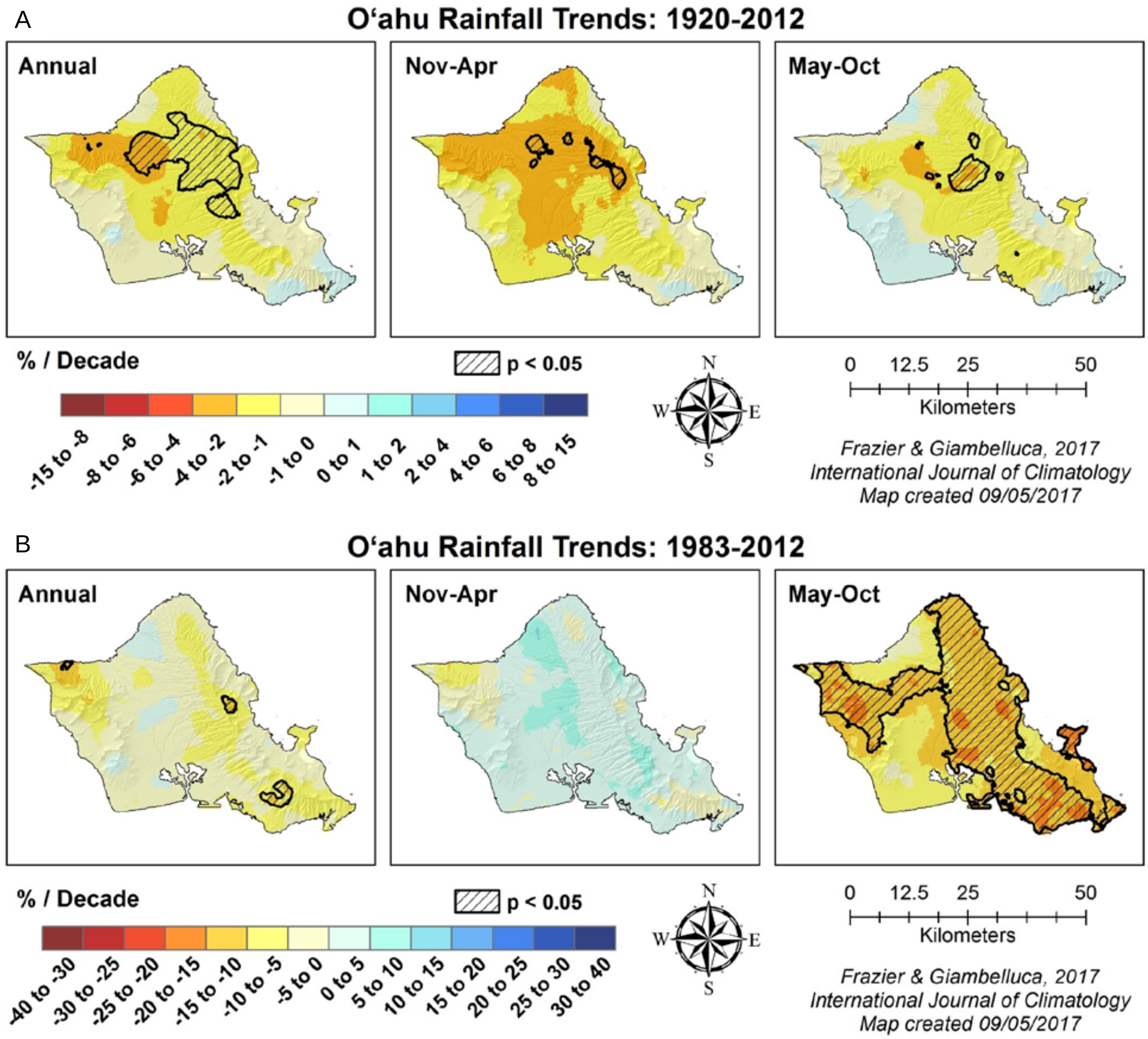


Figure 3-14. Mean daily flow at USGS 16211600 on Makaha Stream, Oahu.

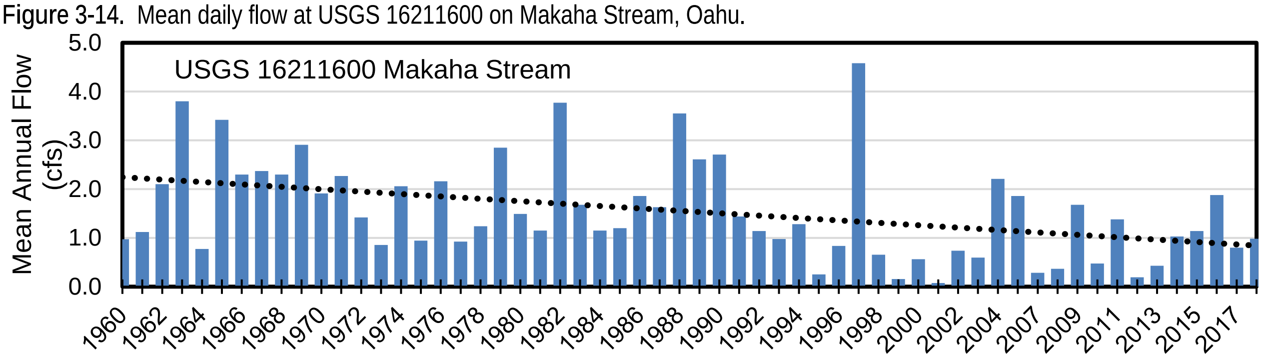
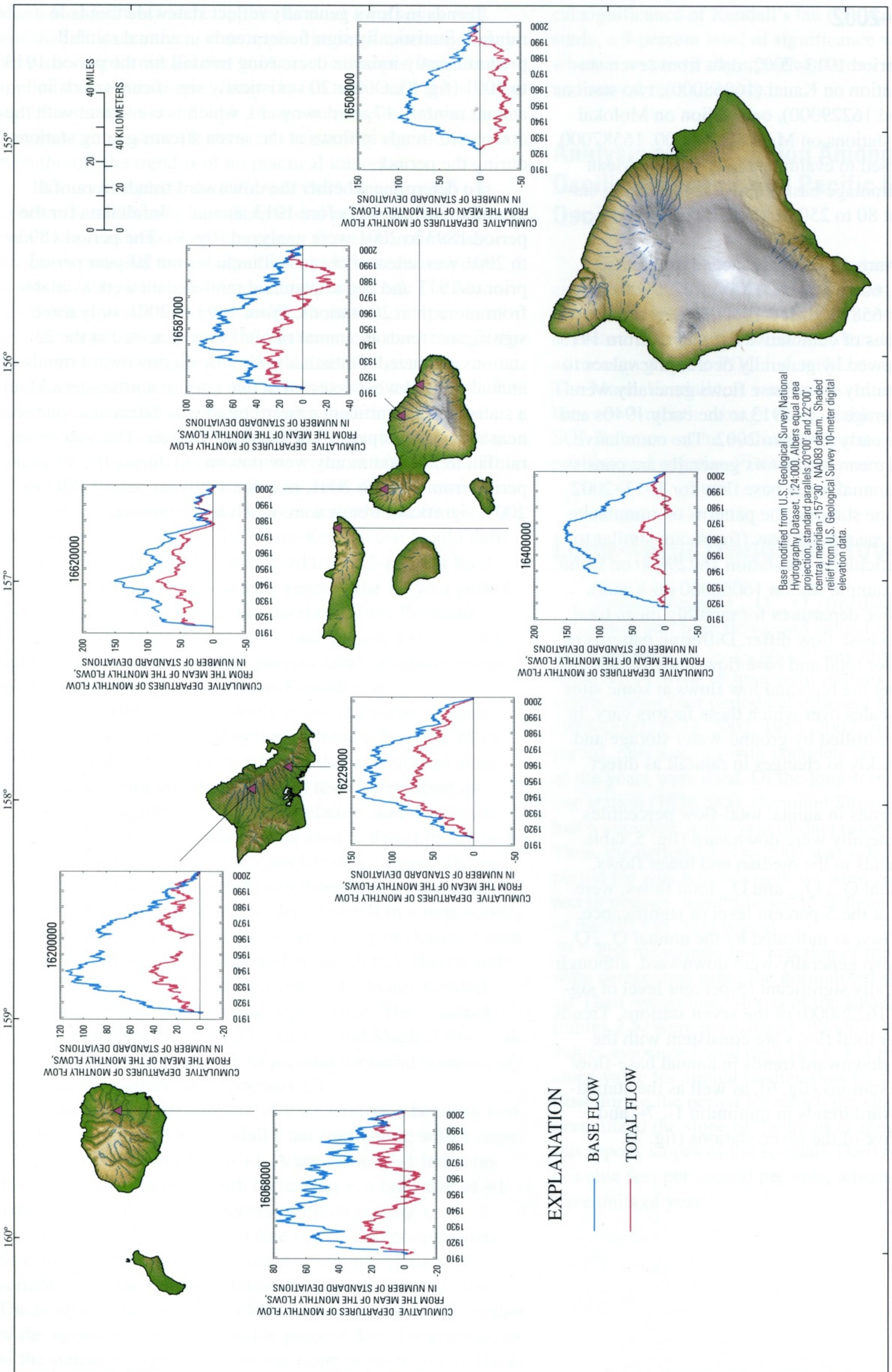


Figure 3-15. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii. This data is based on complete water years from 1913 through 2002. (Oki, 2004, Figure 4)



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.

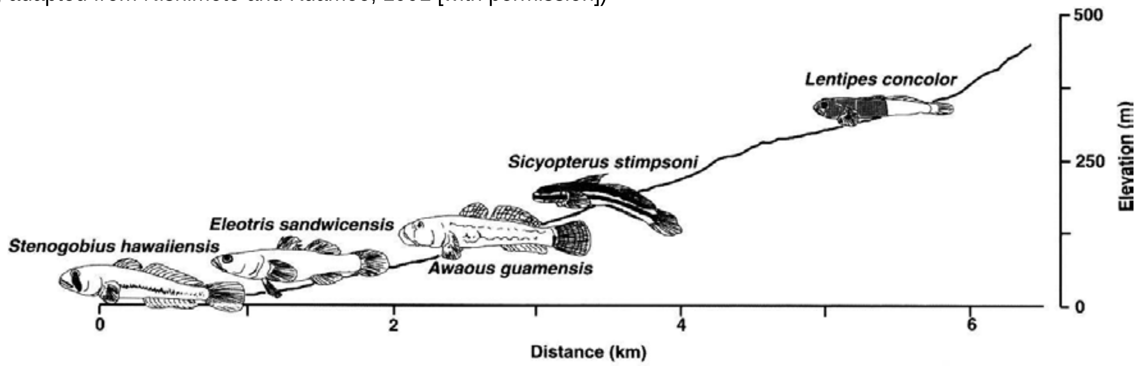
Table 4-1. List of commonly mentioned native stream organisms. (Source: State of Hawaii, Division of Aquatic Resources, 1993)

Scientific Name	Hawaiian Name	Type
Awaous stamineus	‘O‘opu nakea	Goby
Lentipes concolor	‘O‘opu hi‘ukole (alamo‘o)	Goby
Sicyopterus stimpsoni	‘O‘opu nopili	Goby
Stenogobius hawaiiensis	‘O‘opu naniha	Goby
Eleotris sandwicensis	‘O‘opu akupa (okuhe)	Eleotrid
Atyoida bisulcata	‘Opae kala‘ole	Shrimp
Macrobrachium grandimanus	‘Opae ‘oeha‘a	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 fresh water 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 did not recommend that the Kaupuni hydrologic unit streams be listed as candidate streams for protection based on aquatic resources. At the time of the assessment, there was not enough information to make any determinations concerning the distribution of native species in the hydrologic unit.

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. Since the HSA was released, additional surveys have identified other group one native species (i.e., *Eleotris sandwicensis, Stenogobius hawaiiensis*). A copy of the updated inventory report for Kaupuni is in Appendix A. The following is a summary of the findings.

- **Point Quadrat Survey.** In the Kaupuni watershed, stream surveys were conducted in 1979, and 1990 by the Division of Aquatic Resources. Few native species have been identified in Kaupuni stream or its tributaries, while many non-native species have been identified in the hydrologic unit, mostly in the estuary, lower, and middle reaches (Table 4-2). However, no DAR surveys have been conducted in the headwaters or since flow restoration has taken place over the last few years. Streamflow restoration would likely benefit recruitment and survival of native species in the estuary, lower, and middle reaches.

- **Insect Survey.** At least one native insect species (e.g., *Coleoptera sp*.) has been identified in the Kaupuni hydrologic unit, and the watershed met the criteria as a biotic stream of importance for native macrofauna diversity (>5 spp.). However, the watershed did not meet the DAR qualification for native insect diversity (>19 spp).

- **Watershed and Biological Rating.** The Kaupuni watershed has a medium land cover rating for Oahu and statewide due to the high percentage of conservation land. A lack of wetland and estuarine reaches due to urbanization gives the watershed a medium rating for shallow waters on Oahu and statewide and the watershed rates poorly for stewardship due to the degree of urbanization, channelization, and invasive species. Kaupuni Stream has a medium rating for stream size and reach diversity, and a low rating for wetness, resulting in a medium total watershed rating for Oahu and statewide. The watershed rates poorly for number of native species found and for introduced species, resulting in a medium rating for all species and total biological rating for the island and the state. These scores combined gave Kaupuni watershed a medium overall watershed rating.

Table 4-2. Present (P) of native species by stream reach for the Kaupuni Hydrologic unit, Oahu. (Source: DAR, 2008)

species	Estuary	Lower	Middle	Upper	Headwaters
Atyoida bisulcata				P	
Macrobrachium grandimanus					
Kuhlia sandvincensis	P				
Awaous stamineus		P			
Eleotris sandwicensis		P			
Sicyopterus stimpsoni					
Stenogobius hawaiiensis		P			

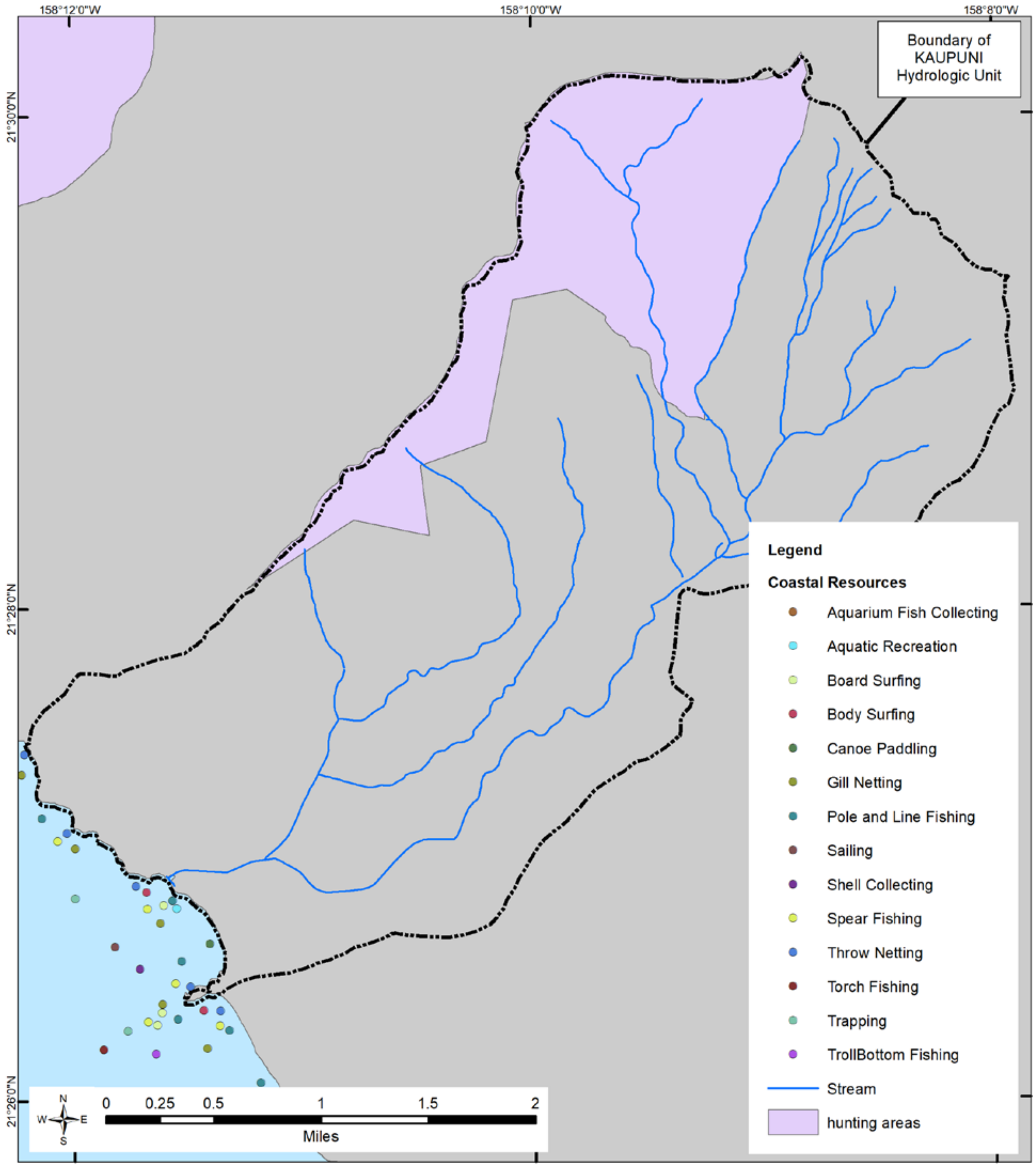
5.0 Outdoor Recreational Activities

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 camping, hiking, fishing, hunting, nature study, science views, and parks as recreational opportunities in the Kaupuni hydrologic unit and classifying the watershed as having "substantial" recreational resources (National Park Service, 1990). There are many additional inland and near-shore opportunites, including hiking and cultural experiences (Figure 5-1). Mammal hunting is permitted in one portion of the Waianae Kai Forest Reserve, but not in the rest of the hydrologic unit.

Since changes to streamflow and stream configurations have raised concerns regarding their impact to on-shore and near-shore activities, the Commission attempted to identify these various activities in relation to Kaupuni Stream. A 1981 Oahu Resource Atlas, prepared by the State of Hawaii Department of Transportation's Harbors Division, inventoried coral reefs and coastal recreational activities. Looking at available GIS data, some of the activities the Commission identified that were known to occur or observed at or near Kaupuni include: pole and line fishing, bait fishing, gill netting, torch fishing, throw netting, surfing, canoe paddling, seaweed and shell collecting (Figure 5-1).

Figure 5-1. Coastal resources and hunting areas in the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2002b)

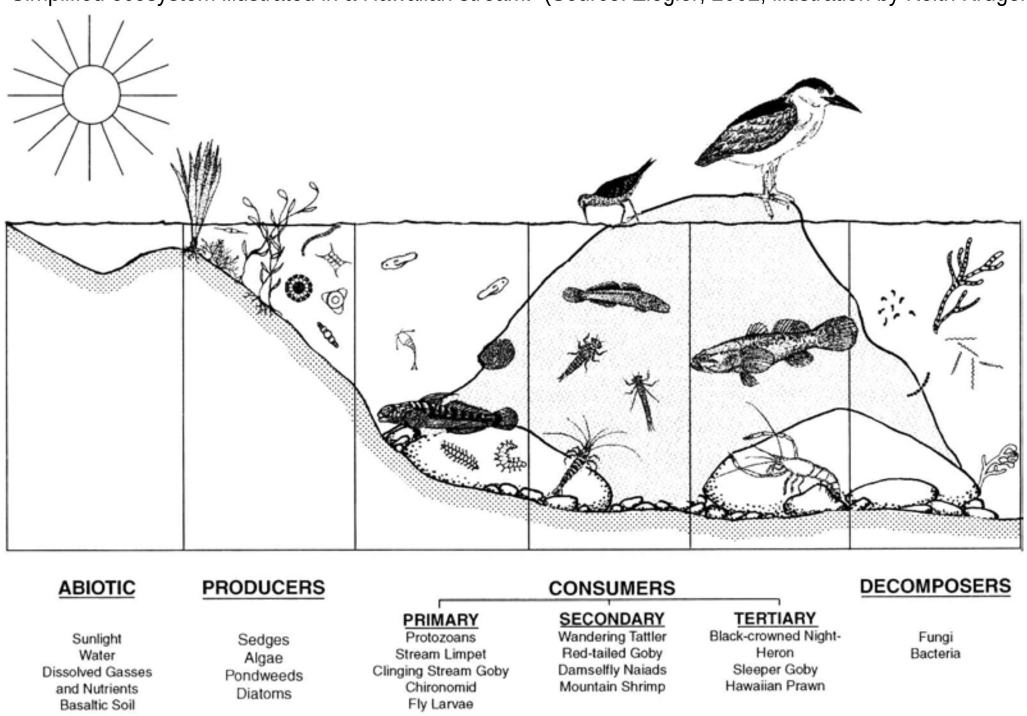


6.0 Maintenance of Ecosystems

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 Kaupuni Stream deserved to be a candidate stream for protection based on its outstanding cultural resources. While the Waianae Valley watershed is degraded by mismanagement and is dominated with non-native species, substantial archeological evidence and the strong support of the local population warrant a renewed protection of the biocultural landscape. Restoration of upland riparian vegetation and the expansion of traditional cultural practices, including the cultivation of food resources has expanded the ecological and cultural value of the watershed, including the restoration of streamflow.

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 Kaupuni Stream were classified as “limited” 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).

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

Category	Value
Listed threatened and endangered bird species: 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.	0
Recovery habitat: 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
Threatened and Endangered Birds: Eighteen species of birds of threatened or endangered birds are associated with streams, four of which are water birds exclusively. The remainder are forest birds whose habitat includes streams but the degree of relationship is unknown.	0
Protected areas: 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: 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.	W+ (over ½ mi^2 of palstrine wetland)
Native forest: 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: 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.	Hau, Pigs, Goats

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, or historic landmarks. In Kaupuni, 3.632 square miles (39.1 percent) is located in the Waianae Kai Forest Reserve and falls under the jurisdiction of the Department of Land and Natural Resources Division of Forestry and Wildlife. The City & County of Honolulu owns 0.36 square miles (3.8 percent) of land in the Kaupuni hydrologic unit. In addition to the individual management areas outlined above, 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 ten partnerships established statewide, two of which are on Oahu.

Table 6-2 provides a summary of the partnership area, partners, and management goals of the Waianae Mountains Watershed Partnership.

Table 6-2. Watershed partnerships associated with the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Division of Forestry and Wildlife, 2008b)

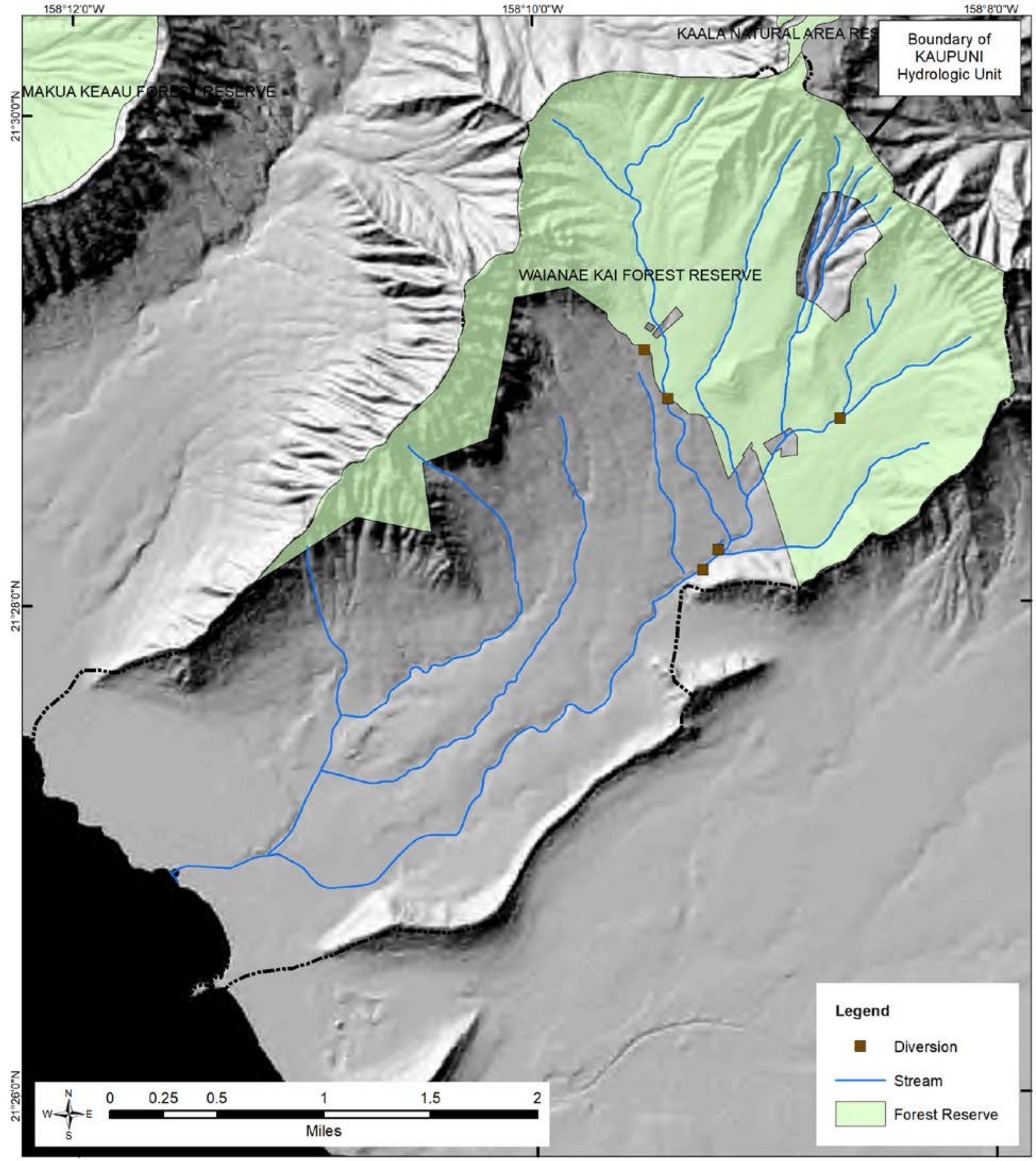
Management Area	Year Established	Total Area (mi^2)	Area (mi^2)	Percent of Unit
Waianae Mountains Watershed Partnership	2010	72.68	3.92	42.1
The Waianae Mountains Watershed Alliance (WMWA) is comprised of the City and County of Honolulu Board of Water Supply, Gill-Olson Joint Venture, MAO Organic Farms (Waianae Community Re-Development Corporation), U.S. Army Garrison Hawaii, Navy Region Hawaii, Kaala Farms, State Department of Hawaiian Home Lands, the State Department of Land and Natural Resources. The core mission is to work together to protect, restore, and enhance the Waianae Mountains watersheds while incorporating traditional, cultural and community values for the benefit of future generations. The management priorities of the WMWP include: 1) Baseline watershed monitoring of forest health and threat assessments; 2) installation of fencing to control movement of feral ungulates; 3) invasive weed control; and 4) restoration of forest and stream 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). Cummulatively, 1.7 percent (0.154 square miles) of the Kaupuni hydrologic unit is classified as wetlands (estuarine, freshwater emergent, freshwater forested or pond), mostly occurring in the low elevation reaches of the hydrologic unit or as high elevation bog (Table 6-3 and Figure 6-4).

Table 6-3. Wetland classifications for Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015n)

System Type	Class	Area (mi^2)	Percent of Unit
Palustrine	Freshwater Emergent Wetland	0.015	0.16
Marine	Estuarine and Marine Wetland	0.023	0.25
Palustrine	Freshwater Forested/Shrub Wetland	0.079	0.85
Marine	Estuarine and Marine Deepwater	0.025	0.27
Palustrine	Freshwater Pond	0.005	0.05
Palustrine	Riverine	0.007	0.08

Figure 6-2. Reserves that include the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2007b; 2015n)



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 Kaupuni. There is likely also native and potentially endangered damselfly species (*Megalagrion sp*) in the headwaters, although their distribution is not well known. Most of unit is dominated by invasive vegetation and the considerable number of invasive aquatic species may limit their distribution. The density of threatened and endangered plant species is very high at elevations above 1,400 feet, but low in most of Waianae Valley (Table 6-4, Figure 6-6).

Table 6-4. Distribution of threatened and endangered plant species for Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015f)

Vegetation Type	Area (mi^2)	Percent
Very High concentration of threatened and endangered species	2.104	22.8
High concentration of threatened and endangered species	0.076	0.8
Medium concentration of threatened and endangered species	2.879	31.0
Low concentration of threatened and endangered species	4.233	45.6
Little or no threatened and endangered species	0.00	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. Most of Kaupuni provides minimal critical habitat for native forest birds except in the uppermost elevations near Mt Kaala and where native cliff vegetation supports endangered plants or invertebrates.

Table 6-5. 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 6-3. The Waianae Mountains Watershed Partnership boundaries in the the Kaupuni hydrologic unit, Oahu.

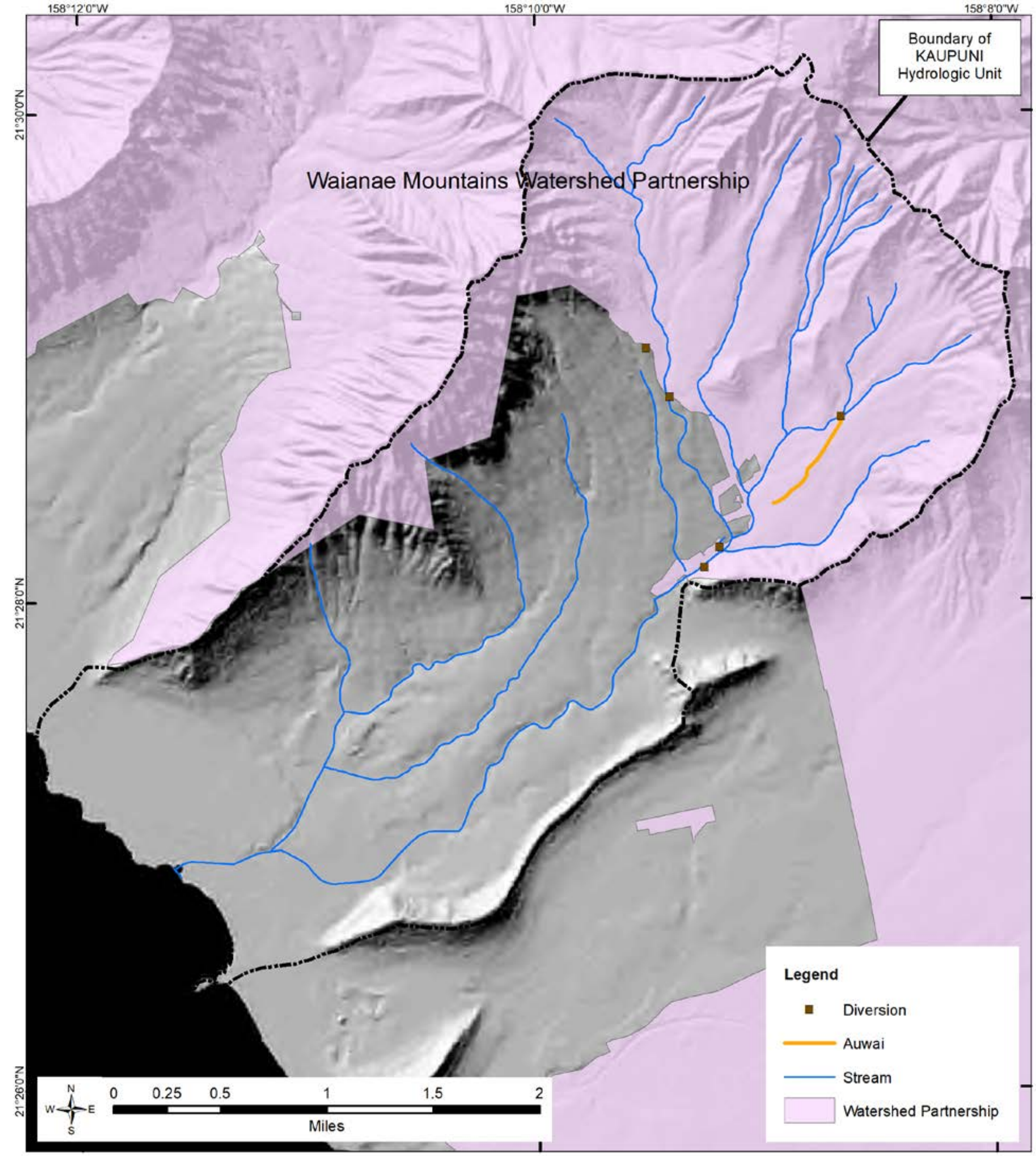


Figure 6-4. Wetlands in the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2007b; 2015c)

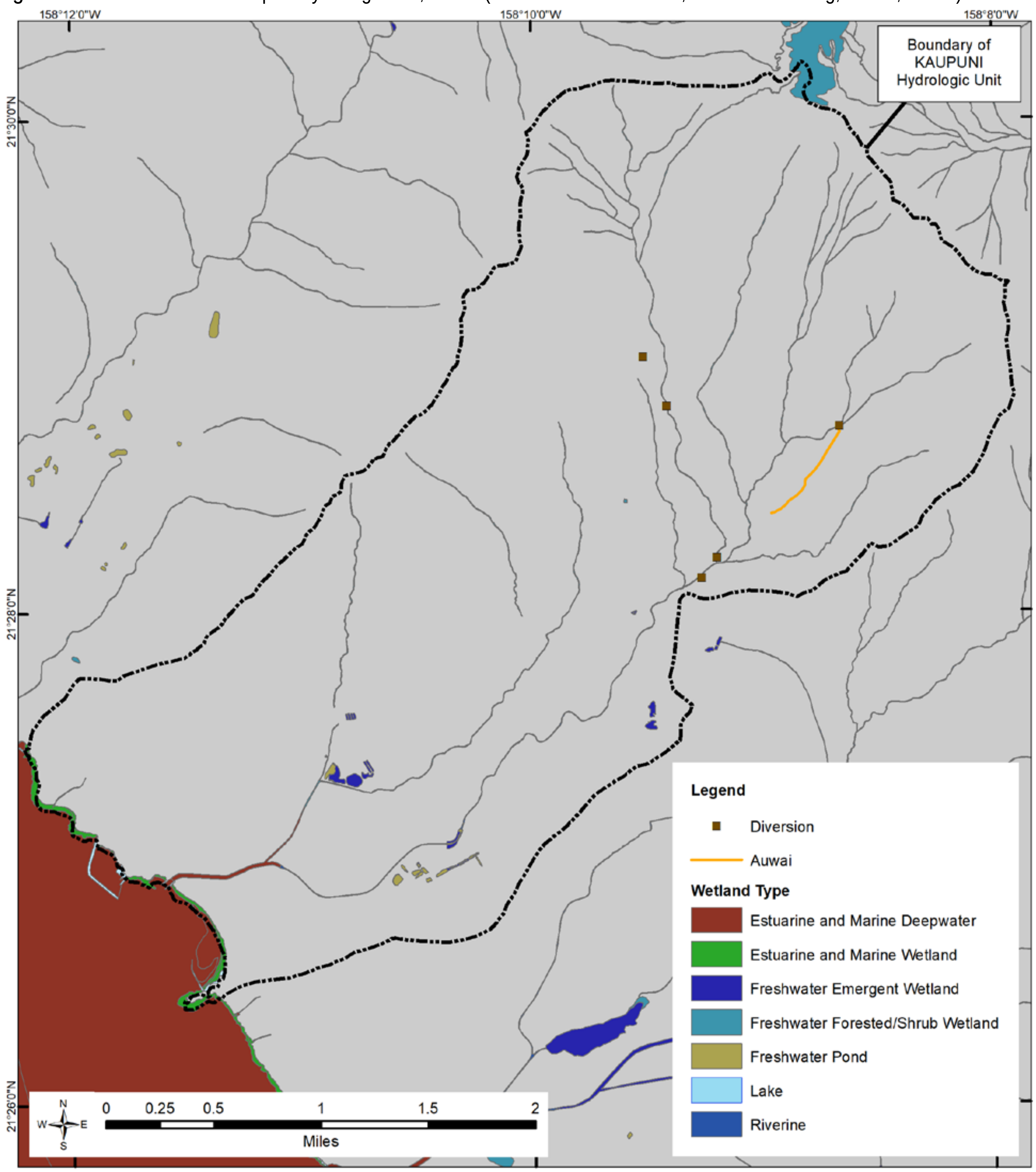


Figure 6-5. Distribution of critical ecosystem habitat in Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2004b)

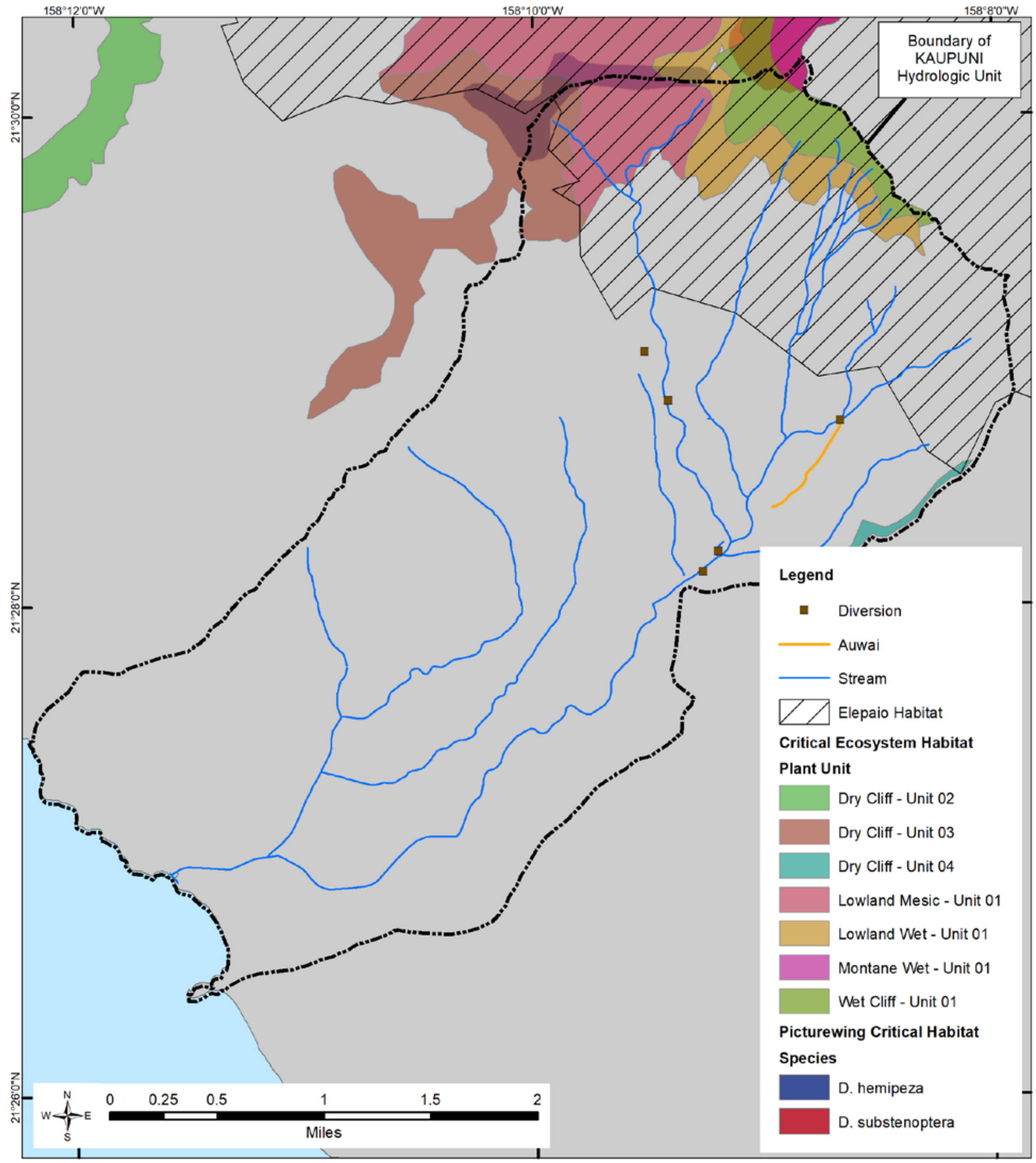
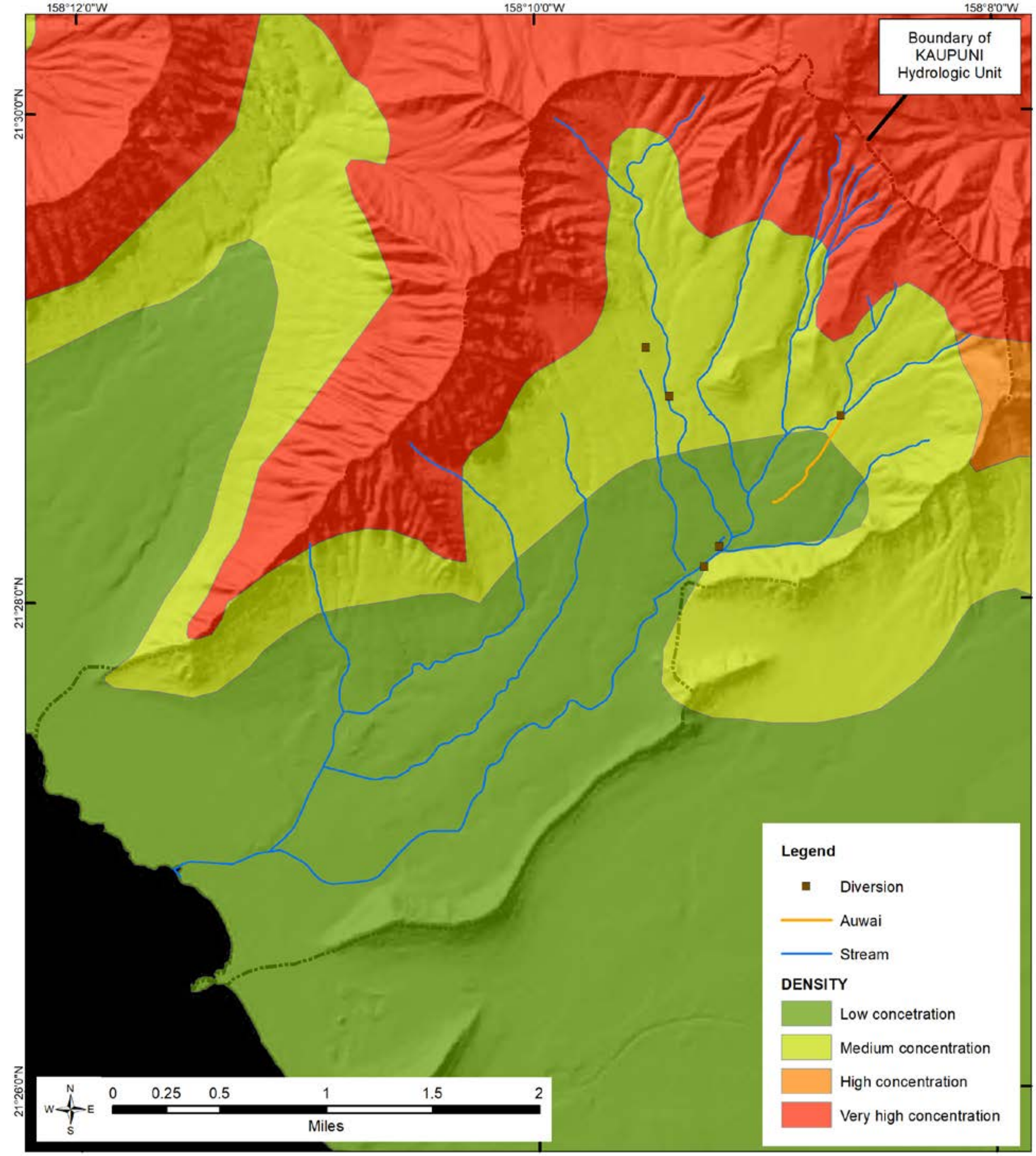


Figure 6-6. Density of threatened and endangered plants in Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015d)



7.0 Aesthetic Values

Aesthetics is a multi-sensory experience related to an individual's perception of beauty. Since aesthetics 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.

The Kaupuni hydrologic unit supports substantial hiking and aesthetic viewpoint opportunities, although there are few wildlife opportunities.

In a 2007 Hawaii State Parks Survey, released by the Hawaii Tourism Authority (OmniTrak Group Inc., 2007), scenic views accounted for 21% of park visits statewide. Other aesthetic-related motivations include viewing famous landmarks (9%), hiking trails and walks (7%), guided tour stops (6%), and viewing of flora and fauna (2%). Out-of-state visitors' most common reasons to visit state parks for scenic views (26%) was the number one reason for visiting a park above outings with family and friends (25%). By contrast, residents primarily used state parks for outings with family and friends (33%) followed by ocean/water activity (23%) and then scenic views (11%). While scenic views accounted for 51% of park activities by residents, they accounted for 82% of visitor activities. Oahu residents were very satisfied with scenic views (9.1 out of 10, with 10 being outstanding), with out-of-state visitors giving a score of 9.6 out of 10.

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.

There is no general navigation by boats in the Kaupuni hydrologic unit.

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 Kaupuni hydrologic unit.

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).

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.

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. The U.S. Environmental Protection Agency (USEPA) defines "[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

[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.

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[2]. 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. In 2018, the DOH Clean Water Branch published their biennial water quality monitoring and assessment report to meet the CWA §303(d) and CWA §305(b) requirements.

The sources for the 2018 Integrated Report are data collected from November 1, 2015 to October 31, 2017. The report identifies areas in need of restoration and serves as a baseline to validate the state’s efforts to improve water quality. Impaired waters are listed after review of all existing and readily available water quality-related data and information. While available data are not comprehensive of all the streams in the State, all state waters are subject to monitoring (HAR 11-54).

The distribution of on-site sewage disposal systems (e.g., cesspools and septic systems) leads to high levels of pollution in nearby water bodies due to groundwater leaching and runoff. There are many cesspools in the Kaupuni hydrologic unit which likely contribute to the high levels of contamination in surface waters at lower elevations (Figure 10-2). Of the 473 onsite sewage disposal systems in the hydrologic unit, 401 are cesspools. The current WQS require the use of *Enterococci* as the indicator

[2]Current and previous reports can be found at: https://health.hawaii.gov/cwb/clean-water-branch-home-page/integrated-report-and-total-maximum-daily-loads/

bacteria for evaluating public health risks in the waters of the State; however, no new data were available for this parameter in inland waters. As mentioned in Section 5.0, Outdoor Recreational Activities, 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 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).

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)."

Kaupuni Stream is classified as Class 1a inland waters from its headwaters to approximately the 700 ft 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. Figure 10-1 shows the Kaupuni hydrologic unit, including inland and marine (coastal) water classifications. Water quality data collected from one location in Kaupuni are summarized in Table 10-1.

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 permitted under regulation. In the 2018 DOH report, only 108 marine water bodies were assessed with 81.5% not attaining water quality standards for at least one or more conventional pollutants (usually turbidity). Further, 66% of marine assessments failed to meet nutrient water quality standards, and 47% failed to meet the chlorophyll *a* standard. only 88 streams statewide had sufficient data for evaluation of whether exceedance of WQS occurred. The marine waters Pokai Bay are classified as Class A waters. In the 2018 DOH report, Kaupuni Stream was identified as not meeting inland water quality standards based on visual assessment for total nitrogen, nitrate-nitrite, total phosphorus, and turbidity. Similarly, for marine waters, Pokai Bay did not meet the standards for total nitrogen and chloraphyl *a* in the 2018 DOH report.

Table 10-1. Mean and standard deviation (SD) water quality parameters for various locations in the Kaupuni hydrologic unit, Oahu (Source: EPA, 2020)

station ID		**station name**			**elevation (ft):** 374						
16211600		Kaupuni Stream at alt 374 ft									
Alkalinity		Bicarbonate		Calcium		Carbon Dioxide		Carbonate		Chloride	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
5	113.6 (9.07)	5	138.4 (11.0)	5	23.2 (3.49)	5	14.54 (11.00)	5	0.0 (0.0)	10	28 (2.7)
Floride		Hardness (Ca,Mg)		Hardness (non-carbonate)		Iron		Magnesium		Manganese	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
5	0.18 (0.05)	5	115.4 (12.5)	4	4.25 (4.35)	3	46.7 (30.6)	5	14 (1.22)	2	10 (14.14)
Nitrate		Orthophosphate		Phosphorus		Potassium		Silica		Sodium	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
9	0.068 (0.109)	3	0.043 (0.006)	3	0.134 (0.0171)	5	2.74 (0.56)	5	56.4 (7.3)	5	25.6 (2.51)
Sp Conductance		Strontium		Sulfate		Temperature		TDS		Zinc	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
5	346 (39)	3	166.7 (41.6)	5	20.6 (5.55)	6	22.08	15	79.9 (117.2)	2	0.00

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

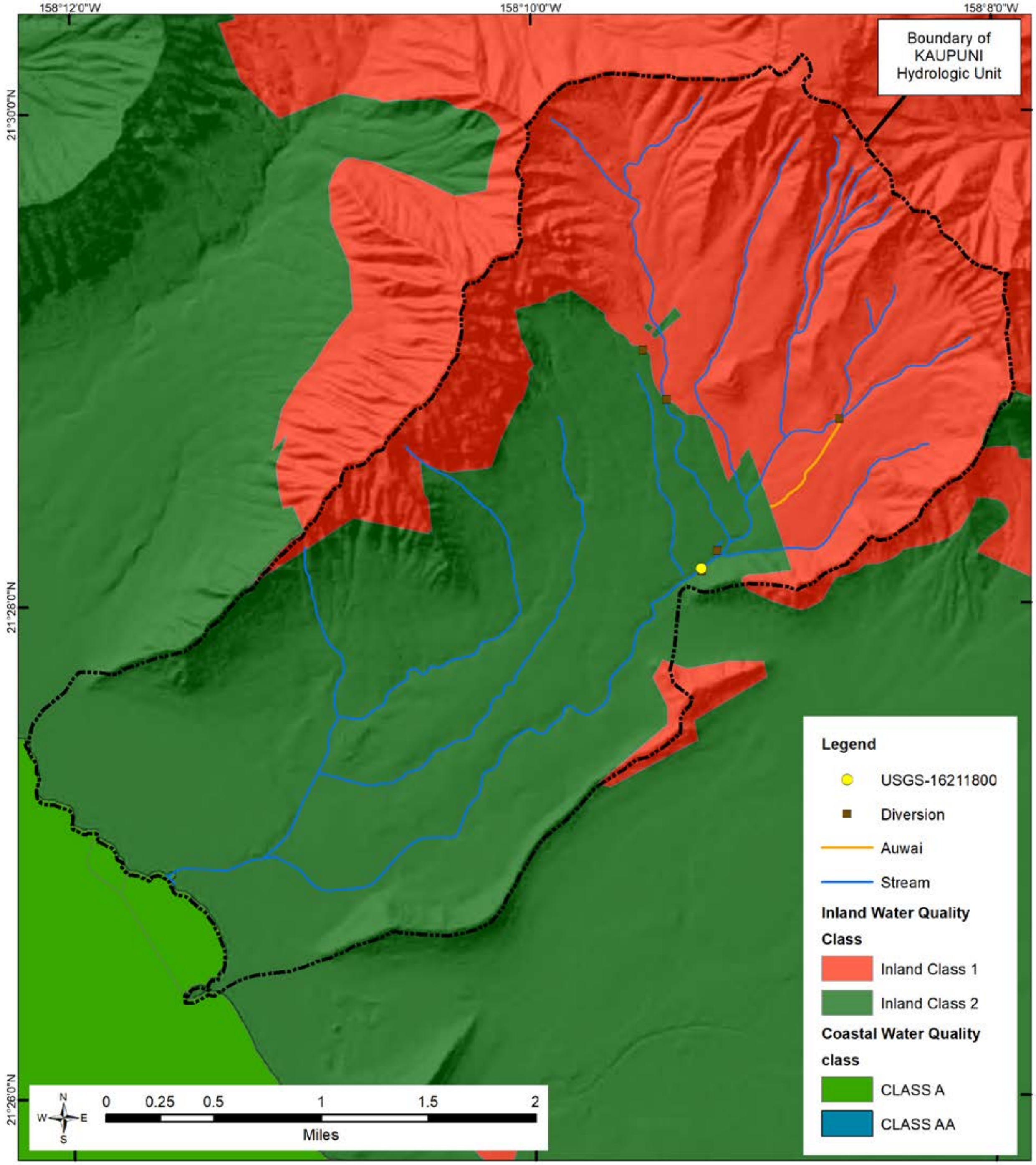
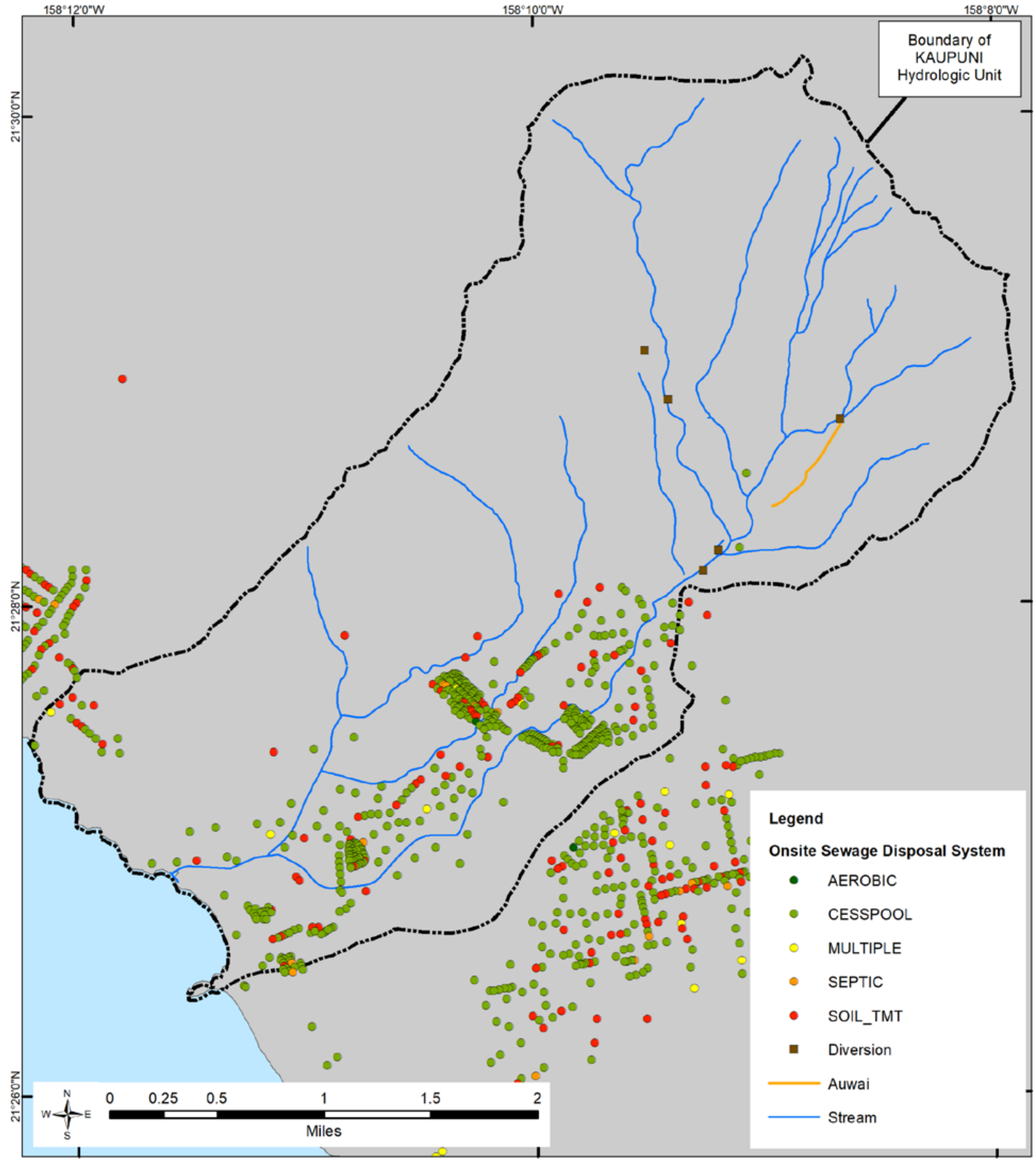


Figure 10-2. On-site sewage disposal systems and wastewater treatment facilities in the Kaupuni hydrologic units, Oahu. (Source: State of Hawaii Department of Health, 2020)



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, there are no private water systems in the Kaupuni hydrologic units regulated by the DOH, Safe Drinking Water branch.

12.0 Protection of Traditional and Customary Hawaiian Rights

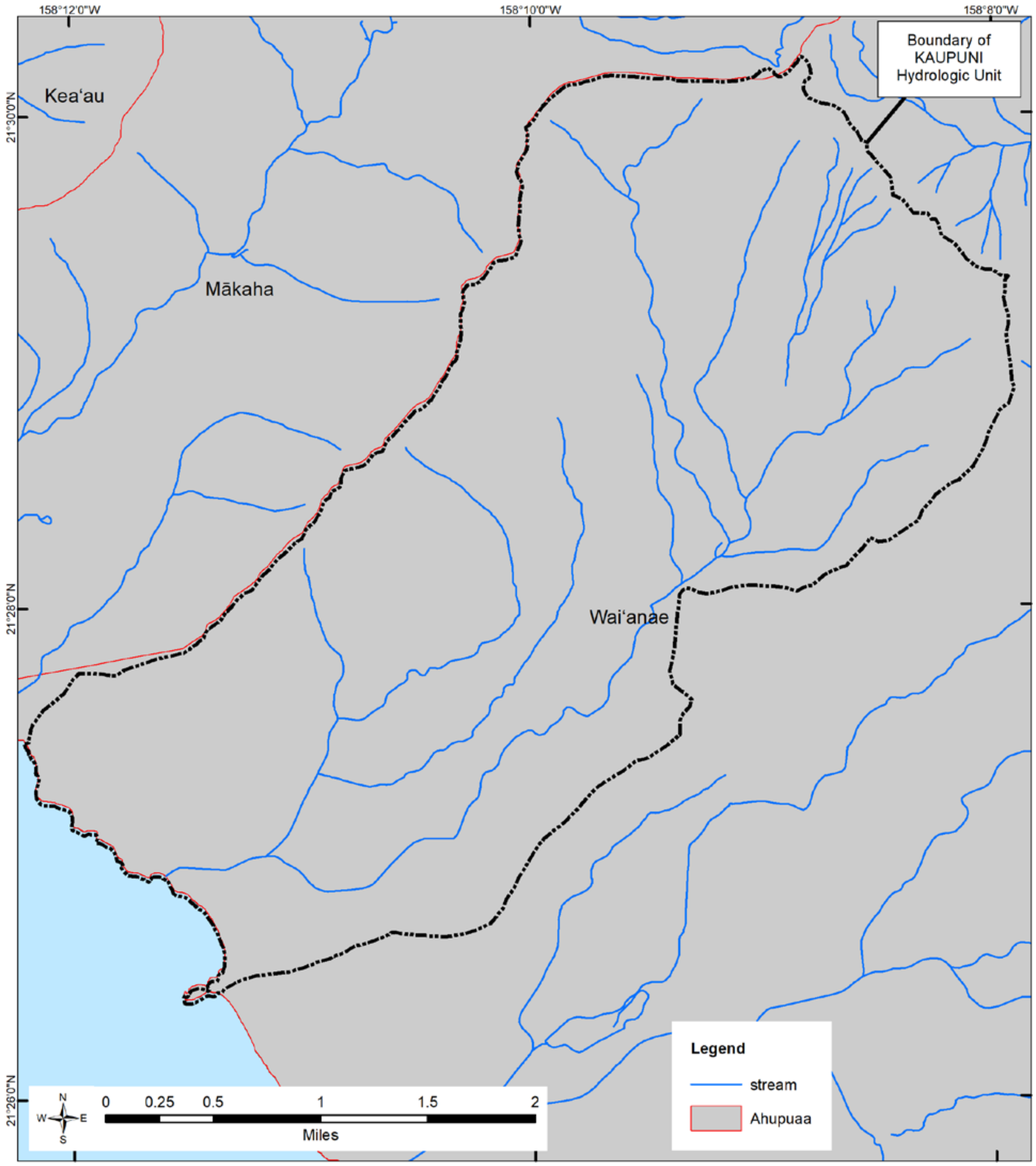
The maintenance of instream flows is important to the protection of traditional and customary Hawaiian rights, as they relate to the maintenance of stream resources (e.g., hihiwai, opae, oopu) for gathering, recreation, and the cultivation of taro. Article XII, Section 7 of the State Constitution addresses 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 ahupuaa 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 ahupuaa boundaries. The hydrologic unit of Kaupuni (and also Lualualei) are included in the *ahupuaʻa* of Waianae as shown in Figure 12-1. The *ahupuaʻa* 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 ahupuaa boundaries in the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015j)



Appurtenant Water Rights

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 Hawaii Supreme Court issued its decision in the Waiahole 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

[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.

> established, future uses are not limited to the cultivation of traditional products approximating 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 Waiahole 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 loi (flooded terraces) and loi 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 loi, water may either be fed to individual loi through separate little ditches if possible, or in the case of steeper slopes, water would overflow and drain from one loi to the next. Outflow from the loi may eventually be returned to the stream.

The loi 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 oopu, awa, and aholehole within the waters of the loi 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; loi 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 hydrologic unit of Kaupuni. Table 12-1 presents the results of the Commission's assessment. Of particular importance is the presence of terracing and oral testimony that indicates loi kalo existed along streams in Kapuni. There is archeological evidence that dryland kalo or other crops was also grown in Kaupuni. The series of TMK parcels and associated land commission awards suggest extensive cultivation of the riparian areas of Kaupuni stream.

[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.

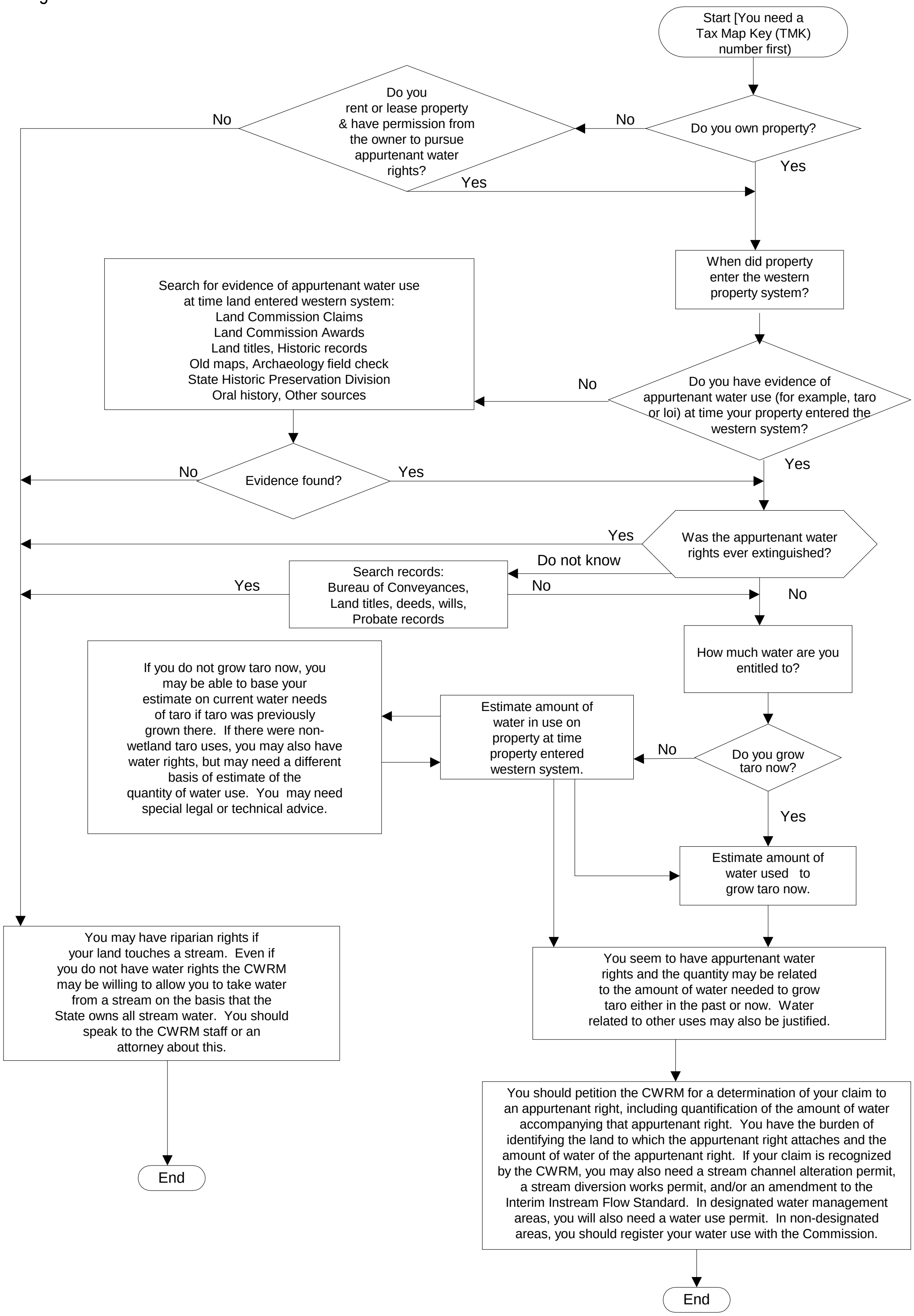


Table 12-1. Land Awards, claimants, associated tax map key (TMK) parcels, and landowners for the Kaupuni hydrologic unit, Oahu. [LCA is Land Commission Award; Gr. is Grant; por. is portion; and G.L. is Government Lease]

Land Award	TMK	Landowner	Claimant
Gr 5971	185001062	State DLNR	Waianae Company
Gr 5263:2	multiple	multiple	The Makaha Coffee Co
Gr 4046	multiple	multiple	Waianae Company
LCA 10585:1	185008034	C&C of Honolulu	Olaelae
LCA 3097:2	multiple	multiple	Keonekapu
LCA 7713:51	multiple	multiple	Kamamalu, Victoria
LCA 843	185001008	C&C of Honolulu	Punahoa
LCA 3091:2	185001008	C&C of Honolulu	Kamakalauhiwa
LCA 3072:2	185011018	Okimoto Holdins, LLC	Namuliwai
LCA 3001:2	multiple	multiple	Nawahine
LCA 3076:2	multiple	multiple	Kauhiahiwa
LCA 3276:1	multiple	multiple	Waimalu, S
LCA 10585:2	185001067	C&C of Honolulu	Olaelae
LCA 3029:1	multiple	multiple	Kaapuiki
LCA 3090:2	multiple	multiple	Keaona
LCA 2962:2	185003041	Waianae Baptist Church	Alealeikawai
Gr 4200	185002001	C&C of Honolulu	Waianae Company
LCA 8307:2	multiple	multiple	Waianee
LCA 9484:3	multiple	multiple	Hema
LCA 9492:3	multiple	multiple	Paaluhi
LCA 10356:1	multiple	multiple	Nuhi
LCA 5236	multiple	multiple	Ione
LCA 1754:1	multiple	multiple	Kalama
LCA 5408 B	multiple	multiple	Kaimukanaka
LCA 9484:2	multiple	multiple	Hema
LCA 1754:2	multiple	multiple	Kalama
LCA 9484:1	multiple	multiple	Hema
LCA 5408:2	multiple	multiple	Mahi
LCA 5408:1	185002022	Ee Waianae Solar LLC	Mahi
LCA 7709:1	multiple	multiple	Keoiwa
LCA 5408 C	multiple	multiple	Nailimae
LCA 1754:3	multiple	multiple	Kalama
LCA 5296	multiple	multiple	Kaopukea
LCA 9493:1	multiple	multiple	Kuheleloa 1
LCA 10356:3	multiple	multiple	Nuhi
LCA 10356:2	multiple	multiple	Nuhi
LCA 9492:2	multiple	multiple	Paaluhi
LCA 9492:1	multiple	multiple	Paaluhi
LCA 9865:3	multiple	multiple	Wainee
LCA 8189:2	multiple	multiple	Makea
LCA 9865:1	multiple	multiple	Wainee

Table 12-1. continued.

Land Award	TMK	Landowner	Claimant
LCA 8189:1	multiple	multiple	Makea
LCA 9487	multiple	multiple	Kauo
LCA 8189 B	multiple	multiple	Manu
LCA 5408 D	multiple	multiple	Haupu
LCA 1754:4	multiple	multiple	Kalama
LCA 9485:1	multiple	multiple	Lae
LCA 1754:5	multiple	multiple	Kalama
LCA 9485:2	185014007	Chung, James S Jr Trust	Lae
LCA 9482:1	multiple	multiple	Kawaamaole
LCA 9491:2	multiple	multiple	Kaneele
LCA 8189 D	multiple	multiple	Kaainui
LCA 9489:1	multiple	multiple	Holi
LCA 9480:5	multiple	multiple	Ohule
LCA 9479:1	multiple	multiple	Kahinu
LCA 9493:2	multiple	multiple	Kuheleloa 1
LCA 9486 C:5	multiple	multiple	Kuheleloa 2
LCA 9479:2	multiple	multiple	Kahinu
LCA 9483:1	multiple	multiple	Kahue
LCA 9480:6	multiple	multiple	Ohule
LCA 9483:3	multiple	multiple	Kahue
LCA 9479:3	multiple	multiple	Kahinu
Gr 3929	multiple	multiple	Waianae Company
LCA 9489:2	multiple	multiple	Holi
LCA 8189 C:2	multiple	multiple	Kumukahi
LCA 9480:1	multiple	multiple	Ohule
LCA 9486 C:2	multiple	multiple	Kuheleloa 2
LCA 9480:2	multiple	multiple	Ohule
LCA 9486 C:4	multiple	multiple	Kuheleloa 2
LCA 9481:1	multiple	multiple	Kihewa
LCA 9480:3	multiple	multiple	Ohule
LCA 9480:4	multiple	multiple	Ohule
LCA 9486 C:1	multiple	multiple	Kuheleloa 2
LCA 9481:2	multiple	multiple	Kihewa
LCA 3098:1	multiple	multiple	Kamakai
LCA 7334:2	multiple	multiple	Kulepe
LCA 3095:2	multiple	multiple	Pooloa
LCA 4465	multiple	multiple	Nalu
LCA 3095:1	multiple	multiple	Pooloa
LCA 7334:1	multiple	multiple	Kulepe
LCA 2961	multiple	multiple	Akaloa
LCA 3035	multiple	multiple	Kalawaiahoohalahala

Table 12-1. continued.

Land Award	TMK	Landowner	Claimant
LCA 3119:2	multiple	multiple	Puhipaka
LCA 3018:2	multiple	multiple	Mulea
LCA 2970	multiple	multiple	Pauli
LCA 2971	multiple	multiple	Hawea
LCA 3074	multiple	multiple	Kamoao
LCA 3022	multiple	multiple	Kauanauoo
LCA 2953	multiple	multiple	Hauna
LCA 3070	multiple	multiple	Kaapuiki
LCA 3080:1	multiple	multiple	Kamai
LCA 3018:1	multiple	multiple	Mulea
LCA 3094:1	multiple	multiple	Kauhanea
LCA 3032	multiple	multiple	Keahia
LCA 2988:2	multiple	multiple	Lokoino
LCA 3094:2	multiple	multiple	Kauhanea
Gr 3928	multiple	multiple	Waianae Company
LCA 3098:2	multiple	multiple	Kamakai
LCA 3004	multiple	multiple	Napoe
LCA 8522	multiple	multiple	Kuhia, E
LCA 3073	multiple	multiple	Keauhee
LCA 2988:1	multiple	multiple	Lokoino
LCA 3089	multiple	multiple	Kapela
LCA 7334:3	multiple	multiple	Kulepe
LCA 2977:3	multiple	multiple	Paupau
LCA 2999:1	multiple	multiple	Nakea
LCA 3084	multiple	multiple	Kauaiomano
LCA 2976	multiple	multiple	Kaiolohua
LCA 3000	multiple	multiple	Nakai
LCA 3079:1	multiple	multiple	Kanehailua
LCA 3087 B	multiple	multiple	Kahaleula
LCA 3039	multiple	multiple	Olaelae
LCA 3097:1	multiple	multiple	Keonekapu
LCA 3076:1	multiple	multiple	Kauhiahiwa
LCA 3072:1	multiple	multiple	Namuliwai
LCA 3071	multiple	multiple	Keanini
LCA 3096	185004035	Wong, Miao Ying	Kakio
LCA 2952	multiple	multiple	Elemakule
LCA 2957:1	multiple	multiple	Hauwawa
LCA 3029:2	multiple	multiple	Kaapuiki
LCA 2974	multiple	multiple	Poopuakala
LCA 3114	multiple	multiple	Ua
LCA 3276:2	multiple	multiple	Waimalu, S
LCA 3015:1	multiple	multiple	Makalio

Table 12-1. continued.

Land Award	TMK	Landowner	Claimant
LCA 3091:1	185004035	Wong, Miao Ying	Kamakalauhiwa
LCA 3956 B	185004010	Wong, Miao Ying	Kekuahanai
LCA 3080:3	185004037	Anawati, Alfred A	Kamai
LCA 2993	multiple	multiple	Opunui
LCA 3029:3	multiple	multiple	Kaapuiki
LCA 3016	multiple	multiple	Malamakuhiana
LCA 3950B	multiple	multiple	Aluli
LCA 3080:2	multiple	multiple	Kamai
LCA 2962:1	multiple	multiple	Alealeikawai
LCA 3080:5	multiple	multiple	Kamai
LCA 3090:1	multiple	multiple	Keaiba
LCA 7713:51	multiple	multiple	Kamamalu, Victoria
LCA 903:3	multiple	multiple	Lauhulu
LCA 2951:2	multiple	multiple	Ehu
LCA 903:2	185005019	Hawaiian Association of Seventh-Day Adventists	Lauhulu
LCA 884:1	multiple	multiple	Puhi
LCA 4974 B	multiple	multiple	Hulupii
LCA 903:1	185005014	Hawaiian Association of Seventh-Day Adventists	Lauhulu
LCA 7451:3	multiple	multiple	Kailianu
Gr 4329	185005036	State DHHL	Waianae Company
LCA 3132	multiple	multiple	Kaupea
LCA 3126	multiple	multiple	Niau
Gr 4125	185005003	C&C of Honolulu	Waianae Company
LCA 3087	185006007	C&C of Honolulu	Kanepaina
LCA 3131	185006001	State of Hawaii	Kuapuu
Gr 4040	185006002	C&C of Honolulu	Widemann, HA
LCA 3133:1	multiple	multiple	Ohule

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 Hawaii.

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 12-4 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).

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) Mean	Range	Mean daily range	Temperature measurements greater that 27ºC (percent)
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

Historical uses can also provide some insight into the protection of traditional and customary Hawaiian rights. Handy and Handy in *Native Planters of Old Hawaii* (1972), provide a limited regional description as follows:

> Wai‘anae extends from Ka‘ena wouthward along the leeward slopes of the Wai‘anae range as far as the boundary of the rich district of ‘Ewa...Wai‘anae is a dry coastal strip with poor soil and only four rather insignificant streams reahing the sea from rocky mountain gulches or valleys. (p. 467)
>
> The largest valley on this leeward side of the mountain range of the same name is Wai‘anae-kai, opposite the area names Wai‘anae-uka on the northeastern slopes. Although relatively poor terrain, this valley nevertheless had once a condiserable development of wet-taro culture along the main stream and its tributaries in the uplands now covered by forest and water reserve… (p. 468)

The extensive terracing in the uplands of Waianae Valley indicate to the large population which resided in the valley. Post-contact descriptions of the area attest to this…

> Names were obtained for 14 distinct terrace sections, watered by Olahua Stream, extending as far down as the site of the present power house. The section named Honua, including the group of terraces farthest inland, belonged to the *ali‘i* of the valley…A short distance below the power house terraces [were] still cultivated by Hawaiians [in

> 1935]. The names of four terrace sections formerly watered by Kikoʻo Stream were recorded, also four names for terrace sections watered by Kumaipo Stream.
> (p. 468; as quoted from Handy, 1940, p. 84)

Wetland kalo was supplemented with the bountiful fishing opportunities along the coastline as well as dryland products:

> Gourds, of the *ipu manalo* variety, were found growing wild in the uplands in 1935. Lower down, in the dry area, there were sweet-potato plantations and coconut trees.
> (p. 468)

Archaeological Evidence for Hawaiian Agriculture

There are many identified archaeological sites throughout the Kaupuni hydrological unit. In the middle and upper elevations, there is much terracing along the stream channels which indicate historical kalo loi was grown here. This is supported by Ladefoged et al. (2009) who modeled the extent of pre-contact agriculture across the Hawaiian Islands (Figure 12-3). There are many important cultural features includeing heiau, terracing, homesites, platforms, pits, grinding stones, mounds, and walls consistent with irrigated agricultural complexes and cultural practices (Table 12-4).

Individual cultural resources of Kaupuni hydrologic unit were not classified by the Hawaii 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 12-5). The Kaupuni hydrologic unit has archeological evidence addressing broad patterns in prehistory, with culturally significant sites including burials, religious structures, and trails. The terracing and auwai system that supported loi kalo along streams are still evident in some regions.

Table 12-4. Archaeological sites in the Kapuni hydrologic units, Oahu. (Source: Kipuka Database, 2020)
[LCA is Land Commission Award; Gr. is Grant;

Historic Site #	State Site #	SHPD Library	Land Award	Description
03998	50-80-07-03998	O-00250	7713:51	96 features including subsurface deposits and burials; total of 40 prehistoric features including 10 burials
00153	50-80-07-00153	O-00082	none	Kuilioloa Heiau on tip of Kaneilio point; 3 platforms with terracing; restored in 1980; legendary significance
03967			none	none
09993			none	none
01181	50-80-07-01181	O-00479	multiple	Waianae complex: heiau, habitation cave with extensive midden deposits & series of stone platforms; in good condition; prehistoric occupation, includes Kamaile Heiau
02320	50-80-07-02320	O-00761	none	Surface scatter of pounders in various state of manufacture & repair; destroyed
03332	50-80-07-03332	O-00456	none	Coral, lithic & midden scatter with possible paving on top of a knoll; basalt retaining wall w/ earthen terrace
03331	50-80-07-03331	O-00456	none	2 retaining walls, both are rock & mortar and extend into drainage & diversion channel; may once formed a dam across drainage, 1939 inscribed on one section
03329	5080-07-03329	O-00456	none	2 retaining wall segments constructed across slope, fronting a flat plain drainage area; small basalt boulders tacked against slope
03328	5080-07-03328	O-00456	none	2 retaining wall segments constructed with watersorn basalt boulders and large cobble
03327	5080-07-03327	O-00456	none	Linear rock retaining wall on SE bank of Kawiwi Stream constructed with waterworn basalt boulders
03325	5080-07-03325	O-00456	none	Mikilua Flume: mostly of sheet metal directly on ground w/ segments on wooden trestles; some sections of earthen ditches
03330	5080-07-03330	O-00456	none	Ditch sunk in dryland forest floor with no appreciable bank built up; may be part of ditch on 1906 map by Monsarrat
03200	5080-07-03200	O-00093	none	L-shaped site of agricultural habitation features
04844	50-80-07-04844	O-00298	none	Stacked wall
04845	50-80-07-04845	O-00298	none	Wall located 85m on the makai side of the deepest gully, 100m upslope of fenceline
04846	50-80-07-04846	O-00298	none	Complex of retaining walls and plaforms of various sizes on makai side of gully
02950	50-80-07-02950	O-00446	none	Waianae-Kai cattle walls of stacked construction integrated with various barbed wire and fence systems
00165	50-80-07-00165	O-00162	none	Punanaula Heiau on a ridge at the foot of Kawiwi w/ 2 large terraces with platforms and 2 enclosures on lower makai side paved with waterworn stones & iliili
02951	50-80-07-02951	O-00446	Ohule 3133:1	Waianae Kai Complex: very large site of 28 features w/ agricultural, habitational, & religious components
01179	50-80-07-01179	O-00181	none	Waianae Taro loi: series of terraces defined by flat earthen field areas faced w/stacked basalt; auwai system; surface artifiacts
00213	50-80-04-00213	O-00094	none	Kumakalii Heiau in Pukaloa Gulch not far from Kolekole Pass; destroyed

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 for the Islands of Hawaii, Maui, Lanai, and Kauai,* there are no fishponds present in the Kaupuni hydrologic unit (DHM, Inc., 1990). However, early accounts by McAllister (1933) describe a large freshwater fishpond called Pueha in which young mullet were enclosed untiled they completed their growth, giving the area the name *Wai* (for water) and *'anae* (full grown mullet).

Table 12-5. Cultural resource elements evaluated as part of the Hawaii Stream Assessment for Kaupuni 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.	Limited
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.	25
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.	CDE

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.	Moderate
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.	High
Historic Resources: 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.	none
Taro Cultivation: 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.	Yes

Registered Diversions Supporting Traditional & Customary Practices

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 with locations that are depicted in Figure 14-3. Table 12-6 provides a description of registed diversions that support instream uses.

Table 12-6. Registered diversions supporting instream uses in the Kaupuni hydrologic unit, Oahu.
[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	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.535	KAALA FARM	8-5-005:0	0.187	Yes	Yes	Yes	Yes

Photos. Honua Stream at old plantation diversion looking downstream with intake on right bank (CWRM 01/2016); b) Honua Stream flowing over diversion dam (CWRM 01/2016); c) upstream view of old plantation intake (CWRM 01/2016); d) upstream view of Honua Stream below intake (CWRM 5/2020).

a)

b)

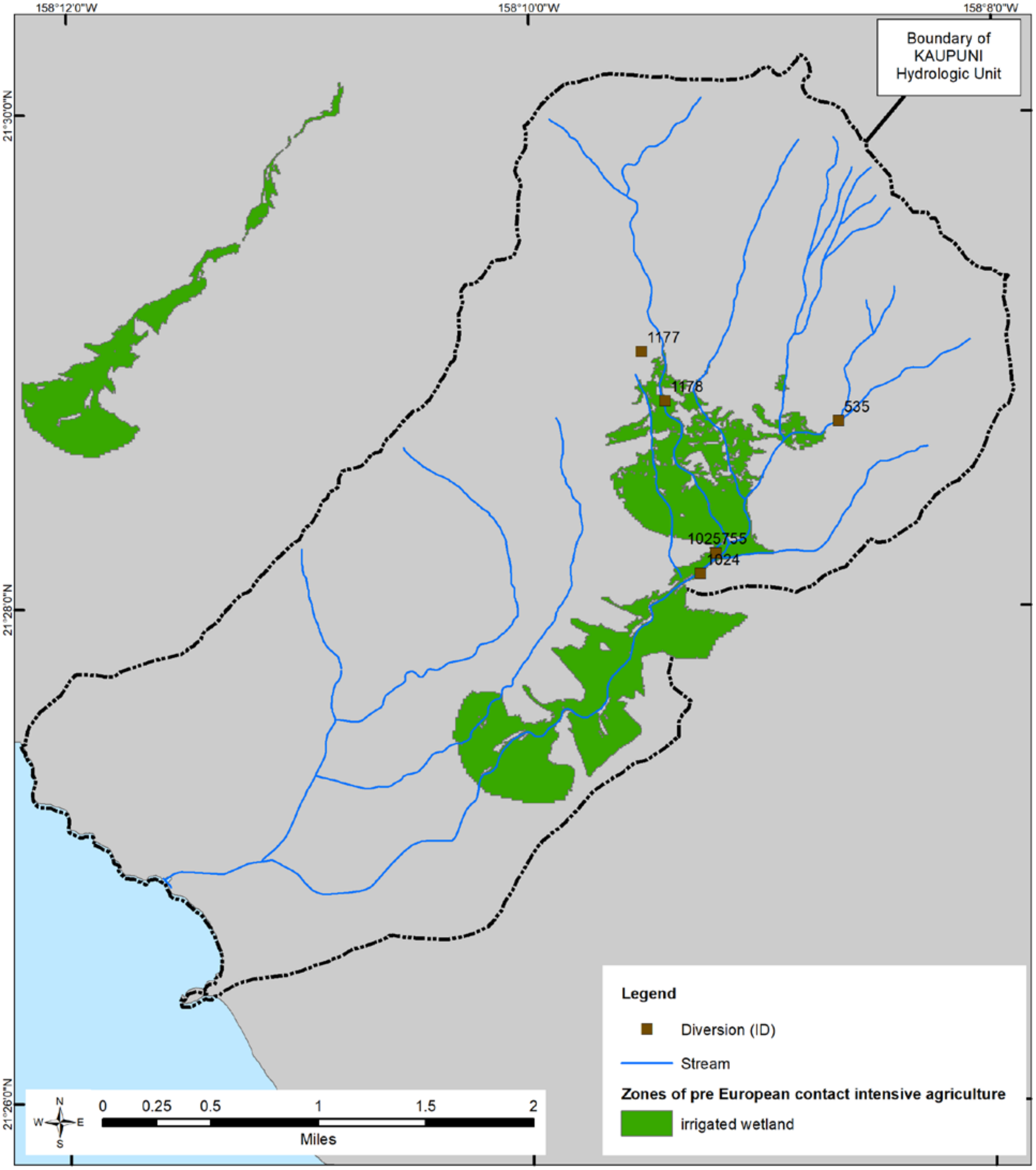
c)

d)

Table 12-6. continued.

e) Outflow from piped auwai to Kaala Farm from Kanewai Stream (CWRM 5/2017); f-h) Kaala Farm loi (CWRM 5/2017); i) return flow to Honua Stream from Kaala Farm			
e)		f)	
g)		h)	
i)			

Figure 12-3. Zones of pre-contact intensive agriculture in Kaupuni hydrologic unit, Oahu. (Source: Ladefoged et al., 2009)



13.0 Public Trust Uses of Water

The State Water Code (Hawaii 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 Hawaii 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.

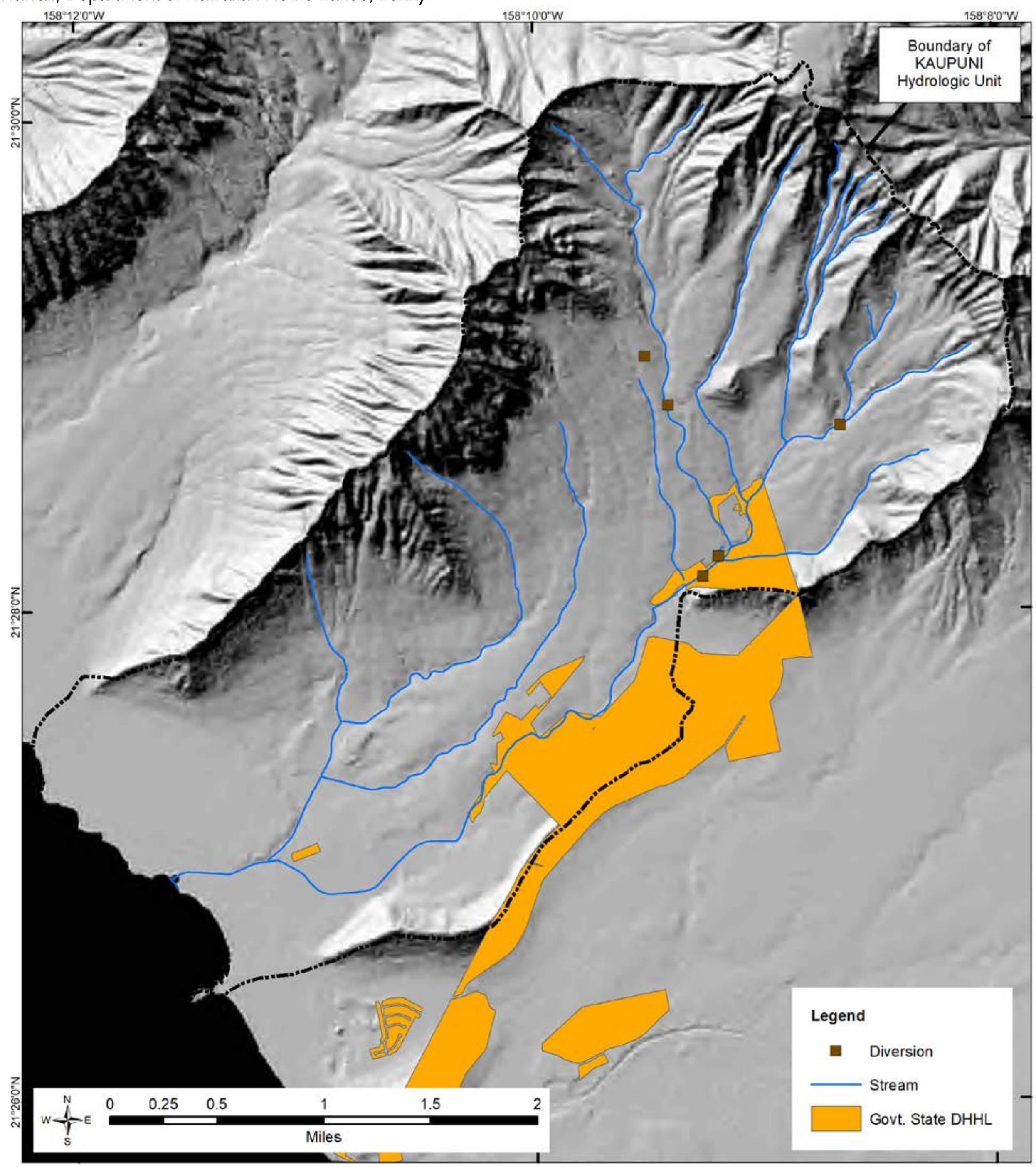
This solidified the Public Trust Doctrine as constitutional law. Further, Article 11, Section 7, states that the "State has an obligation to protect, control, and regulate the use of Hawaii's water resources for the benefit of its people." The Public Trust Doctrine now identifies four priority uses of 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 Kaupuni 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. The Honolulu BWS municipal system provides domestic and agricultural water use from groundwater sources in and nearby the hydrologic unit, and was covered in Chapter 3. The following is an analysis of reservations of water for Hawaiian Home Lands.

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, 2004). The DHHL manages a total of 350.7 acres (0.548 square miles) within the Kaupuni hydrologic unit (Figure 13-1). However, DHHL's long-range plan for the parcel assumes loi kalo development supplied by surface water (State of Hawaii Department of Hawaiian Home Lands, 2011). Based on the 2017 State Water Projects Plan Update for DHHL, DHHL has a projected water need in 2021 of 0.004 mgd for potable water from the Waianae Aquifer System and 0.0136 mgd of non-potable water from the Kaupuni Stream for loi kalo. Long range (2026-2031) projections of demand include increased need for potable water to approximately 0.124 mgd based on population growth.

Figure 13-1. Hawaiian Home Lands development parcels identified in the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Department of Hawaiian Home Lands, 2011)



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. Many of the diversions registered with the Commission in 1989 have been abandoned or gone unused for many years, as determined by follow-up site visit verifications.

Historic Agricultural Demands

In 1878, the first sugar fields were planted in Waianae Valley by Judge Hermann Widemann as part of the Waianae Sugar Company (WSC), the first major sugar plantation on Oahu. As the Company developed water resources through stream diversions, groundwater development tunnels, and irrigation systems, more acerage was planted (Figure 14-1). By 1890, 600 acres were planted in sugar cane and an elaborate irrigation system was built including hydropower to supply electricity for the plantation village (Figure 14-2). However, WSC closed in 1947 due to competition for labor, reduced water supply, and market forces.

Registered Diversions

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 with locations that are depicted in Figure 14-1. Table 14-1 provides a description of registed diversions that support instream uses.

Figure 14-1. Registered stream diversions and irrigation systems (abandonded and in use) in the Kaupuni hydrologic unit, Oahu.

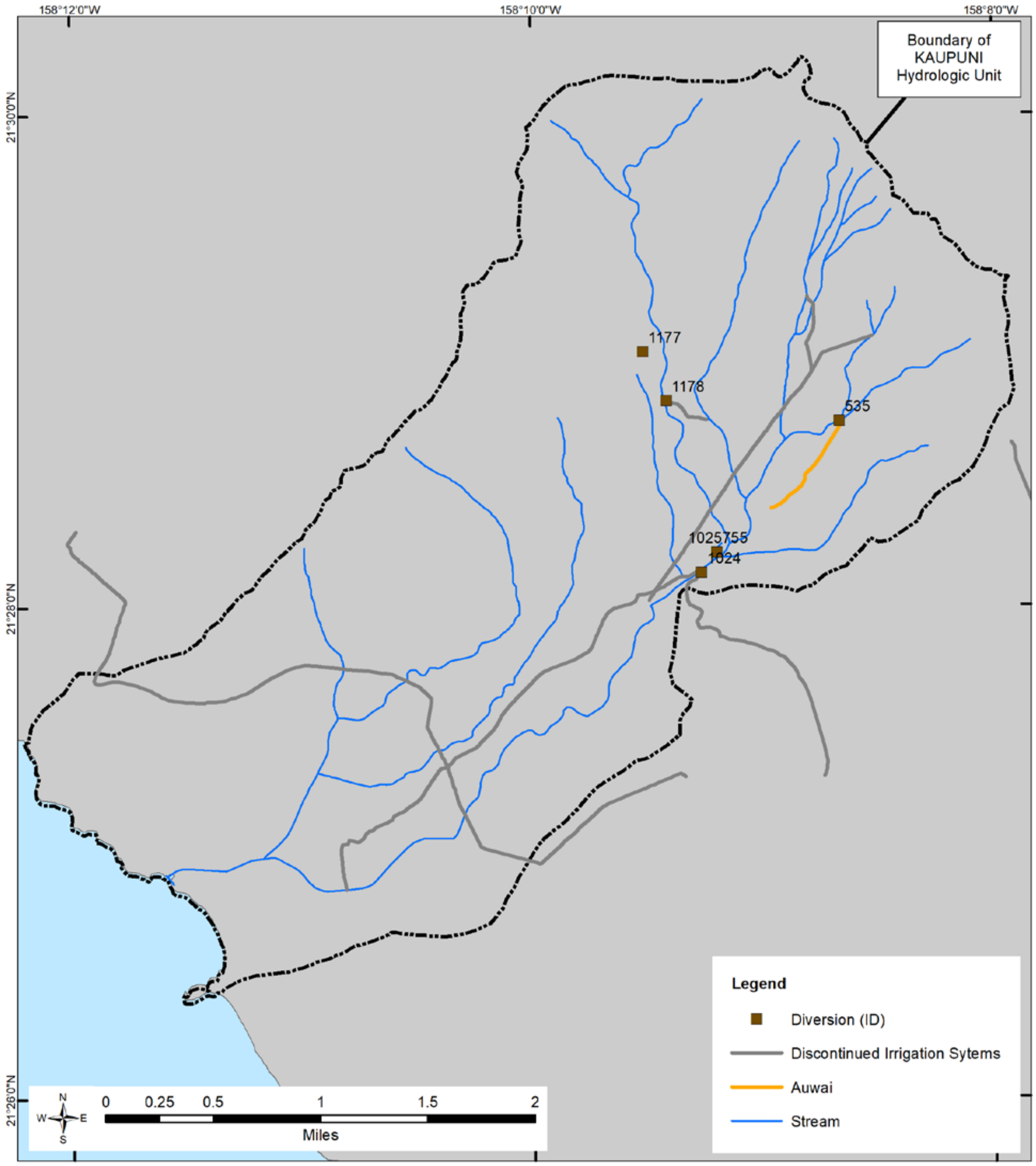


Table 14-1. Registered diversions supporting instream uses in the Kaupuni hydrologic unit, Oahu.
[Source of photos are denoted at the end of each description; CWRM, Commission on Water Resource Management; Chevrons ( ) indicate general direction of natural water flow to and out of diversions; Arrows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

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.1177	WAIANAE RANCH	8-5-006:011	--	Yes	Yes	Yes	Yes

Photos. Diversion of spring flow into pipe registered by Waianae Ranch (lessee of Land Division) for cattle watering; a-d) spring flow currently used for loi kalo (CWRM 03/2012)

a)

b)

c)

d)

Table 14-1. continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.1178	WAIANAE RANCH	8-5-006:011	--	No	Yes	No	No

Photos. Original diversion fed a flume that transferred water to next stream eastward (irrigation system is destroyed) for Waianae Sugar Company; pipe registered by Waianae Ranch (lessee of Land Division) for cattle watering, broke in 1991 and diversion is unused. a) Kumaipo Stream at 1600ft elevation looking downstream at diversion location based on remnant flume structure (CWRM 12/23/2016); b) Kumaipo Stream at 1600ft elevation looking upstream at diversion location (CWRM 12/23/2016)

a)

b)

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.1025	SILVA T	8-5-005:032	--	No	Yes	Yes	No

Photos. Hand carry water by bucket from BWS leakage flowing from Kunesh Tunnel; diversion was inactive in 1992 and in 2016 verifications (CWRM also consulted with Eric Enos, Kaala Farm).

a) No photos available

b)

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.1024	SILVA T	8-5-005:036	--	No	Yes	Yes	Yes

Photos. Old plantation dam with PVC pipe on Honua Stream; diversion was inactive in 1992 and in 2018 verifications (CWRM also consulted with Eric Enos, Kaala Farm); a) plantation dam on Kaupuni Stream from left bank with pipeline in photo (CWRM 11/2018); b) upstream view of Kaupuni Stream below dam (CWRM 11/2018); c) upstream view of dam with old pipeline on right bank (CWRM 11/2018); d) Kaupuni Stream above dam (CWRM 11/2018)

a)

b)

c)

d)

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.755	MANUEL JM	8-5-005:032	--	No	Yes	No	Yes

Photos. Hand carry water by bucket from BWS leakage flowing from Kunesh Tunnel; diversion was inactive in 1992 and in 2016 verifications (CWRM also consulted with Eric Enos, Kaala Farm).

Figure 14-2. Modified USGS survey map of Waianae Valley with development tunnels, stream diversions, irrigation flumes, measurement points, and pipelines identified with modifications by Board of Water Supply.

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 Hawaii 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 14-4). 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.

Current and Future Agricultural Demands

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 for 2015 (Figure 14-5). Using the 2015 Department of Agriculture Baseline Agriculture Survey, very little of the land designated as agriculture in the Kaupuni hydrologic unit is being used for agriculture. As of 2015, there was approximately 178.6 acres (0.279 square miles) of agriculture (Table 14-2). Water diverted from surface water sources in Kaupuni supplies the irrigation needs of loi and other diversified crops at Kaala Farm, a cultural learning center. Kaala Farm is expanding the production of banana, breadfruit, and taro fed by water from Kanewai Stream. From 2010-2019, the HBWS delivered an average of 0.64 mgd potable water to farmers in Waianae Valley (Figure 14-3).

Table 14-2. Crop area from the 2015 agricultural baseline and estimated demand (based on 3400 gallons per acre per day) for the Kaupuni hydrologic unit, Oahu. (Source: Perroy et al., 2015).

Crop	Area (acres)	Area (mi²)	Percent of Unit	Estimated Demand (mgd)
Diversified Crop	144.64	0.226	2.45%	0.492
Pasture	29.44	0.046	0.50%	n/a
Flowers/Foliage/Landscape	2.56	0.004	0.04%	0.009
Tropical Fruits	1.92	0.003	0.03%	0.007
Total	178.56	0.279	3.01%	0.518

Figure 14-3. Mean daily metered water delivery for agricultural uses in the Waianae aquifer system, Oahu. (Source: HBWS)

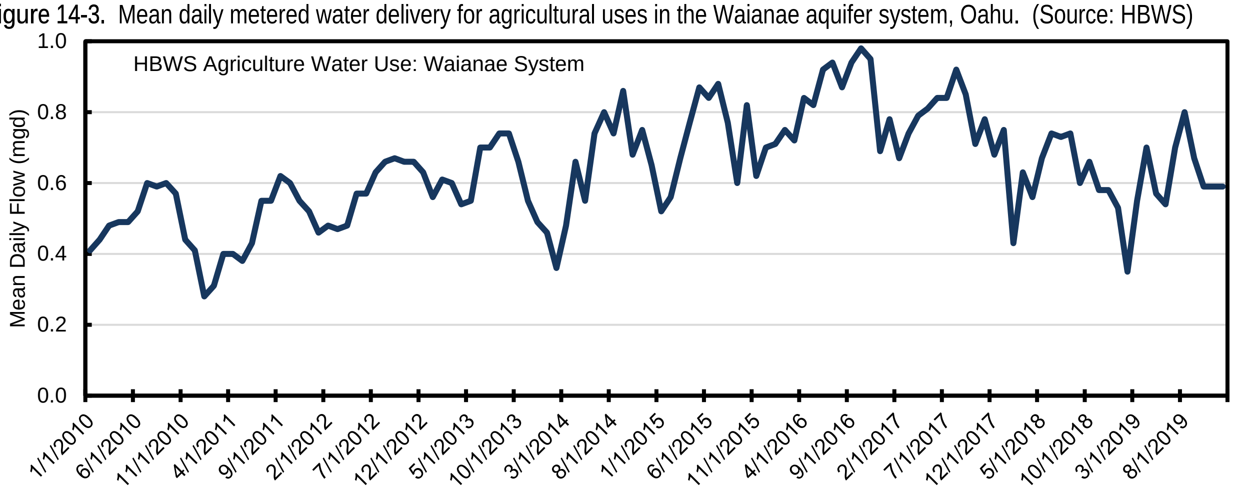


Figure 14-4. Agricultural Lands of Importance to the State of Hawaii (ALISH) for the Kaupuni hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015g)

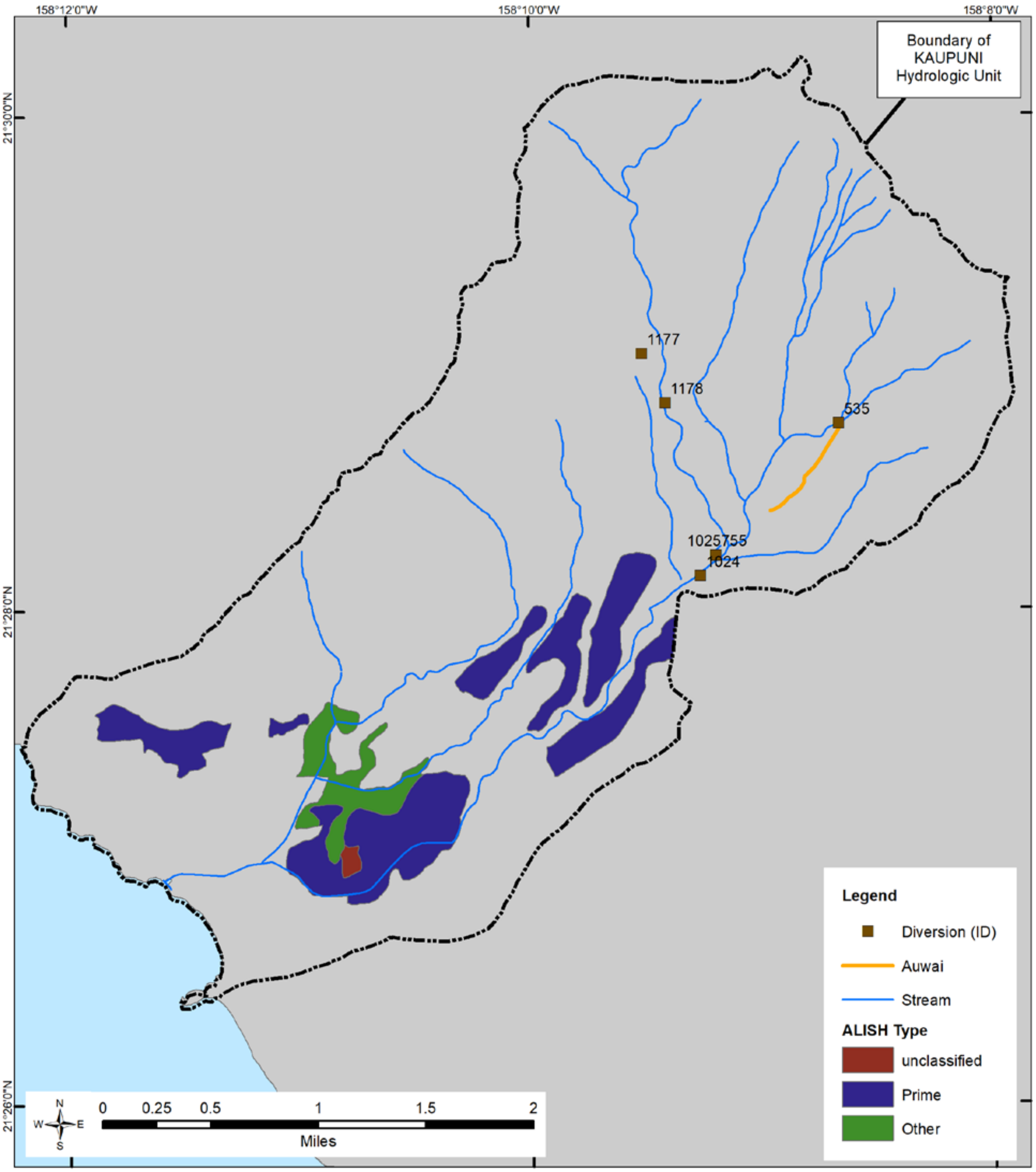
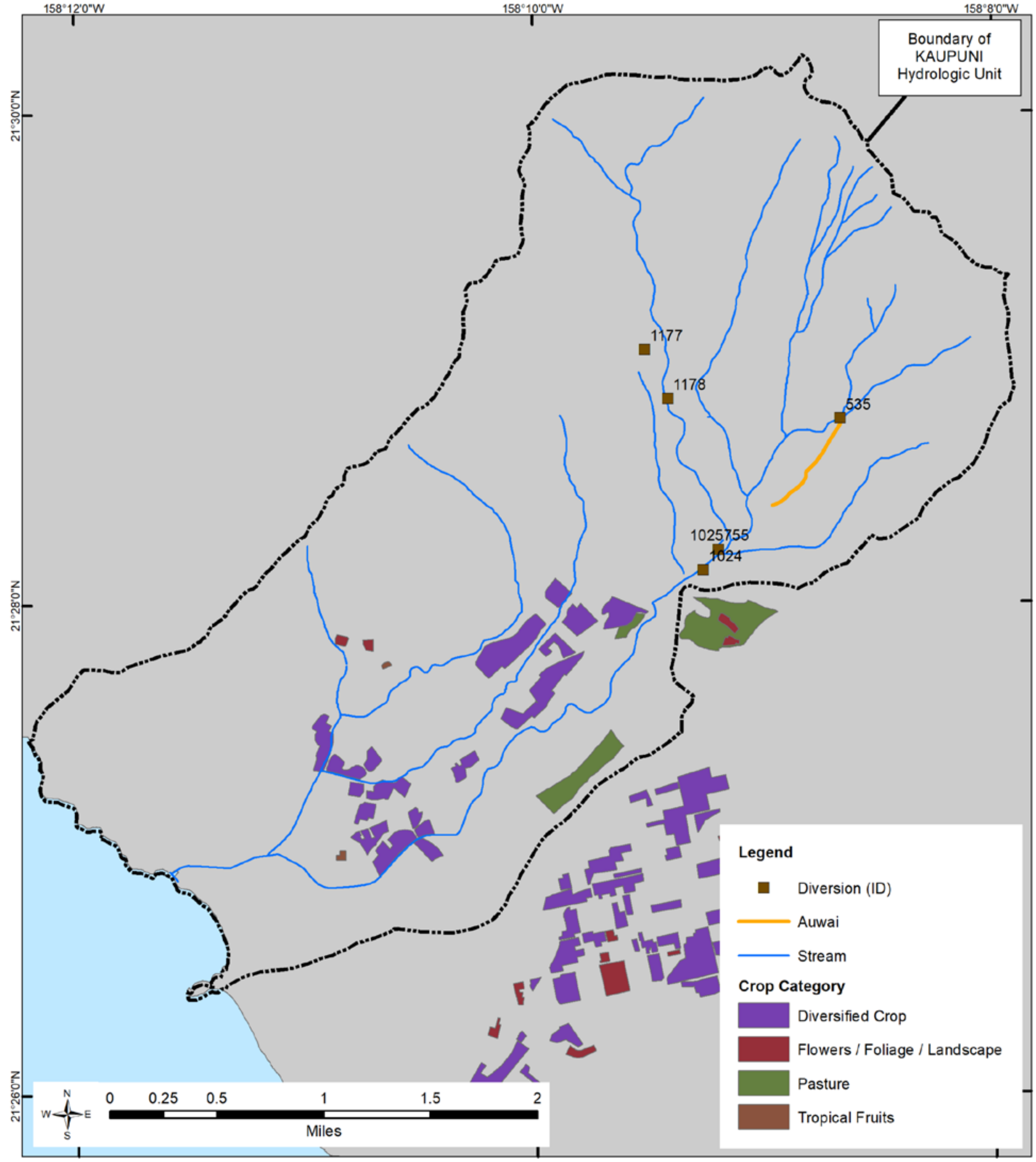


Figure 14-5. 2015 agricultural baseline by crop category in the Kaupuni hydrologic unit, Oahu. (Source: Perroy et al., 2015)



15.0 Bibliography

Amear, T., Chisholm, I., Beecher, H., Locke, A., and 12 other authors. (2004). Instream flows for riverine resource stewardship, revised edition. Instream Flow Council, Cheyenne, WY, 268 p.

Anthony, S.S., Hunt, Jr., C.D., Brasher, A.M.D., Miller, L.D., and Tomlinson, M.S. (2004). Water quality on the Island of Oahu, Hawaii, 1999-2001, U.S. Geological Survey Circular 1239, 37 p.

Cheng, C.L. (2016). Low-Flow Characteristics for Streams on the Islands of Kauai, Oahu, Molokai, Maui, and Hawaii, State of Hawaii. U.S. Geological Survey Scientific Investigations Report 2016-5103.

Cowardin, L.M., Carter, V., Golet, F.C., and LaRoe, E.T. (1979). Classification of wetlands and deeper habitats of the United States, U.S. Fish and Wildlife Service, Office of Biological Services, FWS/OBS-79/31, 131 p.

DBET. (2016). Residential home sales in Hawaii, trends and characteristics: 2008-2015.

DES, Department of Environmental Services, City and County of Honolulu. (2019). Waimanalo Wastewater Treatment Plant. https://www.honolulu.gov/cms-env-menu/site-env-sitearticles/1193-wwm_waimanalo_wwtp.html [accessed April 2020]

DHM, Inc., Bishop Museum, Public Archaeology Section, Applied Research Group, and Moon, O'Connor, Tam and Yuen. (1990). Hawaiian fishpond study, Islands of Hawaii, Maui, Lanai and Kauai: Prepared for State of Hawaii, Office of State Planning, Coastal Zone Management Program, 196 p.

Ego, K. (1956). Life history of fresh water gobies. Project no. F-4-R. Fresh Water Game Fish Management Research, Department of Land and Natural Resources, Territory of Hawaiʻi, Honolulu, 24 p.

Ekern, P.C., and Chang, J-H. (1985). Pan evaporation: State of Hawaii, 1894-1983. Hawaii Department of Land and Natural Resources, Division of Water and Land Development, Report R74, p.1-3, 38-48.

Engott, J.A., and Vana, T.T. (2007). Effects of Agricultural Land-Use Changes and Rainfall on Ground-Water Recharge in Central and West Maui, Hawaiʻi, 1926–2004: U.S. Geological Survey Scientific Investigations Report 2007–5103, 56 p.

Engott, J.A., Johnson, A.G., Bassiouni, M., Izuka, S.K., Rotzoll, K. (2017). Spatially distributed groundwater recharge for 2010 land cover estimated using a water budget model for the island of Oahu, Hawaii. Scientific Investigations Report 2015-5010.

Englund, R., and Filbert, R. (1997). Discovery of the native stream goby, *Lentipes concolor*, above Hawaii's highest waterfall, Hiilawe Falls. Bishop Museum Occasional Papers, v. 49, p. 62-64.

Englund, R., Polhemus, D. A., and Preston, D. J. (2000). Assessment of the impacts of rainbow trout predation on native aquatic invertebrate species within Kokee State Park streams, Kauai, Hawaii. Bishop Museum Technical Report 18.

Falinski, K., Reed, D., Callender, T., Fielding, E., Newbold, R., and Yurkanin, A. (2018). Hui O Ka Wai Ola Water Quality Data [data set]. Zenodo. http://doi.org/10.5281/zenodo.1173717 (accessed Dec 2018).ai

Federal Emergency Management Agency. (2014). FEMA Flood Hazard Zones. Retrieved August 2015, from Hawaii State GIS Web site: http://hawaii.gov/dbedt/gis/data/dfirm_metadata.htm

Ferris, J.G., Knowles, D.B., Brown, R.H., Stallman, R.W. (1962). Theory of aquifer tests. U.S. Geological Survey Water-Supply Paper 1536.

Fitzsimons, J.M., and Nishimoto, R.T. (1990). Territories and site tenacity in males of the Hawaiian stream goby *Lentipes concolor* (Pisces: Gobbidae). Ichthyological Exploration of Freshwaters, v. 1, p. 185-189.

Frazier, A.G., Giambelluca, T.W. (2017). Spatial trend analysis of Hawaiian rainfall from 1920 to 2012. International Journal of Climatology, 37(5): 2522-2531.

Frazier, A.G., Elison Timm, O., Giambelluca, T.W., Diaz, H.F. (2018). The influence of ENSO, PDO, and PNA on secular rainfall variations in Hawai‘i. Climate Dynamics, 51 (5-6): 2127-2140.

Giambelluca, T.W., Nullet, M.A., Ridgley, M.A., Eyre, P.R., Moncur, J.E.T., and Price, P. (1991). Drought in Hawaii. State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development, Report R88, 232 p.

Giambelluca, T.W., and Nullet, D. (1992). Influence of the trade-wind inversion on the climate of a leeward mountain slope in Hawaii. Climate Research, 1, p. 207-2126.

Giambelluca, T.W., Chen, Q., Frazier, A.G., Price, J.P., Chen, Y.-L., Chu, P.-S. Eischeid, J.K., and Delparte D.M. (2013). Online Rainfall Atlas of Hawaii. Bulletin of the American Meteorological Society, 94, 313-316.

Giambelluca, T.W., Shuai, X., Barnes, M.L., Alliss, R.J., Longman, R.J., Miura, T., Chen, Q., Frazier, A.G., Mudd, R.G., Cuo, L., Businger, A.D. (2014). Evapotranspiration of Hawai‘i. Final report submitted to the U.S. Army Corps of Engineers—Honolulu District, and the Commission on Water Resource Management, State of Hawai‘i.

Gingerich, S.B. (1999a). Ground water and surface water in the Haiku area, East Maui, Hawaii: U.S. Geological Survey Water-Resources Investigations Report 98-4142, 29 p.

Gingerich, S.B. (1999b). Ground-water occurrence and contribution to streamflow, Northeast Maui, Hawaii: U.S. Geological Survey Water-Resources Investigations Report 99-4090, 70 p.

Gingerich, S.B. and Oki, D.S. (2000). Ground Water in Hawaii. U.S. Geological Survey Fact Sheet 126-00.

Gingerich, S.B. (2005). Median and Low-Flow Characteristics for Streams under Natural and Diverted Conditions, Northeast Maui, Hawaii. U.S. Geological Survey, Scientific Investigations Report 2004-5262, 72 p.

Gingerich, S.B., Yeung, C.W., Ibarra, T.N., and Engott, J.A. (2007). Water use in wetland kalo cultivation in Hawai`i: U.S. Geological Survey Open-File Report 2007-1157, 68 p. [http://pubs.usgs.gov/of/2007/1157/]. Version 1.0, July 24, 2007, Revised Figure 36, p.

Gingerich, S.B., Engott, J.A. (2012). Ground water availability in the Lahaina District, West Maui, Hawaii. U.S. Geological Survey, Scientific Investigations Report, 2012-5010, 90 p.

Grady, C. E. (2006). Volume and Petrologic Characteristics of the Koloa Volcanics, Kauai, Hawaii. Master of Science in Geology and Geophysics. University of Hawaii Manoa

Handy, E.S.C., Handy, E.G., and Pukui, M.K. (1972). Native Planters in Old Hawaii: Their Life, Lore, and Environment. Bishop Museum Press, Honolulu, Hawaii: Bernice P. Bishop Museum Bulletin 233, 676 p.

Holmes, A. (1920). The nomenclature of petrology. New York, NY.

Honolulu Board of Water Supply. (2011). Koolaupoko Stream Diversion Survey, 2008-2011: Stream Diversion Field Notes. Honolulu Board of Watery Supply Water Resources Division Hydrology-Geology Section conducted for State of Hawaii Commission on Water Resource Management.

Izuka, S.K., Hill, B.R., Shade, P.J, Tribble, G.W. (1992) Geohydrology and possible transport routes of polychlorinated biphenyls in Haiku Valley, Oahu, Hawaii. U.S. Geological Survey Water-Resources Investigations Report 92-4168.

Izuka, S.K., Oki, D.S., and Chen, C. (2005). Effects of irrigation and rainfall reduction on ground-water recharge in the Lihue Basin, Kauai, Hawaii: U.S. Geological Survey Scientific Investigations Report 2005-5146, 48 p.

Jacobi, J.D. (1989). Vegetation Maps of the Upland Plant Communities on the Islands of Hawai'i, Maui, Moloka'i, and Lana'i, Technical Report Number 68. University of Hawaii at Manoa, Honolulu, Hawaii: Cooperative National Park Resources Studies Unit.

Juvik, J.O., and Nullet, D. (1995). Relationships between rainfall, cloud-water interception, and canopy throughfall in a Hawaiian montane forest. In Hamilton, L.S., Juvik, J.O., and Scatena, F.N., (eds.), Tropical montane cloud forests: New York, Springer-Verlag, p. 165-182.

Kaiser, B., Krause, N., Mecham, D., Wooley, J., and Roumasset, J. (n.d.). Environmental valuation and the Hawaiian economy: Introduction and executive summary, 140 p. Retrieved January 2008, from http://www.uhero.hawaii.edu/workingpaper/HawaiiEnviroEvaluation.pdf

Kido, M. (1996). Recovery processes in Hawaiian streams, p. 76-93. In: Will stream restoration benefit freshwater, estuarine, and marine fisheries?: Proceedings of the October, 1994 Hawaii stream restoration symposium. State of Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu.

Kikuchi, W.K. (1973). Hawaiian aquacultural system. Doctoral thesis, University of Arizona. Manuscript on file in the Bernice P. Bishop Museum Library, Honolulu

Lau, L. S. and Mink, J. F. (2006). Hydrology of the Hawaiian Islands. Honolulu: University of Hawaii Press, 274 p.

Macdonald, G. A., Davis, D. A. and Cox, D. C. (1960). Geology and ground water resources of the island of Kauai, Hawaii. Haw. Div. Hydrog. Bull. 13, 212 p.

Maui County. (2018a). Draft Maui Island Water Use & Development Plan. Retrieved September 2018, from https://www.mauicounty.gov/2051/Maui-Island-Water-Use-Development-Plan

Maui County. (2018b) West Maui Community Plan. Housing Technical Document. County of Maui Departmetn of Planning. https://wearemaui.org/technical-resource-papers-home

McAllister, J.G. (1933). Archeology of Oahu. B.P. Bishop Museum Bulletin 104. Honolulu, HI.

McRae, M.G. (2007). The potential for source-sink population dynamics in Hawaii's amphidromous species, p. 87-98. In: N.L. Evenhuis and J.M. Fitzsimons (ed.), Biology of Hawaiian streams and estuaries: Proceedings of the symposium on the biology of Hawaiian streams and estuaries. Bishop Museum Bulletin in Cultural and Environmental Studies, v. 3, Honolulu.

Mink, J.F. (1978). Waianae Water Development Study. Honolulu Board of Water Supply Study.

National Park Service, Hawaii Cooperative Park Service Unit. (1990). Hawaii Stream Assessment: A Preliminary Appraisal of Hawaii's Stream Resources: Prepared for State of Hawaii, Commission on Water Resource Management, Report R84, 294 p.

National Oceanic and Atmospheric Administration. (2005). C-CAP Regional Land Cover and Change. Office for Coastal Management. https://coast.noaa.gov/digitalcoast/data/ccapregional.html

National Park Service. (2007). Haleakala National Park. Retrieved January 2008, from http://www.nps.gov/hale/.

Nichols, W.D., Shade, P.J., Hunt Jr., C.D. (1996). Summary of the Oahu, Hawaii, Regional Aquifer-System Analysis. U.S. Geological Survey Professional Paper 1412-A.

Nishimoto, R.T., and Kuamoo, D.G.K. (1991). The occurrence and distribution of the native goby (*Lentipes concolor*) in Hawai‘i Island streams with notes on the distribution of the native goby species, p. 77-95. In: W. Devick (ed.), New directions in research, management and conservation of Hawaiian freshwater stream ecosystems: Proceedings of the 1990 symposium on stream biology and fisheries management. State of Hawaii Department of Land and Natural Resources, Division of Aquatic Resources, Honolulu.

Nishimoto, R.T., and Kuamoo, D.G.K. (1997). Recruitment of goby postlarvae into Hakalau stream, Hawai‘i Island. Micronesica, v. 30, p. 41-49.

Nullet, D. (1987). Energy sources for evaporation on tropical islands. Physical Geography, 8: p. 36-45.

Nullet, D., and Giambelluca, T.W. (1990). Winter evaporation on a mountain slope, Hawaii. Journal of Hydrology: 112, p. 257-265.

Oki, D.S. (2003). Surface Water in Hawaii. U.S. Geological Survey, Fact Sheet 045-03.

Oki, D.S. (2004). Trends in Streamflow Characteristics at Long-Term Gaging Stations, Hawaii. U.S. Geological Survey, Scientific Investigations Report 2004-5080, 120 p.

Oki, D.S., Rosa, S.N., Yeung, C.W. (2010). Flood-frequency estimates for streams on Kauai, Oahu, Molokai, Maui, and Hawaii, State of Hawaii. U.S. Geological Survey Scientific Investigations Report 2010-5035. 121 p.

OmniTrak Group Inc. (2007). Hawaii State Parks Survey: Prepared for Hawaii Tourism Authority, 98 p. Retrieved February 2008, from http://www.hawaiitourismauthority.org/documents_upload_path/reports/HTAPRO-Report-12-01-2007.pdf

Pacific Disaster Center. (2007). Natural Hazards: Flood. Retrieved March 2008, from http://www.pdc.org/iweb/flood.jsp?subg=1.

PBR Hawaii. (2004). Maui Island Plan: Prepared for State of Hawaii, Department of Hawaiian Home Lands, 340 p.

Penn, D.C. (1997). Water and energy flows in Hawai'i taro pondfields: Honolulu, Hawaii, University of Hawaii at Manoa, Ph.D. dissertation, 376 p.

Radtke, R.L., Kinzie III, R.A., and Folsom, S.D. (1988). Age at recruitment of Hawaiian freshwater gobies. Environmental Biology of Fishes, v. 23, p. 205-213.

Rea, A., Skinner, K.D. (2012). Geospatial datasets for watershed delineation and characterization used in the Hawaii StreamStats web application. U.S. Geological Survey Data Series, 680. 12 p.

Scholl, M.A., Gingerich, S.B., and Tribble, G.W. (2002). The influence of microclimates and fog on stable isotope signatures used in interpretation of regional hydrology: East Maui, Hawaii. Journal of Hydrology, 264 (2002), p. 170-184.

Scott, J.M., Mountainspring, S., Ramsey, and Kepler, C.B. (1986). Forest Bird Communities of the Hawaiian Islands: Their Dynamics, Ecology and Conservation. Studies in Avian Biology, No. 9, 431 p.

Shade, P.J. (1999). Water budget of East Maui, Hawaii, U.S. Geological Survey Water Resources Investigations Report 98-4159, p. 36.

Sherrod, D.R., Sinton, J.M., Watkins, S. E., and Brunt, K.M. (2007). Geological Map of the State of Hawaii: U.S. Geological Survey Open-File Report 2007-1089, 83 p., 8 plates, scales 1:100,000 and 1:250,000, with GIS database. U.S. Geological Survey.

Soil Survey Staff. (2020). Web Soil Survey. Natural Resources Conservation Service, U.S. Department of Agriculture. Available at http://websoilsruvey.sc.egov.usda.gov [accessed March 2020]

State of Hawaii, Commission on Water Resource Management. (2005a). Commission on Water Resource Management surface-water hydrologic units: A management tool for instream flow standards. Department of Land and Natural Resources, Commission on Water Resource Management, Report PR-2005-01, 111 p.

State of Hawaii, Commission on Water Resource Management. (2005b). Hawaii Drought Plan 2005 Update. State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development, p. 1-1 to 5-4.

State of Hawaii, Commission on Water Resource Management. (2007). Hawaii Water Plan: Water Resource Protection Plan, Public review draft. Department of Land and Natural Resources, Commission on Water Resource Management, 557 p.

State of Hawaii, Commission on Water Resource Management. (2015c). Surface-water hydrologic unit GIS data layer. Department of Land and Natural Resources, Commission on Water Resource Management. Retrieved July 2015.

State of Hawaii, Commission on Water Resource Management. (2017). State Water Projects Plan Update: Department of Hawaiian Home Lands. http://files.hawaii.gov/dlnr/cwrm/planning/swpp2017.pdf

State of Hawaii, Commission on Water Resource Management. (2019). Water Resources Projection Plan.

State of Hawaii, Commission on Water Resource Management. (2020a). Well index database [Database file]. Retrieved April 2020.

State of Hawaii, Commission on Water Resource Management. (2020b). Diversion Index GIS Layer [Database file]. Retrieved Aprl 2020.

State of Hawaii, Commission on Water Resource Management. (2020c). Water Use Reporting [Database file]. Retrieved April 2020.

State of Hawaii, Commission on Water Resource Management. (2020d). Irrigation Ditch GIS Layer [Database file]. Retrieved March 2020.

State of Hawaii, Department of Hawaiian Homelands. (2011). Waimanalo Regional Plan. https://dhhl.hawaii.gov/po/regional-plans/oahu-regional-plans/ [accessed April 2020]

State of Hawaii, Department of Health, Environmental Planning Office. (1987). Water Quality Standards Map of the Island of Maui [map]. Retrieved July 2015, from http://hawaii.gov/health/ environmental/water/cleanwater/wqsmaps/index.html.

State of Hawaii, Department of Health, Environmental Planning Office. (2018). Final 2018 List of Impaired Waters in Hawaii Prepared Under Clean Water Act §303(d). Retrieved March 2020 from http://hawaii.gov/health/environmental/env-planning/wqm/wqm.html

State of Hawaii, Division of Aquatic Resources. (2015). Point-quadrat survey database. Accessed October 2015.

State of Hawaii, Division of Forestry and Wildlife. (2020a). Watershed Partnership Program. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Division of Forestry and Wildlife. (2020b). Hawaii Forest Reserve System. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020b). Hunting areas [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/huntareas.shp.htm

State of Hawaii, Office of Planning. (2020a). Coastal resources [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020b). Critical habitat [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020c). Ditches [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020d). Vegetation [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020e). 500 foot contours [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020f). Oahu streets [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020g). Na Ala Hele state trails system [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020h). Water Quality Classifications [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/classwater.shp.htm

State of Hawaii, Office of Planning. (2020j). ALISH [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020k). ALUM [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020l). Areas of threatened and endangered plants [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020m). Dams [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020n). Reserves [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020p). Conservation District Subzones [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020q). Tax Map Key parcels, Island of Oahu [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020r). Division of Aquatic Resources (DAR) stream [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020s). Aquifers [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020u). State land use district [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Website: http://planning.hawaii.gov/gis/download-gis-data/

State of Hawaii, Office of Planning. (2020x). Historic land divisions (Ahupuaa) for the island of Oahu [GIS data file]. Retrieved March 2020, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/histlanddiv.shp.htm

State of Hawaii, Office of Planning. (2015b). Soils [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/soils.htm

State of Hawaii, Office of Planning. (2015c). National wetlands inventory [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/wetlands.shp.htm

State of Nevada, Department of Conservation and Natural Resources, Division of Water Resources. (n.d.). Water words dictionary: Technical water, water quality, environmental, and water-related terms. Retrieved February 2008, from http://water.nv.gov/WaterPlanning/dict-1/ww-dictionary.pdf

Stearns, H.T., Vaksvik, K.N. (1935). Geology and ground-water resources of the island of Oahu, Hawaii. Hawaii Division of Hydrography Bulletin 1.

Stearns, H.T. (1946). Geology of the Hawaiian Islands. Hawaii Division of Hydrography Bulletin 8.

Takahashi, K.J., Mink, J.F. (1985). Evaluation of major dike-impounded ground-water reservoirs, Island of Oahu. U.S. Geological Survey Water-Supply Paper 2217.

Takasaki, K.J., Hirashima, G.T., Lubke, E.R. (1969). Water Resourcs of Windward Oahu, Hawaii. U.S. Geological Survey Water-Supply Paper 1894.

University of Hawaii. (2003). Drought Risk and Vulnerability Assessment and GIS Mapping Project. State of Hawaii, Department of Land and Natural Resources, Division of Water and Land Development, 157 p.

U. S. Department of Agriculture, Natural Resources Conservation Service, Conservation Engineering Division. (1986). Appendix A: Hydrologic Soil Groups. Urban Hydrology for Small Watersheds. (Technical Release 55.) Retrieved December 26, 2007 from http://www.info.usda.gov/CED/ftp/CED/tr55.pdf

U.S. Department of Agriculture, Soils Conservation Service. [In cooperation with The University of Hawaii Agriculture Experiment Station.] (1972). Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii. Washington, DC: U.S. Government Printing Office.

U.S. Environmental Protection Agency. (2008). “Impaired Waters and Total Maximum Daily Loads.” Retrieved April 23, 2008 from http://www.epa.gov/owow/tmdl/intro.html

U.S. Environmental Protection Agency. (2020). National Water Quality Montoring Council Water Quality Portal. Retrieved April 10, 2020 from https://www.watequalitydata.us

U.S. Environmental Protection Agency, Region 9, and State of Hawaii, Department of Health. (2002). Revisions to total maximum daily loads for the Ala Wai Canal, Island of Oahu, Hawaii. Retrieved February 2008, from http://hawaii.gov/health/environmental/env-planning/wqm/awtmdlfinal.pdf

U.S. Geological Survey. (1996). Digital raster graphics (DRG) data. Retrieved July 2015, from http://data.geocomm.com/drg/index.html.

U.S. Geological Survey. (2001). Digital elevation model (DEM) – 10 meter. Retrieved July 2015, from http://data.geocomm.com/dem/.

U.S. Geological Survey. (2007). Geologic Map of the State of Hawaii. [With GIS database.] (Open File Report 2007-1089). Reston, VA: D.S. Sherrod, J.M. Sinton, S.E. Watkins, and K.M. Brunt.

U.S. Geological Survey. (2001). National Gap Analysis Project Land Cover Data Portal. https://gapanalysis.usgs.gov/gaplandcover/data/download/

U.S. Geological Survey. (2020). National Water Information System Data Portal. https://waterdata.usgs.gov/nwis [accessed March 2020]

Visher, F.N., Mink, J.F. (1969). Ground water resource sin Southern Oahu, Hawaii. U.S. Geological Survey Water-Supply Paper 1778.

Wilcox, C. (1996). Sugar water: Hawaii’s plantation ditches: Honolulu, University of Hawaii Press, p. 191.

Winchell, Horace. (1947). Honolulu Series, Oahu, Hawaii. Bulletin of the Geological Society of America. 58: 1-48.

Wilson Okamoto & Associates, Inc. (1983). Instream Use Study, Windward Oahu: Prepared for State of Hawaii, Division of Water and Land Development, Report R68, 154 p.

Ziegler, A.C. (2002). Hawaiian natural history, ecology, and evolution. Honolulu: University of Hawaii Press, 477 p.

16.0 Appendices

Appendix A Kaupuni, Oahu, Hawaii. June 2008. DAR Watershed Code: 35005
State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources.

<u>APPENDIX A</u>

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

Atlas of Hawaiian Watersheds & Their Aquatic Resources Kaupuni, O‘ahu