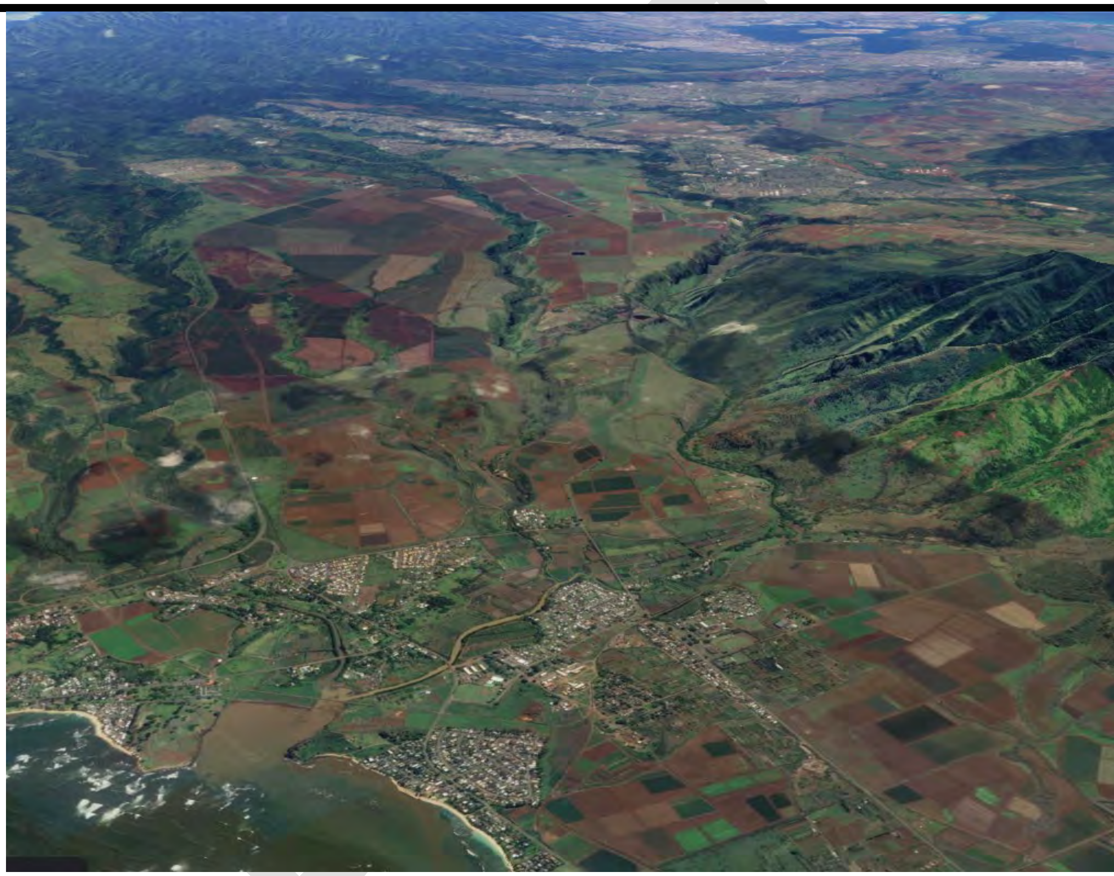
Instream Flow Standard Assessment Report

Island of Oahu
Hydrologic Units 3082
Kiikii

June 2021 **DRAFT PR-2021-03**



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

COVER
Satallite image of Kiikii hydrologic units with the Kaukonahua and Poamoho streams flowing into Kaiaka 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 Kiikii is a 58.4 square mile region located on the north shore of the island of Oahu between the Koolau and Waianae mountains (Figure 1-3). The hydrologic unit includes the ahupuaa of Kamananui and Paalaa in the Moku of Waialua and a portion of the ahupuaa of Waianae. The Kiikii hydrologic unit includes ares of the eastern flank of the Waianae Mountain Range and Mt Kaala, and the western flank of the Koolau Mountain Range, including the watersheds of Kaukonahua and Poamoho, which are 39.8 square miles, and 17.9 square miles in size, respectively. The streams of Kaukonahua and Poamoho have flow paths that measure 28.8 miles and 24.1 miles, respectively, flowing west-northwest into Kaiaka Bay. Mean annual precipitation in the Kaukonahua and Poamoho watersheds are 85.8 inches and 65.7 inches, respectively. The streams flow from a maximum elevation of 3,940 feet to sea level (Figures 1-4 and 1-5). Much of the unit is composed of the lava flows of the shield building Waianae Volcanics and Koolau Volcanics that are characterized by high porosity and transmissivity. The shield-building phase from the Waianae Volcano ended approximately 3 million years ago with erosion and subsidence modifying the original volcano. The saddle region between the Waianae and Koolau rift zones is composed of overlapping layers of alluvium and lava flows. The shield building phase of the Koolau Volcano ended approximately 1.8 million years ago. As Kaukonahua Valley formed, eroded sediments filled the valley floor and lower gradient fluvial regions.

Fog drip and orographic precipitation contributes to groundwater recharge and runoff on the windward sides of the Koolau and Waianae Mountains. Orographic rainfall is blown over the crest of the Koolau and contributes to the water budget of Kiikii. Mt. Kaala, the tallest point on Oahu, and its high elevation bog environment forms a small portion of the Kiikii hydrologic unit and makes a minor contribution to surface flow. Landcover in the hydrologic unit is dominated by non-native scrub and grassland, with upper elevations consisting mostly of both native and non-native evergreen forest while the middle and lower elevations supporting mostly agriculture. The higher elevation portions of the hydrologic unit are composed of conservation land owned by the Department of Land and Natural Resources, Kamehameha Schools, or the United States Army, with other lands owned by Dole Foods or the Department of Agriculture. Watershed landcover and stewardship are rated poorly, with few native aquatic species living above the lowest estuarine reaches. The Hawaii Stream Assessment listed Kiikii as a candidate stream for protection based on its outstanding and “blue ribbon” recreational resources. There are 566 census blocks in the Kiikii hydrologic unit, with a total population of 46,104 people, with census designated places of Haleiwa, Waialua, Schofield Barracks, Whitmore Village, and Wahiawa (U.S. Census Bureau, Office of Planning 2011). There are two main highways that pass through Kiikii: Farrington Highway between Wahiawa and Waialua and Kamehamea Highway between Waialua and Haleiwa (Figure 1-6). Numerous irrigation systems were built during the 1900s to 1930s to support the agricultural water needs of the area as well as numerous reservoirs for storage. Wahiawa Reservoir, produced by the construction of Wahiawa Dam at theconfluence of the North and South Forks of Kaukonahua Stream, supports the Wahiawa Freshwter State Recreation Area. The Wahiawa Ditch transports water from Wahiawa Reservoir to diversified agricultural demands at lower elevations near Haleiwa and Waialua while the Helemano Ditch transports water to upper elevation agricultural demands.

Current Instream Flow Standard

The current interim instream flow standard (IFS) for streams in the Kiikii hydrologic unit 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 Leeward 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."

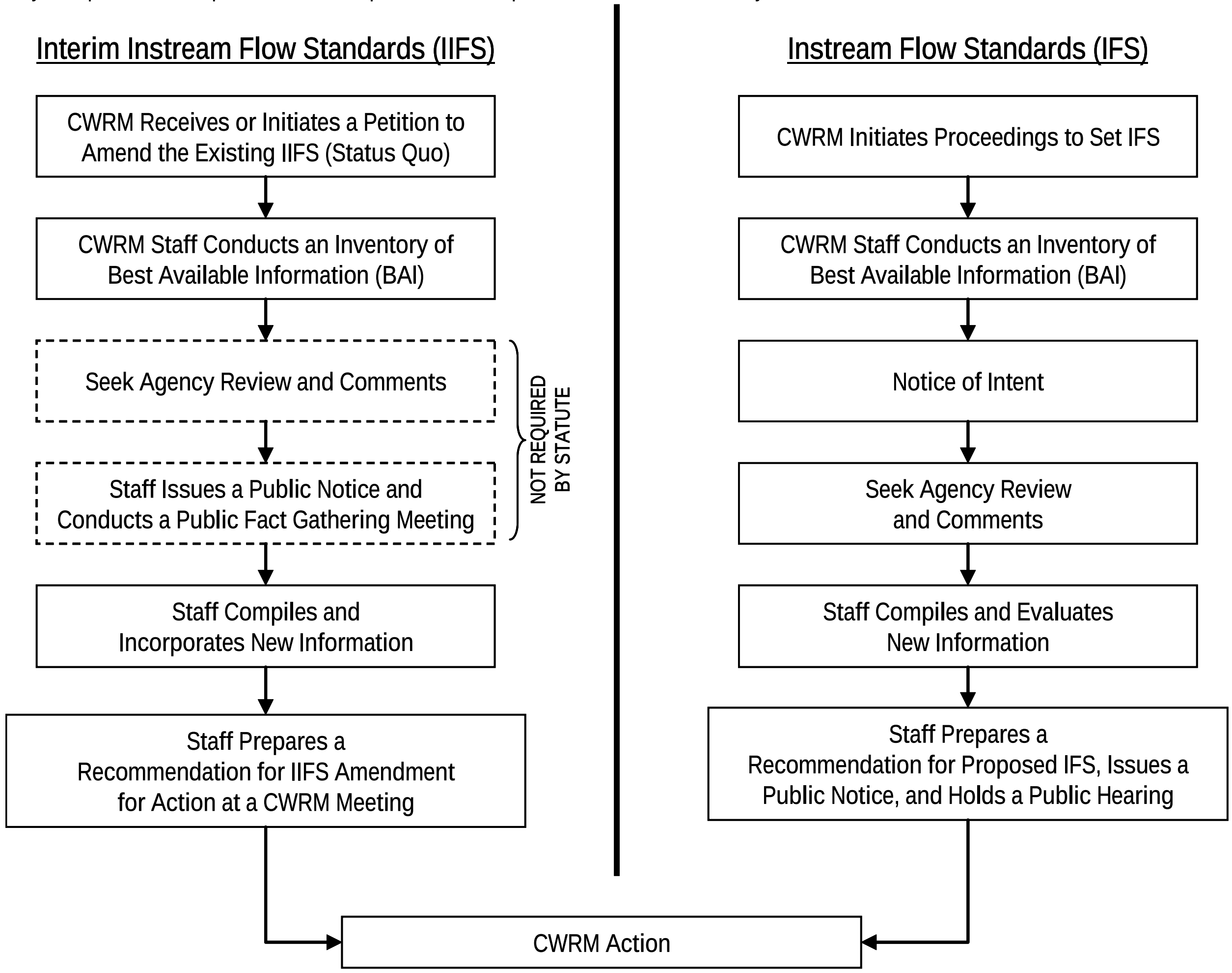
Figure 1-1. Information to consider in setting measurable instream flow standards.

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 Kiikii hydrologic unit and streams on Oahu, Hawaii. (Source: State of Hawaii, Planning Department, 2004; State of Hawaii, Commission on Water Resource Management, 2015c)

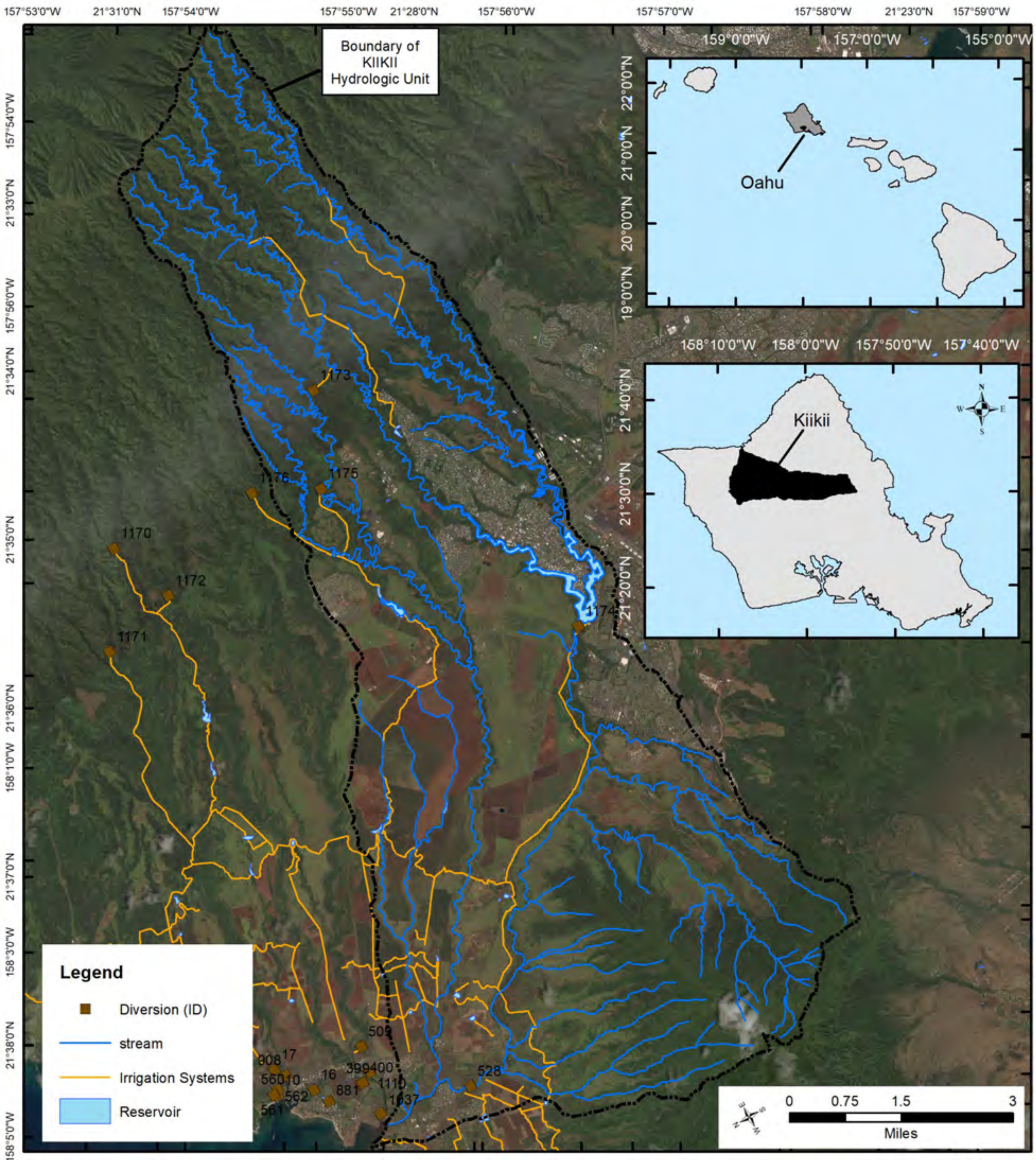


Figure 1-4. Elevation range and contours of the Kiikii hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2004e; U.S. Geological Survey, 2001)

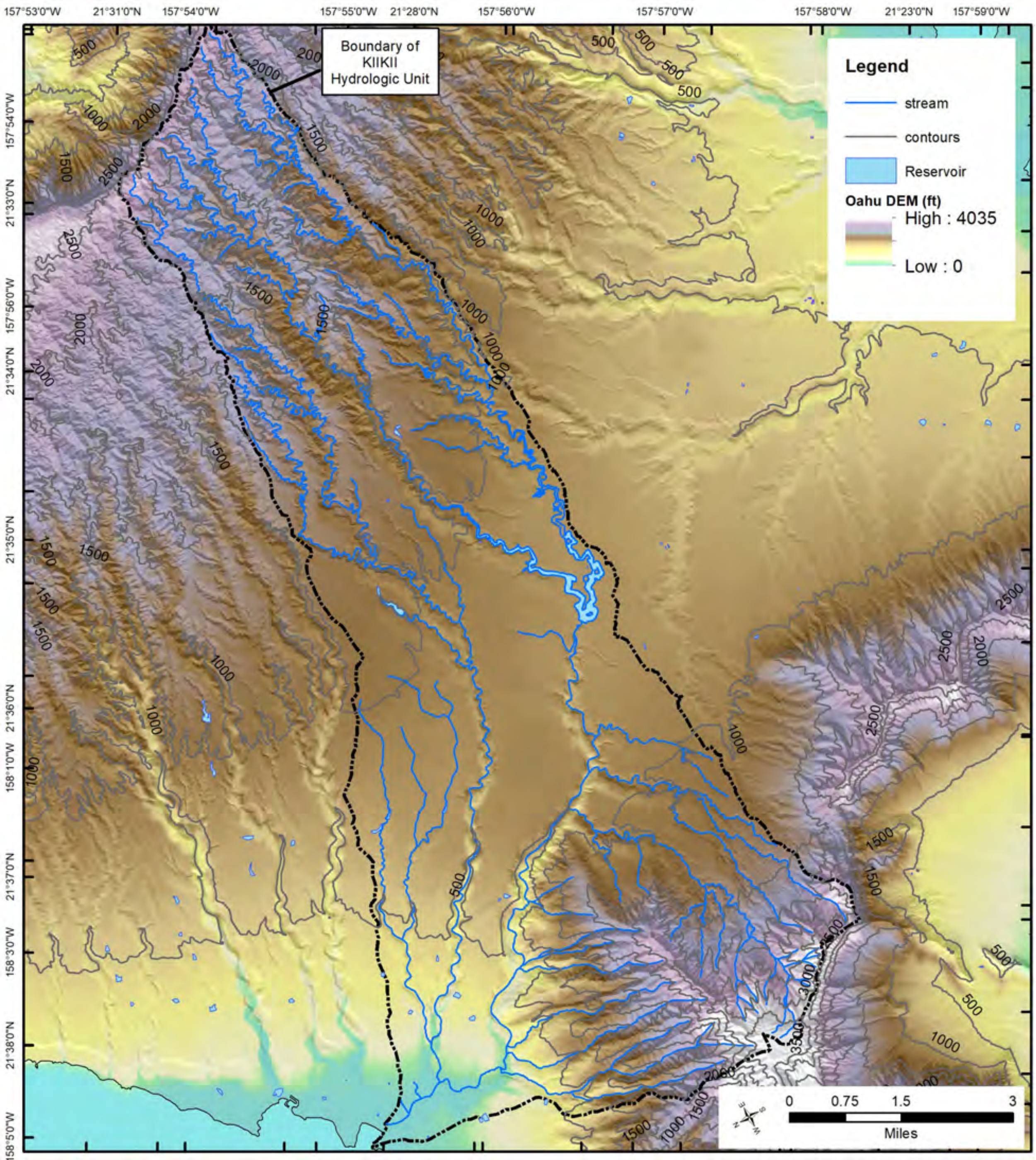


Figure 1-5. USGS topographic map of Kiikii hydrologic unit, Oahu. (Source: U.S. Geological Survey, 1996)

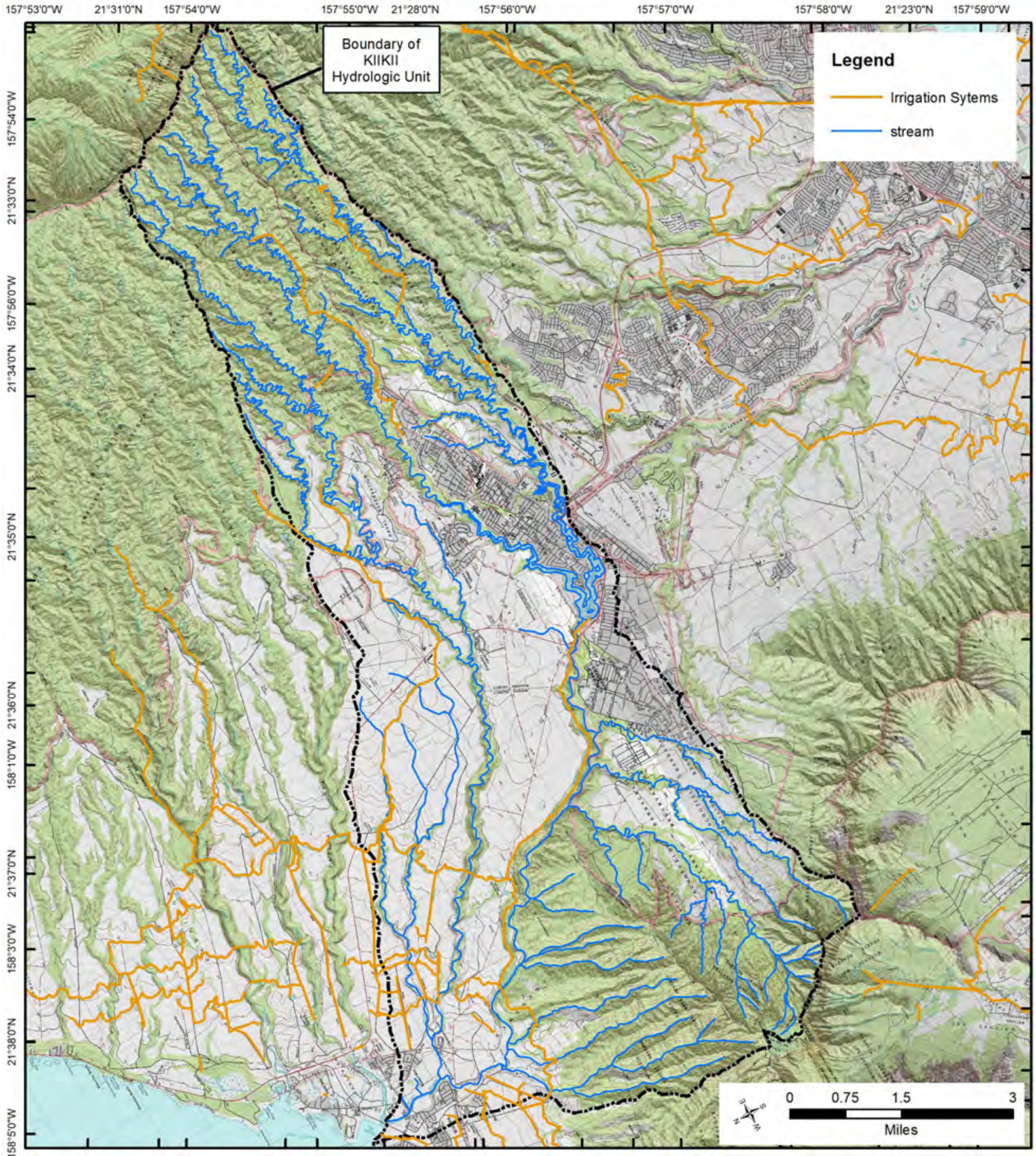
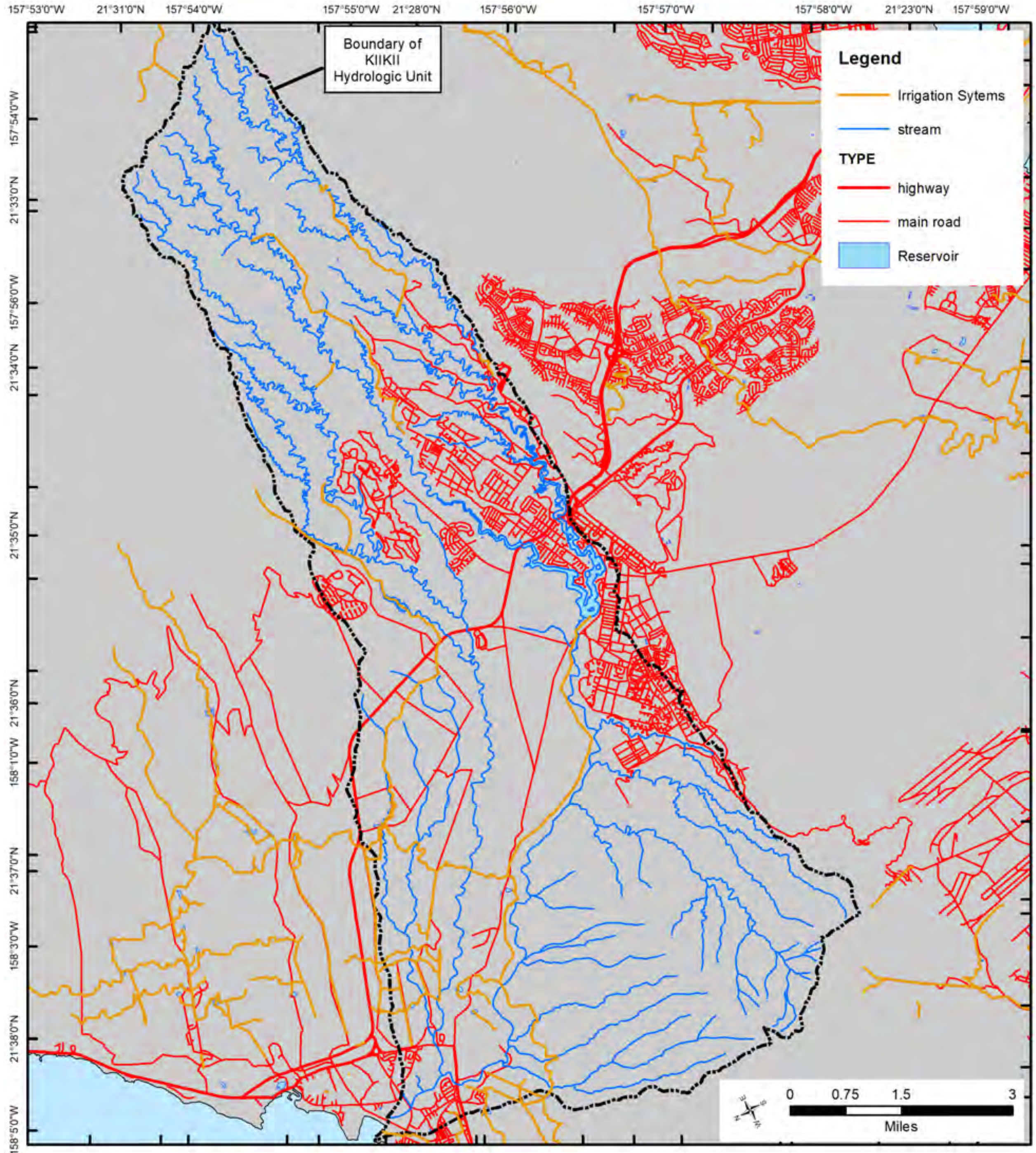


Figure 1-6. Major and minor roads for the Kiikii hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning 2020)



2.0 Unit Characteristics

Geology

The island of Oahu was built by the coalescence of two shield volcanoes: the Waianae volcano to the west and the Koolau volcano to the east (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 and 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.

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 original Koolau dome extended from just north of Puu Konahuanui to a location thousands of feet eastward into what is now the ocean. The steep northeast-facing cliffs in the Kaneohe area are the only remnants of the original caldera wall still visible (Stearns and Vaksvik, 1935). The shield-building phase from the Koolau Volcano ended approximately 1.8 million years ago with erosion and subsidence modifying the original volcano. In between eruption events, eroded sediments were deposited on valley floors and transported downstream. About 800,000 years ago, lava flows from new rifts, tansverse to the former, erupted in the late-phase Honolulu Volcanics Series.

Kaukonahua and Poamoho streams erode into the northeastern flank of the Koolau Range. Koolau Basalt forms the basement rock into which Poamoho and Kaukonahua streams, with older alluvium in the lower elevations (Figure 2-1). The lava flows of the shield building Koolau Volcanics originated from the caldera or the rift zones are characterized by high porosity and transmissivity (Visher and Mink, 1969). Numerous nearly vertical volcanic dikes are found along the rift zone, but have limited distribution in the lateral margins.

The igneous rocks comprise most lava flows and dikes whereas the sedimentary rocks are formed by noncalcareous deposits of weathered igneous rocks as well as the calcareous sediments produced from reef limestone and abraded or corroded by wind or wave action. The lava flows range in thickness from 1 to 400 feet, but are usually less than 75 feet thick (Stearns and Vaksvik, 1935). There are few examples of soil beds more than a few inches think intercalated in the Koolau lavas suggesting that the volcano formed much more rapidly than others in Hawaii. As the magma cooled, the weight of the overlying rocks compressed the dike, which is then denser than the nearby extrusive and highly permeable flows. Such lava flows can support large amounts of basal and high-elevation (both perched and dike-confined) groundwater.

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.

A unique geologic formation around the Schofield region exists called the Schofield Plateau high-level waterbody, where groundwater occurs that is different from either dike impounded or perched groundwater (Nichols et al. 1996). Structural barriers, including rift-zone intrusives, stray dikes that are not part of a well-defined rift zone, and two extensive impounding structures generate groundwater head discontinuities ranging from the tens to hundreds of feet (Hunt 1996). In the late 1930s, Swartz (1940) mapped the electrical conductivity of saltwater beneath the freshwater in the region and delineated the absence of saltwater within a range of depths in the Schofield Plateau, identifying the northern and southern limits of the high-level water. Dale and Takasaki (1976) referred to these geohydrologic barriers as water dams, possibly of intrusive rock that may be a composite of dike-intruded rock, erosional surface on Waianae Volcanics buried by Koolau Basalt, and massive lavas. The Schofield Plateau high-level groundwater is impounded to an elevation of 187-300 feet asl (Visher & Mink 1964). This is in contrast to the basal aquifer which sits approximately 20 feet asl to the north and 30 feet asl to the south of the plateau. The water occurs in permeable Koolau lava flows above the clay-rich confining layer on top of the Waianae Volcanics and is considered continuous and very flat beneath much of the plateau. The hydraulic conductivity of groundwater in Koolau Basalt varies from 1,000 to 5,000 feet per day. However, many unconformities add complexity to these generalization: i.e., on the western side of the plateau's southern limit, there is a dike-intruded ridge of Waianae Volcanics plunging eastward that is overlain by Koolau Basalt, compartmentalizing groundwater movement (Hunt 1996). Despite the importance of this water body to the regional water cycle, the specific movement of water within and from it is not well understood. Transitional areas have been inferred from groundwater levels in wells that, in some cases, were likely penetrating Waianae Volcanics.

The Kiikii watershed and stream network are typical of mature watersheds, with long, deeply incised upper reaches forming narrow valleys among hilly terrain in the middle reaches and merging to produce deep gulches. 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 Kiikii hydrologic unit is depicted in Figure 2-1 and summarized in Table 2-1.

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

Name	Rock Type	Area (mi²)	Percent of Unit
Koolau Basalt	Pahoehoe and aa; wall rock with intrusions	39.124	66.95%
Waianae Volcanics	Talus breccia, Lava flows, Mauna Kuwale rhyodacite, Icelandite vent deposits	10.695	18.30%
Older alluvium	Sand and gravel	6.928	11.86%
Alluvium	Sand and gravel		
Open Water		0.382	0.65%
Kolekole Volcanics	Lava flows	0.190	0.33%
Beach deposits	Beach deposits	0.025	0.04%
Lagoon and reef deposits	Limestone and mudstone	0.023	0.04%

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 Kiikii hydrologic unit, soils are dominated by Wahiawa series, Helemano series, and rough mountainous land (Table 2-2). Soils are predominantly in the Group B soils (61.5%), consisting of silty loam or loam with moderate infiltration rates with slow to medium runoff and a slight to moderate erosion hazard (U.S. Department of Agriculture, National Resource Conservation Service, 1986). The second largest soil hydrologic group, Group D soils (22.5%), have a high content of clay loam, silty clay loam, or clay, resulting in a high runoff potential. Group C soils (14.9%) have an intermediate runoff potential. Finally, Group A soils (0.2%) have a high infiltration rate and are composed of sandy or sandy loam soils. Hydrologic soils groups for the Kiikii hydrologic unit are identified in Figure 2-2.

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

[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.

rainfall. This region is found in the higher elevations of the largest volcanoes (e.g., Mauna Kea, Haleakala).

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

Soil Series Unit	Hydrologic Soil Group	Area (mi^2)	Percent (%)
Wahiawa	B	13.078	22.38%
Rough mountainous land	D	12.160	20.81%
Helemano	B	7.555	12.93%
Tropohumults	C	5.669	9.70%
Kunia	B	2.959	5.06%
Stony steep land	B	2.295	3.93%
Leilehua	B	2.028	3.47%
Kolekole	C	2.020	3.46%
Kemoo	B	1.955	3.35%
Paaloa	B	1.498	2.56%
Lahaina	B	1.263	2.16%
Halawa	B	1.096	1.88%
Rock land	D	0.901	1.54%
Kawaihapai	B	0.844	1.44%
Manana	C	0.774	1.32%
Ewa	B	0.651	1.11%
Water > 40 acres		0.529	0.91%
Haleiwa	B	0.418	0.72%
Waialua	B	0.307	0.53%
Waipahu	C	0.177	0.30%
Mamala	A	0.107	0.18%
Alakai	D	0.080	0.14%
Fill land, mixed	C	0.021	0.04%
Fill land	C	0.020	0.03%
Keaau	D	0.015	0.03%
Jaucas	A	0.005	0.01%

The Kiikii hydrologic unit is situated on the leeward side of the Koolau Mountains and as such receives less orographic rainfall (Figure 2-4). The high spatial variability in rainfall is evident by the large variation in mean annual rainfall across the hydrologic unit. Mean annual rainfall at five locations in or near the Kiikii hydrologic unit for recent calendar years are provided in Table 2-3. Mean annual rainfall at various stations in or near the Kiikii hydrologic unit for various periods of record are provided in Table 2-4. Above 2000 ft, rainfall is highest during the months of November to January, where the mean monthly rainfall varies from 10.69 to 11.33 inches (Table 2-5).

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

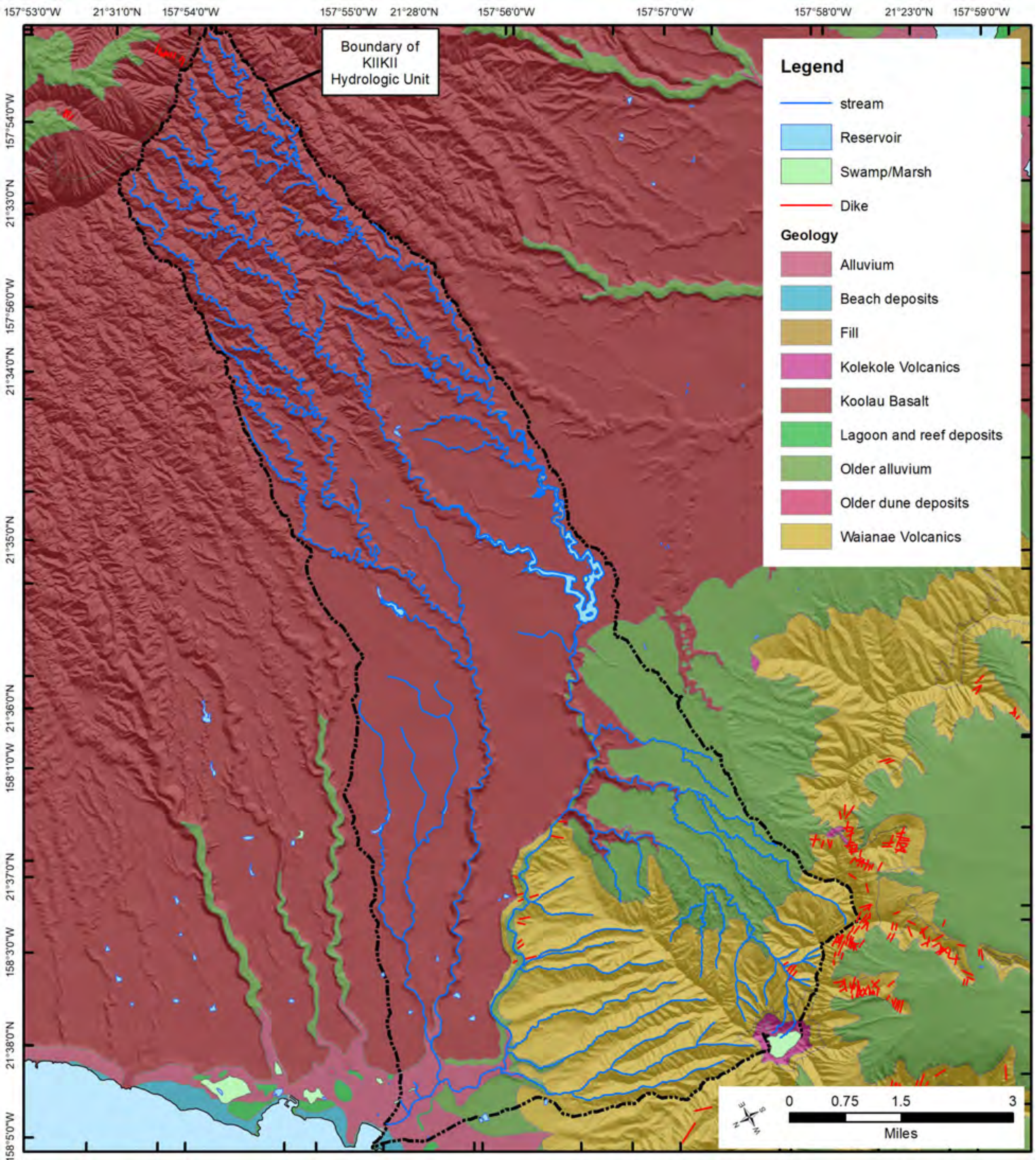


Figure 2-2. Soil series classification of the Kiikii hydrologic unit, Oahu. (Source: Soil Survey Staff, 2020)

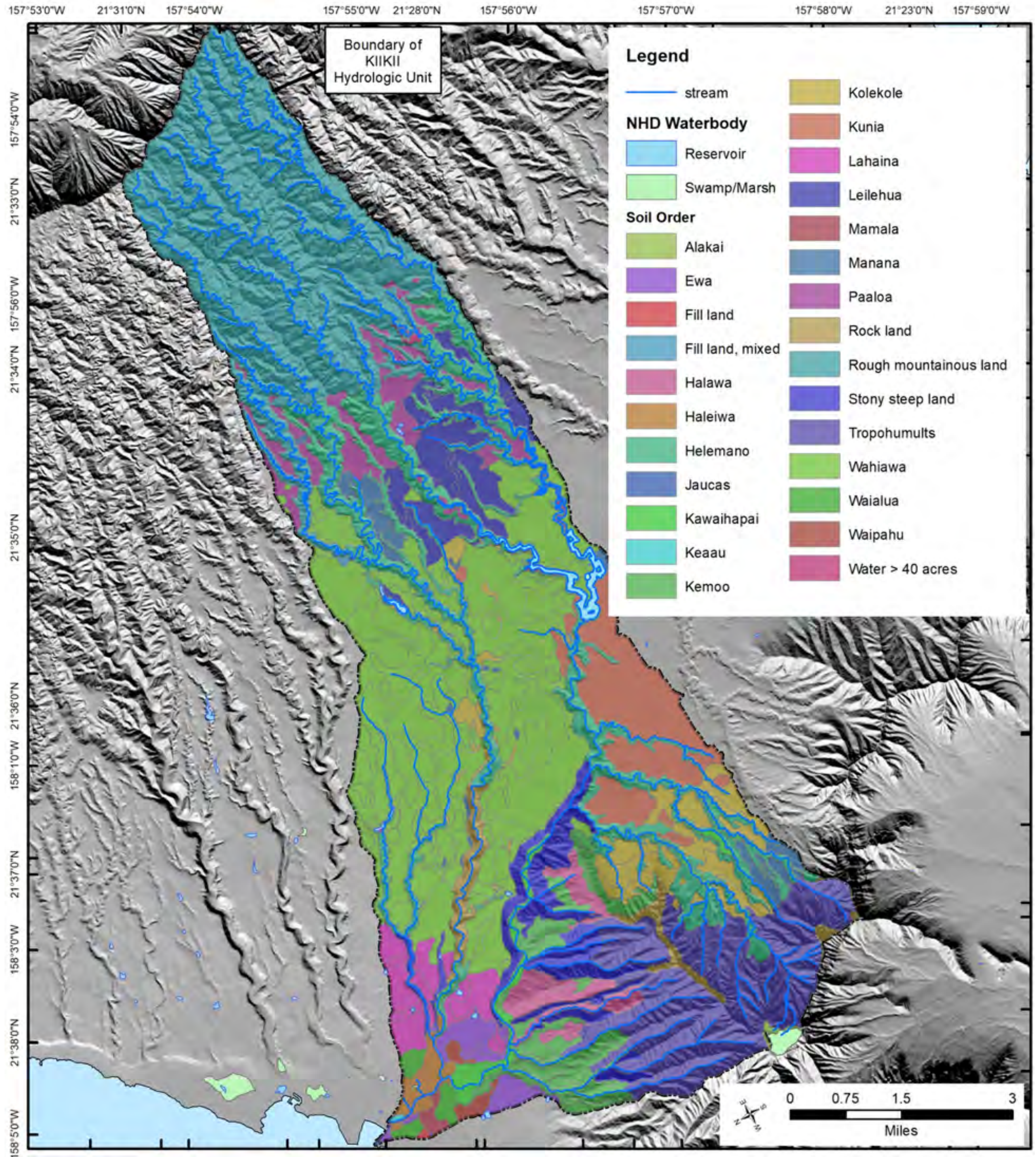


Figure 2-3. Orographic precipitation in the presence of mountains higher than 6,000 feet.

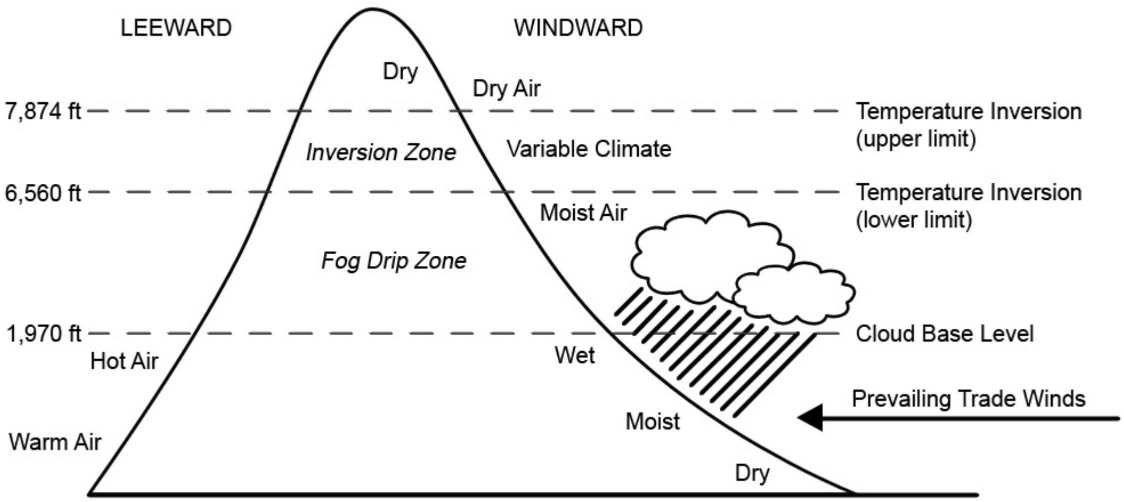


Table 2-3. Mean annual rainfall (mm) for five locations in or near the Kiikii hydrologic unit from calendar year 2012 to 2018. (Source: USGS 2020; Remote Automated Weather Stations (RAWS)

Station name	Type	coverage	2012	2013	2014	2015	2016	2017	2018
883.12 Poamoho	USGS	100%	4657	3959	4783	5072	4652	3716	5291
Schofield East	RAWS	83.0%	539	618	1083	1111	774	692	834
Oahu Forest Reserve	RAWS	91.8%	4650	3901	5768	6550	1708	1059	2063
897.9 Pupukea Rd	USGS	100%	2026	1434	1875	2186	2160	1500	1795
Wahiawā Dam	virtual	100%	3694	3964	4329	4593	4058	3253	4472

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. The crest of the Koolau Range runs along the southeast to northwest rift zone from the original Koolau Caldera, forming a steep precipice that generates orographic rainfall on the windward side. Some of this rainfall is blown by the trade winds towards the leeward side of the crest, influencing the water budget of leedward watersheds such as Kiikii. Further, Mt. Kaala, the tallest peak (4,025 feet a.s.l) in the Waianae range, is also situated in the Kiikii hydrologic unit, and influences rainfall due to its position in the trade winds. 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).

Shade (1999) used the monthly fog drip to rainfall ratios for the windward slopes of Mauna Loa on the Island of Hawaii (Table 2-5) 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 Kiikii 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 7.0 percent of Kiikii (4.096 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 25.2 percent (35.42 inches versus 140.81 inches) of the upper (>2,000 ft) watershed, assuming the same ratios apply here (Table 2-5). The total estimated mean annual contribution of fog drip to the Kiikii hydrologic unit is about 31.38 millon gallons or about 0.086 million gallons per day.

Table 2-4. Mean annual rainfall (in) for stations at locations in or near the Kiikii hydrologic unit for given periods of record. (Source: Giambelluca et al., 2013 Rainfall Atlas of Hawaii)

Station name	SKN	Period of Record	Elevation (ft)	Mean Annual Rainfall (in)
Waialua Mauka	876	1926-1968	1250	60.96
Poamoho No.2	882.4	1967-Present	1960	196.48
Helemano Intake	881	1918-1979	1275	79.37
Wahiawa Water Co	878	1906-1953	1170	95.88
Kaukonahua Mauka	875.1	1914-1968	1255	65.01
Helemano	875	1927-1973	1160	58.13
Wahiawa Bot Gar	874.1	1927-1957	965	51.91
Whitmore	873.1	1948-1983	990	49.27
Kaukonahua	873	1924-1965	1000	52.16
Helemano Reserv	871	1918-1994	1030	46.99
Waialua Camp	867	1924-1972	1000	51.88
Brodie 2	866	1926-1983	980	41.83
Poamoho	865	1923-1980	940	41.06
Area BB	863.1	1945-1980	1160	45.22
Waialua Dam	863	1905-1986	855	38.85
Brodie 4	860	1924-1973	800	39.34
Field 201	859	1937-1968	860	38.65
Maili Point	857.1	1930-1942	1600	36.46
Field 208	857	1934-1980	920	38.20
Helemano 6	856	1934-1983	470	33.58
Kemoo 9	855	1924-2000	730	36.22
Helemano 9	854	1934-1983	310	33.43
Helemano 7	853	1931-1983	520	33.27
Helemano 4	852	1935-1983	180	31.27
Kemoo 3	851	1934-1983	285	32.32
Valley 2	850	1935-1983	45	32.00
Kahua Ranch	849	1952-1984	90	34.05
Puu Iki	848	1952-1984	1040	40.10
Waialua	847	1901-2003	32	30.86
Mt Kaala	844	1932-Present	4015	81.54
Deep Well	814.1	1945-1980	865	43.22
Wheeler Field	810	1909-1949	845	38.21

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 Kiikii hydrologic unit, average annual solar radiation ranged from 158.2 to to 218.5 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).

Table 2-5. Fog drip to rainfall ratios for the windward slopes of Mauna Loa on the island of Hawaii and approximate contributions to the Kiikii Hydrologic Unit based on elevations greater than 2000 feet using mean monthly rainfall and equivalent ratios.

Month	Ratio (%)	Mean Rainfall (in)	Contribution (in)
January	13	11.33	1.47
February	13	9.46	1.23
March	13	9.70	1.26
April	27	9.04	2.44
May	27	6.96	1.88
June	27	6.39	1.73
July	67	6.72	4.50
August	67	7.30	4.89
September	67	7.63	5.11
October	40	9.11	3.64
November	40	10.69	4.28
December	27	11.06	2.99

Evaporation

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

Potential evapotranspiration (PET) is the rate 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.

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

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

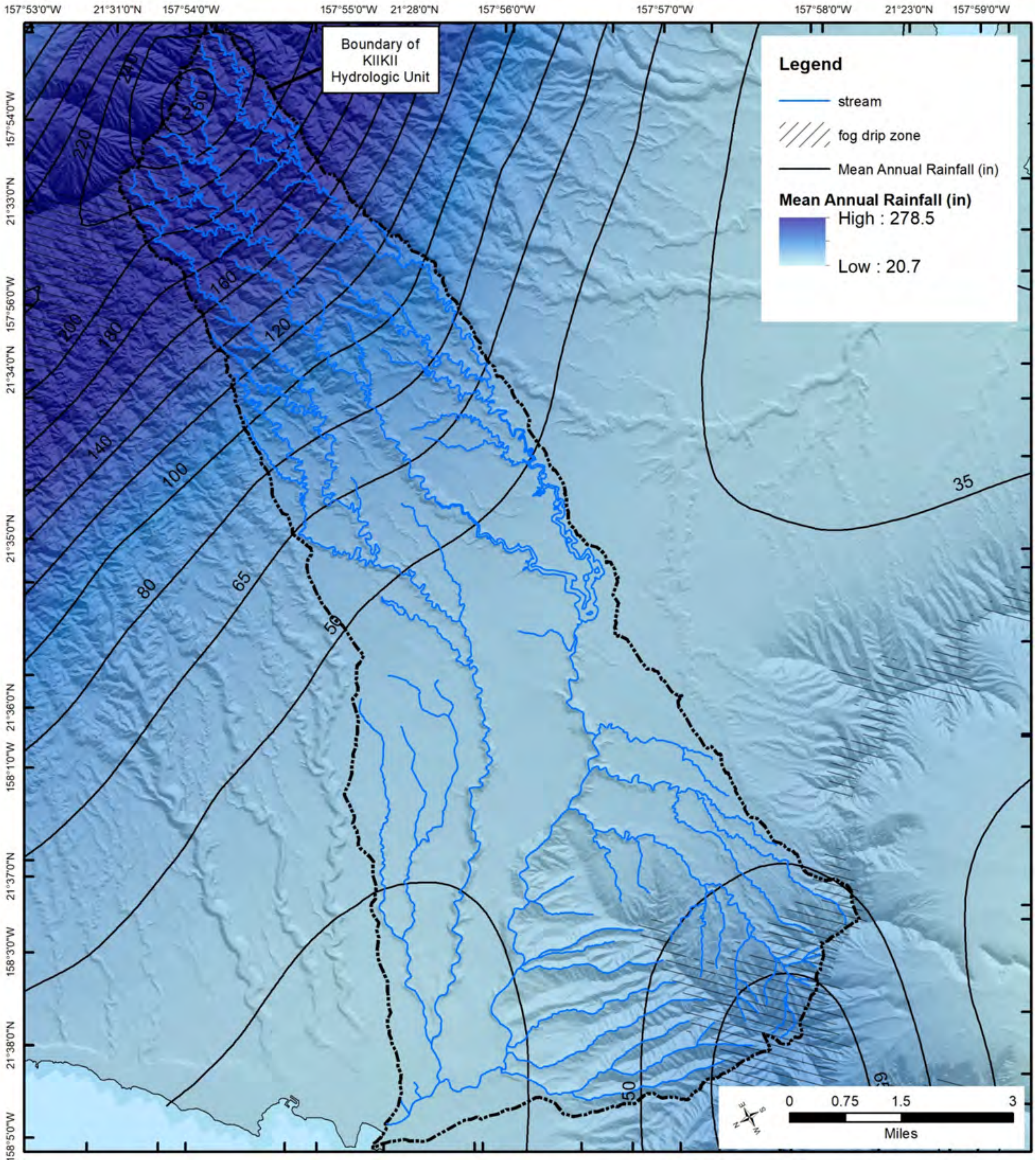
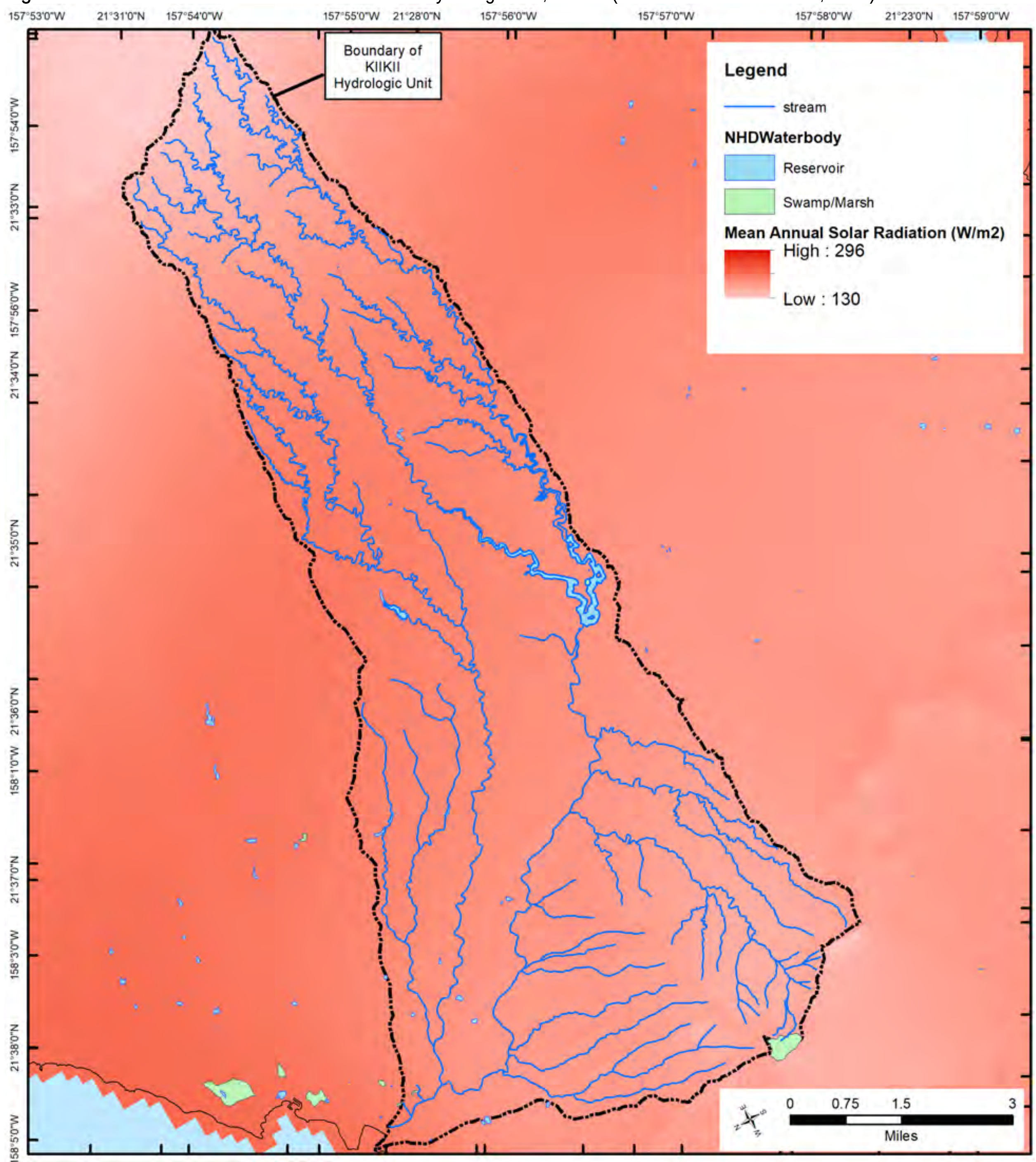


Figure 2-5. Mean annual solar radiation of the Kiikii hydrologic unit, Oahu. (Source: Giambelluc et al., 2014)



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 Kiikii (Figure 2-6) averages 108.4 inches and ranges from 54.9 to 241.0 inches (Giambelluca et al. 2014). Annual actual evapotranspiration for the Kiikii hydrologic unit ranges from 23.3 inches to 46.7 inches per year, with an average of 27.2 inches per year.

Evaporation from Wahiawa Reservoir

To estimate the water lost through evaporation from Wahiawa Reservoir, total daily evapotranspiration (ET) and solar radiation (R) data were available from the Schofield Barracks remote automated weather station (RAWS) 1.891 miles away from Wahiawa Reservoir. From 1 January 2012 to 30 June 2018 (2373 days), ET was available for 1853 days (78.1%) and solar radiation for 1946 days (82.0%) from this station. Missing data were gap-filled using a combination of linear correlation with total daily solar radiation ($ET = 0.0003*R + 0.0487$; $R^2 = 0.88$), or the mean ET for the Julian day from all other years ($n = 3$ to 6). Evapotranspiration from the reservoir varied seasonally, with total mean values peaking from May to August above 6.53 inches per day (Figure 2-7).

Figure 2-6. Mean monthly rainfall at Wahiawa Reservoir (bars) and mean daily evaporation from Wahiawa Reservoir (line) by month from 2012 to 2018. (Source: Remote Automated Weather Station, Schofield Barracks Station)

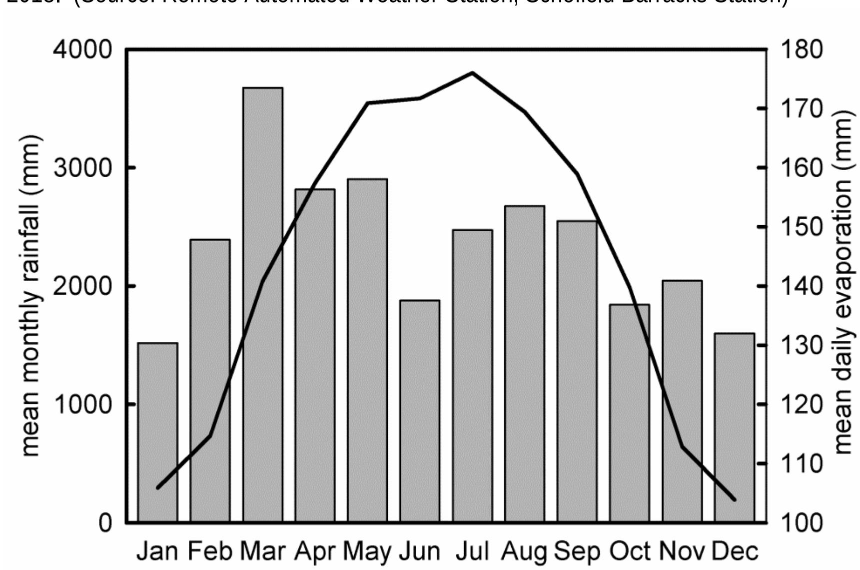
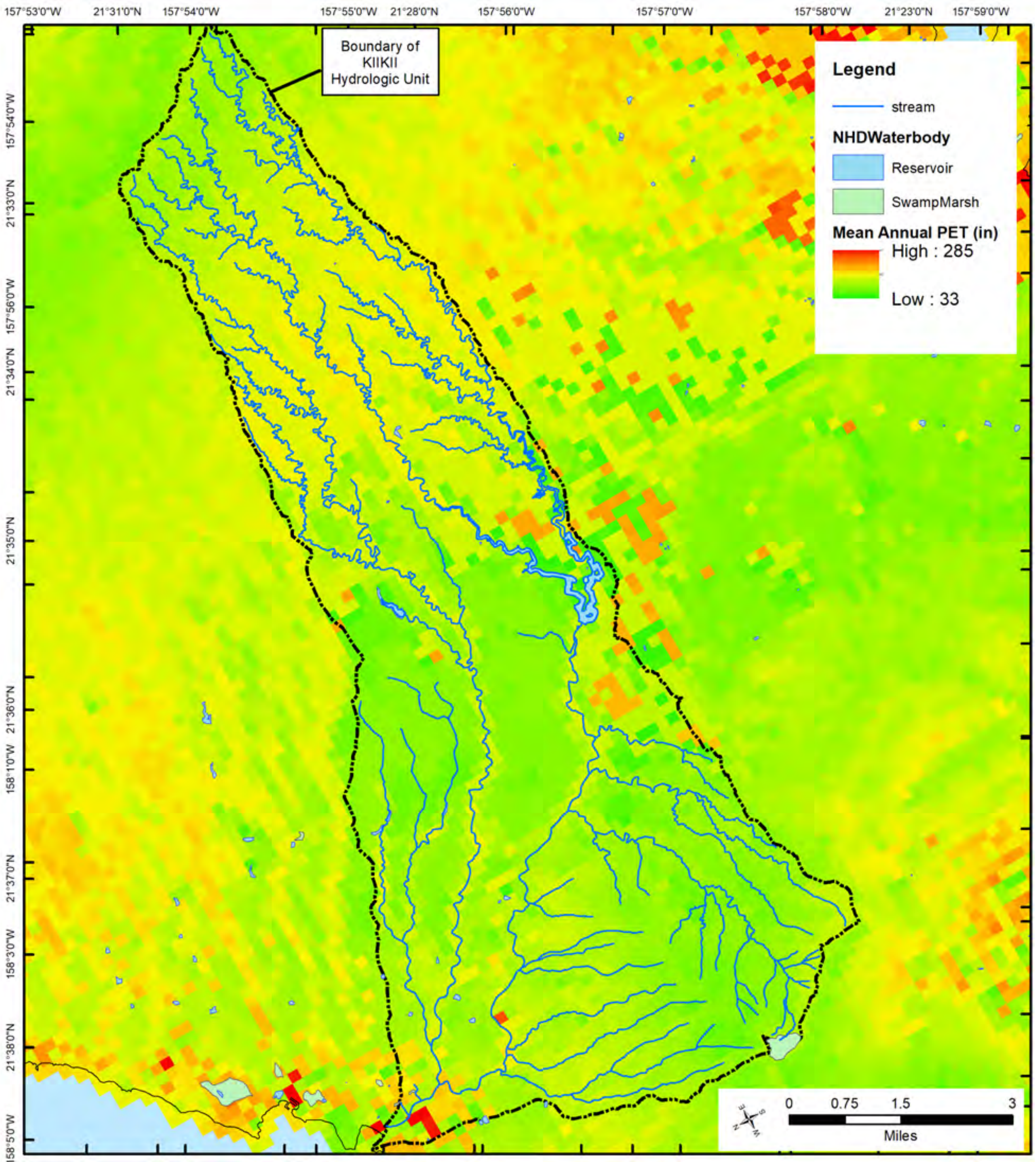


Figure 2-7. Mean annual potential evapotranspiration (Penman-Monteith method) for Kiikii hydrologic unit, Oahu. (Source: Giambelluca et al., 2014)



Land Use

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

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

As of 2014, 57.8 percent of the land in Kiikii (33.807 square miles) was designated as agriculture and 34.6 percent of the land (20.235 square miles) as conservation (State of Hawaii, Office of Planning, 2015d). A small portion of the hydrologic unit is designated as urban (4.398 square miles, 7.5 percent) and none as rural (Figure 2-8).

Land Cover

Land cover for the hydrologic units of Kiikii 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 Kiikii, e.g., forest, shrub, developed areas, and wetlands (Table 2-5, Figure 2-9). 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 2-6, Figure 2-10).

Based on the two land cover classification systems, the land cover of Kiikii consists mainly of evergreen forest, cultivated land, grassland, scrub and developed areas dominated by alien vegetation. There is minimal wetland and native vegetation is limited to the higher elevations of the unit, especially in the Poamoho and Kaukonahua watersheds. The land cover maps (Figures 2-9, 2-10) provide a general representation of the land cover types in the Kiikii 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 2-6. C-CAP land cover classes and area distribution in Kiikii 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	29.159	49.9%
Cultivated	Areas intensely managed for the production of annual crops	11.944	20.4%
Grassland	Natural and managed herbaceous cover	5.448	9.3%
Scrub	Areas dominated by woody vegetation less than 6 meters in height	4.389	7.5%
Low Intensity Developed	Constructed surface with substantial amounts of vegetated surface	3.342	5.7%
Medium Intensity Developed	Areas with a mixture of constructed materials and substantial amounts of vegetation	1.735	3.0%
High Intensity Developed	Contains significant land area covered by concrete, asphalt and other constructed materials with less than 20% vegetation	0.872	1.5%
Developed Open Space	Areas mostly managed grasses or low-lying vegetation planted for recreation, erosion control, or aesthetic purposes	0.693	1.2%
Water		0.408	0.7%
Bare Land		0.288	0.5%
Palustrine Forested Wetland	Included tidal and nontidal wetlands dominated by woody vegetation 5 meters in height or more	0.100	0.2%
Palustrine Emergent Wetland	Includes tidal and nontidal wetlands dominated by persistent emergent vascular plants, mosses or lichens	0.036	0.1%
Palustrine Scrub Wetland		0.003	0.0%
Unconsolidated shore		0.001	<0.1%
Estuarine Forested Wetland		<0.001	<0.1%
Estuarine Scrub/Scrub Wetland		<0.000	<0.1%

Peak floods in Kiikii have been monitored at multiple locations throughout the hydrologic unit for various periods of time (Table 2-8). 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 Kaukonahua Stream at Farrington Highway near the mouth are estimated as 4750, 9500, 13,800, 25,900, and 32,200 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 Kiikii 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 57.0 square miles (97.5%) is designated Flood Zone D, where there are possible but undetermined flood hazards. Another 0.719 square miles (1.2%) is designated Flood Zone X as an area of minimal flood hazard, 0.654 square miles (1.12%) designated as flood zone AE with a 1% chance of flooding floodplains or shallow flooding due to ponding, and 0.053 square miles (0.09%) is designated as flood zone VE or coastal high hazard with high velocity water including waves defined by the 1% annual change flood reflecting the combined influence of Stillwater flood elevations, frontal dunes, and wave effects (Figure 2-11).

Table 2-7. HI-GAP land cover classes and area distribution for the Kiikii hydrologic unit, Oahu. (Source: HI-GAP, 2005)

Land Cover	Area (mi^2)	Percent of Unit
Alien Forest	14.482	24.79%
Cultivated Cropland	14.120	24.17%
Alien Shrubland	7.172	12.28%
Alien Grassland	5.277	9.03%
Developed, Low Intensity	4.306	7.37%
Mixed Native-Alien Forest	3.316	5.68%
Closed Ohia Forest	2.622	4.49%
Open Ohia Forest	2.004	3.43%
Open Koa-Ohia Forest	1.160	1.98%
Native Shrubland/Sparse Ohia	0.961	1.65%
Open Water	0.767	1.31%
Developed, High Intensity	0.708	1.21%
Ohia Forest	0.558	0.95%
Uluhe Shrubland	0.552	0.95%
Very Sparse Vegetation to Unvegetated	0.166	0.28%
Mixed Native-Alien Shrubs and Grasses	0.123	0.21%
Native Wet Cliff Vegetation	0.100	0.17%
Undefined	0.010	0.02%
Wetland Vegetation	0.008	0.01%

Table 2-8. The magnitude of peak flows with specific recurrence intervals based on measured peaks flows at select monitoring locations in the Kiikii hydrologic unit, Oahu. (Source: USGS, 2020)

			peak flood magnitudes (cfs)				
station ID	**station name**	period of record	2-year	5-year	10-year	50-year	100-year
16201000	RB of NF Kaukonahua Stream	1913-1952	1040	1470	1750	2390	2650
16206000	SF Kaukonahua Stream	1911-1957	1020	1420	1700	2390	2720
16208000	SF Kaukonahua Str at E pump	1957-P	1670	2810	3660	5750	6720
16208500	R Br of SF Kaukonahua Str	1946-1958	601	1440	2170	4170	5150
16201000	RB of NF Kaukonahua Str	1913-1953	1040	1470	1750	2390	2650
16200000	NF Kaukonahua Str abv RB	1913-P	1830	3000	3860	5910	6850
16204000	NF Kaukonahua Str	1946-1968	2490	3160	3610	4610	5040
16201500	Kaukonahua Str at Waialua	1963-P	2360	5300	7960	15600	20100
16343000	Helemano Stream at Haleiwa	1968-1981	3990	9490	14500	29500	37400

Figure 2-8. State land use district boundaries of the kiikii hydrologic unit, Oahu (Source: State of Hawaii, Office of Planning, 2015d).

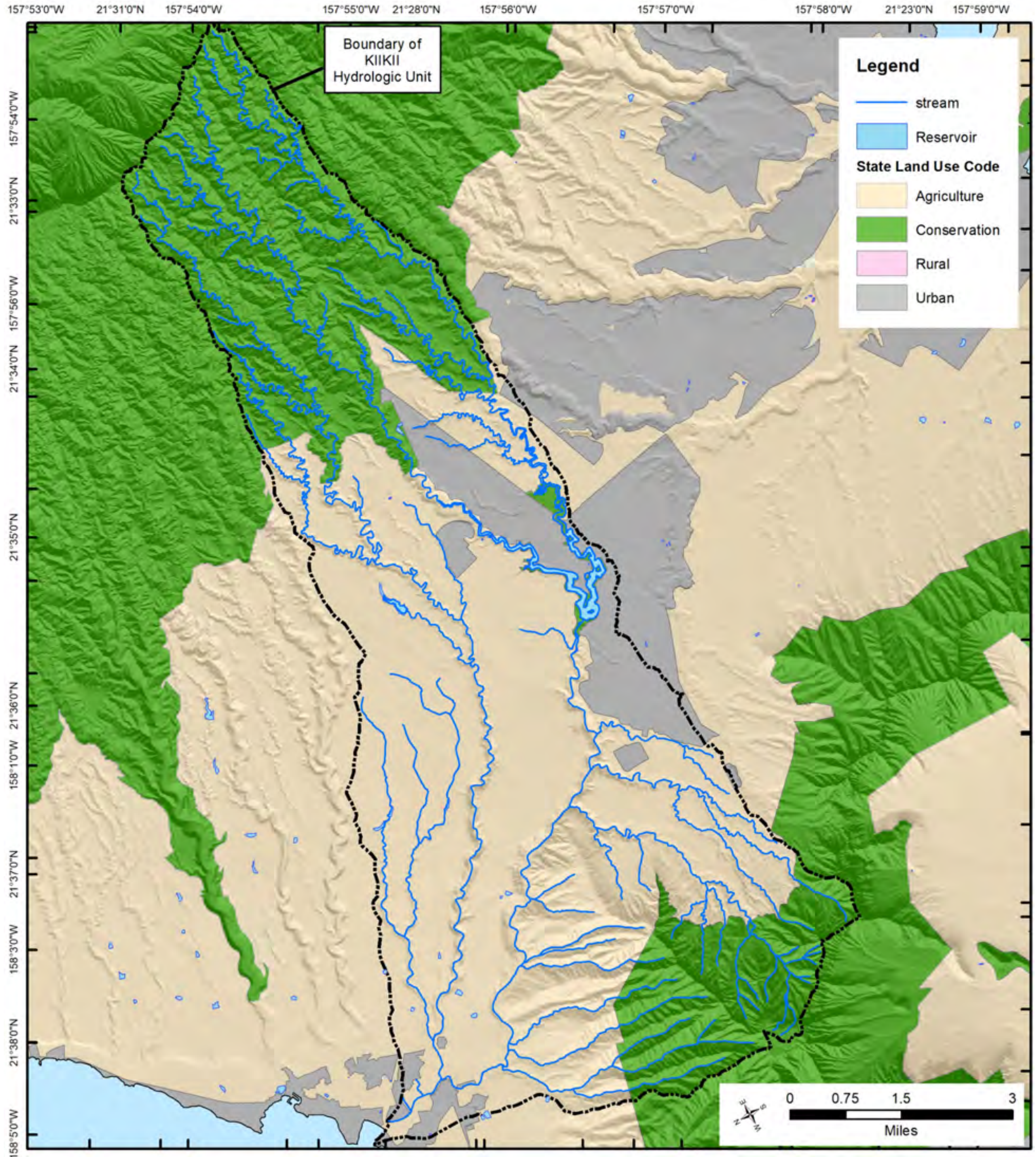


Figure 2-9. C-CAP land cover of the Kiikii hydrologic unit, Oahu. (Source: NOAA, 2005).

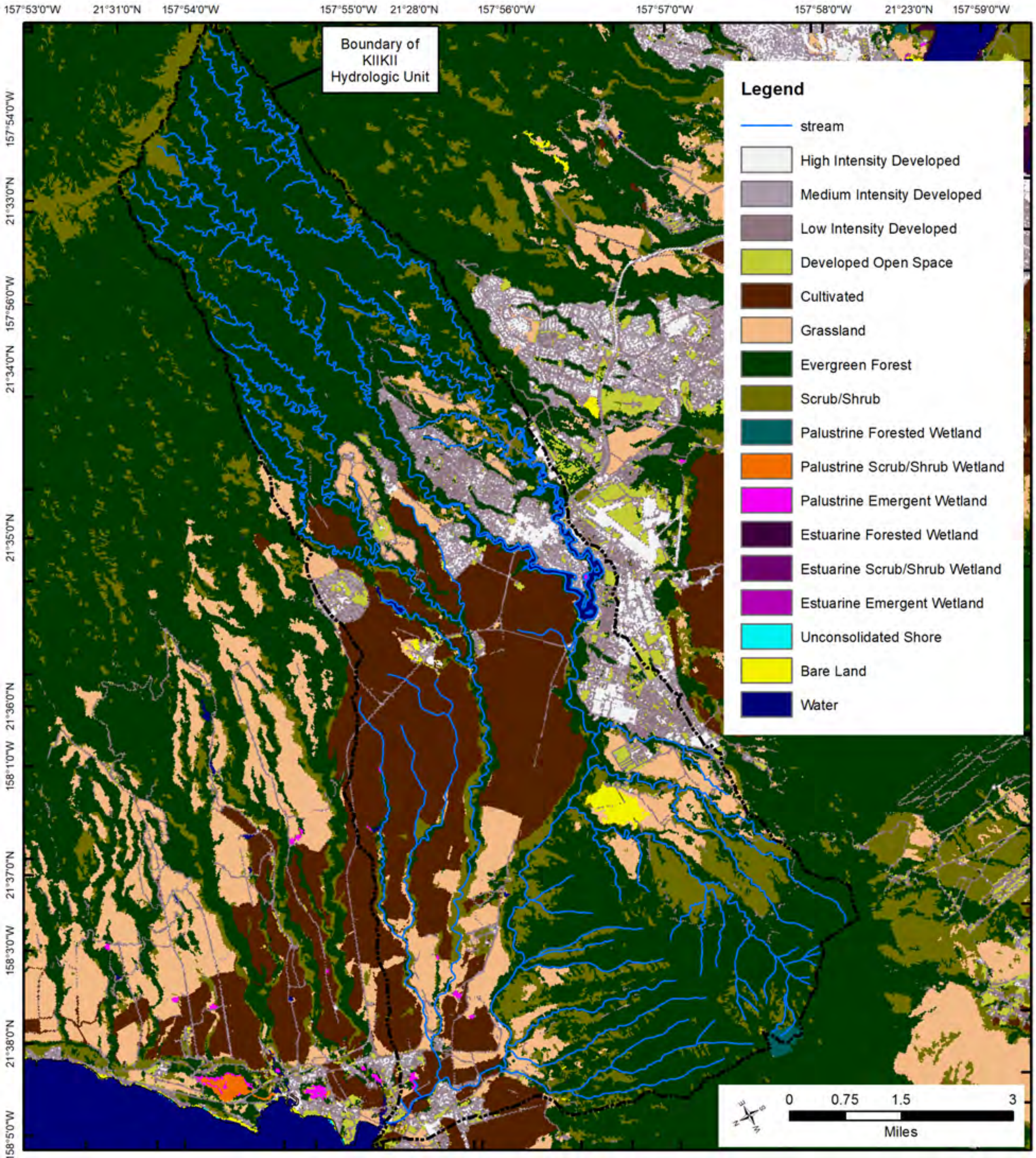
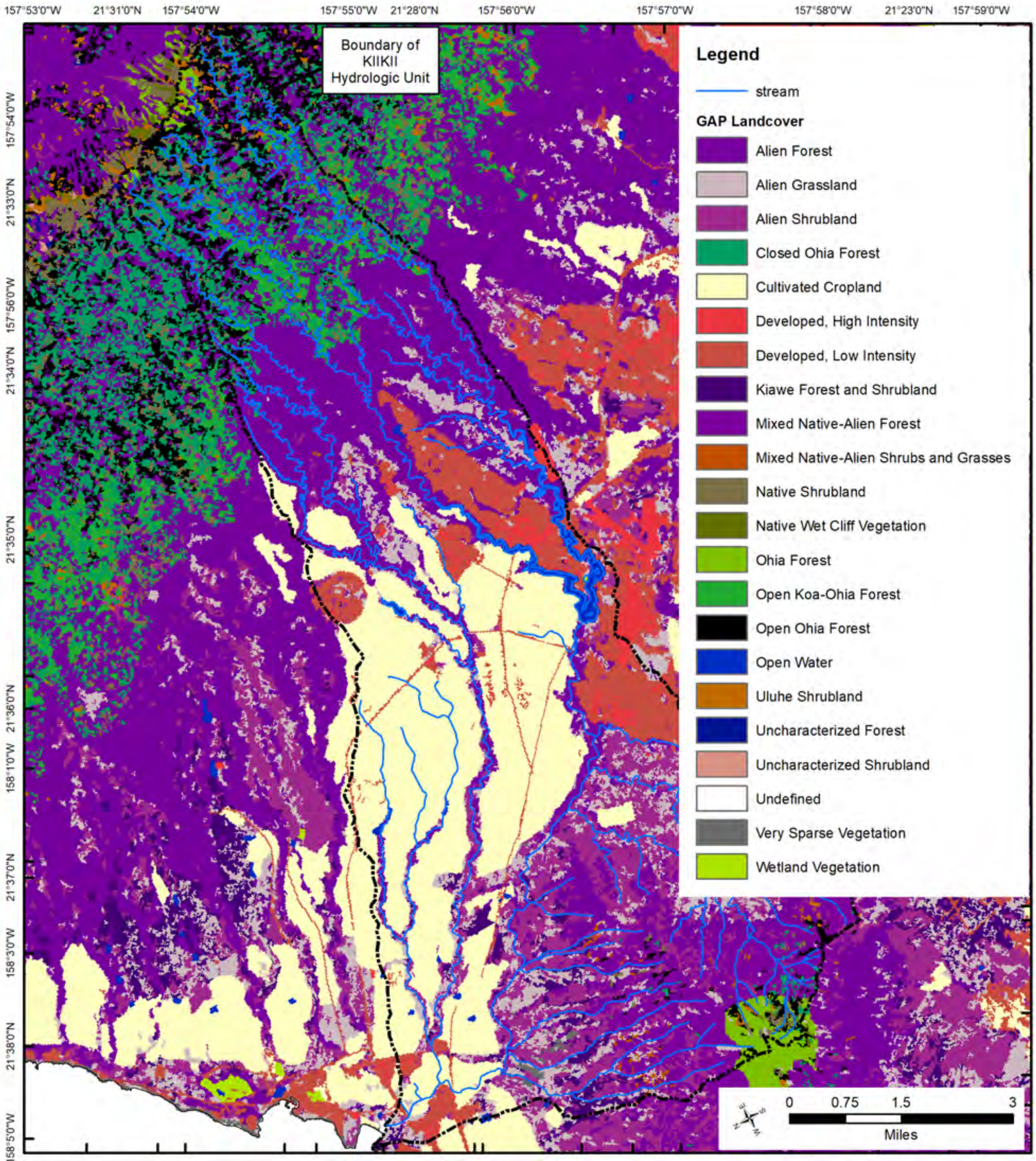


Figure 2-10. Hawaii GAP land cover classes of the Kiikii hydrologic unit, Oahu (Source: USGS, 2001).



Drought

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

Impacts of drought are complex and can be categorized into three sectors: water supply; agriculture and commerce; and environment, public health, and safety sectors (State of Hawaii, Commission on Water Resource Management, 2005b). The water supply sector encompasses urban and rural drinking water systems that are affected when a drought depletes 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.

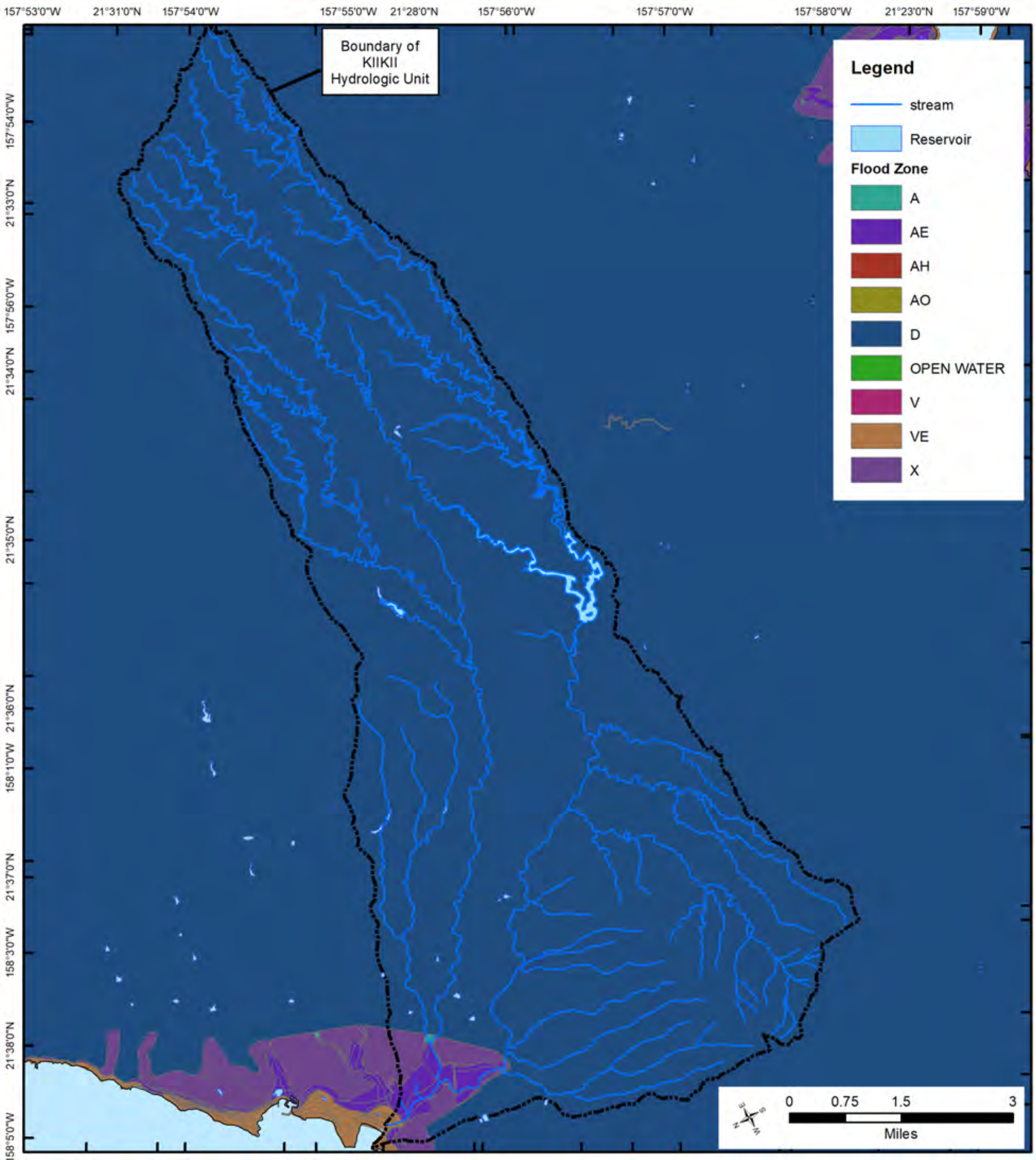
Droughts have affected the islands throughout Hawaii's recorded history. The most severe events of the recent past years are associated with the El Niño phenomenon. In January 1998, the National Weather Service's network of 73 rain gauges throughout the State did not record a single above-normal rainfall, 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 2-8. 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 streams may decline during low rainfall periods (hydrological drought). Haleiwa, in the Kaukonahua and Poamoho watersheds is considered vulnerable to extreme drought for water supply. Areas north of Helemano is subject to severe drought which might affect agriculture and commerce. There is an increase in wildland fire risk due to drought in the Kiikii hydrologic unit, with dry invasive grasses or trees prone to wildfire.

Table 2-9. 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 2-11. FEMA flood zone regions in the Kiikii hydrologic unit, Oahu (Source: Federal Emergency Management Agency, 2014).



3.0 Hydrology

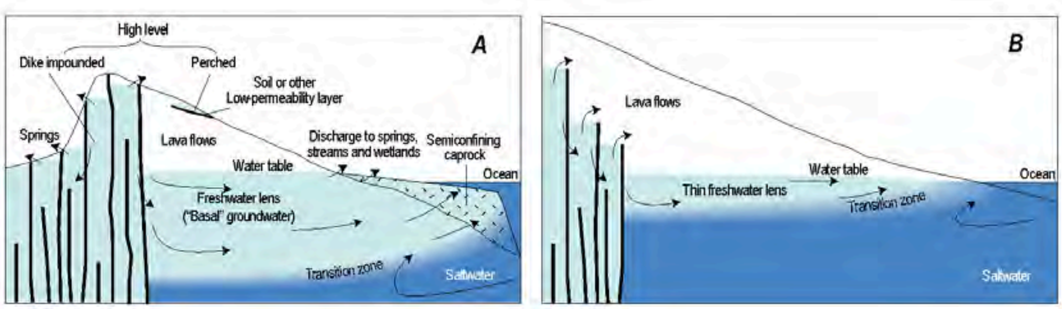
The Commission, under the State Water Code, is tasked with establishing instream flow standards by weighing "the importance of the present or potential instream values with the importance of the present or potential uses of water for noninstream purposes, including the economic impact of restricting 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 Kiikii 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.

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)



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 Kaukonahua Stream, the natural flow in the north fork or south fork of Kaukonahua Stream or Poamoho Stream, or the flow of water in ditches. Historic flow data from these stations are available in Table 3-1. The location of these stations is provided in Figure 3-8.

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

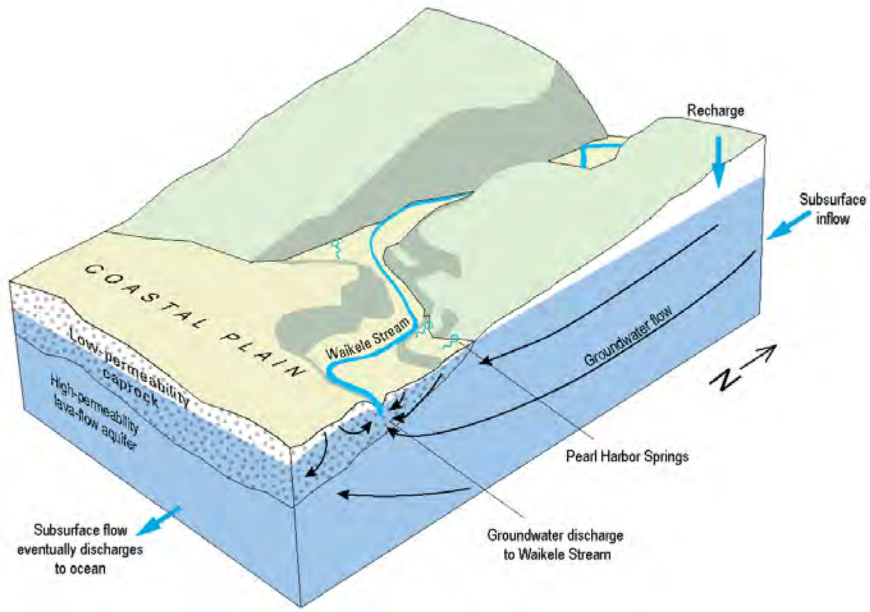
					discharge (Q) for a selected percentage (xx) discharge was equaled or exceeded			
station ID	station name	period of record	mean daily flow	14-day low flow	Q_{50}	Q_{70}	Q_{90}	Q_{95}
16200000	NF Kaukonahua abv RB	1913-P	15.6 (10.1)	0.14 (0.09)	6.8 (4.4)	3.9 (2.5)	1.6 (1.03)	0.93 (0.60)
16201000	NF Kaukonahua	1913-53	11.0 (7.1)	0.15 (0.10)	4.6 (3.0)	2.6 (1.7)	1.1 (0.71)	0.76 (0.49)
16204000	NF Kaukonahua	1946-68	35.8 (22.8)	0.004 (0.002)	12.0 (7.8)	6.0 (3.9)	1.9 (1.2)	1.1 (0.71)
16206000	SF Kaukonahua	1911-57	12.2 (7.9)	0.09 (0.06)	5.6 (3.6)	2.4 (1.6)	0.77 (0.50)	0.48 (0.31)
16208000	SF Kaukonahua at Pump E	1957-P	20.8 (13.5)	0.00 (0.00)	8.6 (5.6)	4.8 (3.1)	1.8 (1.2)	1.1 (0.71)
16210200	Kaukonahua blw Wahiawa Reservoir	2012-P	42.2 (27.3)	0.042 (0.027)	20.5 (13.3)	0.20 (0.13)	0.06 (0.04)	0.05 (0.03)
16210500	Kaukonahua at Waialua	2012-P	44.4 (28.7)	0.17 (0.11)	20.3 (13.1)	0.94 (0.61)	0.42 (0.27)	0.39 (0.25)
16210900	Poamoho Tunnel	1958-79	4.9 (3.2)	0.00 (0.00)	1.1 (0.71)	0.12 (0.08)	0.02 (0.01)	0.01 (0.006)
16210100	Wahiawa Ditch	2012-P	10.8 (7.0)	3.7 (2.4)	10.4 (6.7)	8.0 (5.1)	5.1 (3.3)	4.1 (2.6)
16211000	Poamoho Stream	1947-74	4.3 (2.8)	0.00 (0.00)	1.5 (0.97)	0.41 (0.26)	0.05 (0.03)	0.02 (0.01)

Groundwater

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

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

Figure 3-2. 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).



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, there may be 100 or more dikes per mile, occupying 5% or more of the rock, and holding 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 to 500 feet per day in dike complexes and breccia (Takasaki and mink, 1982).

A general overview of the groundwater occurrence, movement, and interactions with surface water in this area is described in Nichols et al. (1996) and Izuka et al. (2018) and illustrated in Figure 3-3.

The Kiikii hydrologic unit drains a region on the north shore that includes groundwater and runoff from both the Koolau and Waianae mountains, including an area identified as the Schofield Plateau. The Schofield Plateau is a unique geologic formation around the Schofield region where a large body of high level groundwater occurs that is different from either dike impounded or perched groundwater and sits in the saddle between the Koolau and Waianae mountains (Nichols et al. 1996). The plateau is approximately 22.5 km wide and 8 km long, rising from sea level on the north and south sides to approximately 305 m in elevation. The region has a unique geologic history due to its overlaying layers of lava, ash, and debris deposits (Stearns and Vaksvik, 1935). Some groundwater is perched within the weathered ash beds overlaying more dense lava flows (Rosenau et al. 1971). Structural barriers, including rift-zone intrusives, stray dikes that are not part of a well-defined rift zone, and two extensive impounding structures generate groundwater head discontinuities ranging from the tens to hundreds of feet (Hunt 1996). In the late 1930s, Swartz (1940) mapped the electrical conductivity of saltwater beneath the freshwater in the region and delineated the absence of saltwater within a range of depths in the Schofield Plateau, identifying the northern and southern limits of the high-level water. Dale and Takasaki (1976) referred to these geohydrologic barriers as water dams, possibly of intrusive rock that may be a composite of dike-intruded rock, erosional surface on Waianae Volcanics buried by Koolau Basalt, and massive lavas. The Schofield Plateau high-level ground water is impounded to an elevation of 187- to 300 feet asl in permeable Koolau lava flows (Visher & Mink 1964). This contrasts with the basal aquifer which sits approximately 20 feet asl to the north and 30 feet asl to the south of the plateau. The hydraulic conductivity of ground water in Koolau Basalt varies from 1,000 to 5,000 feet per day. The water occurs in permeable Koolau lava flows and is considered continuous and very flat beneath much of the plateau. The hydraulic conductivity of groundwater in Koolau Basalt varies from 1,000 to 5,000 feet per day. However, many unconformities add complexity to these generalization: i.e., on the western side of the plateau's southern limit, there is a dike-intruded ridge of Waianae Volcanics plunging eastward that is overlain by Koolau Basalt, compartmentalizing groundwater movement (Hunt 1996). Despite the importance of this water body to the regional water cycle, the specific movement of water within and from it is not well understood. Transitional areas have been inferred from groundwater levels in wells that, in some cases, were likely penetrating Waianae Volcanics.

Wells in the Kiikii Hydrologic Unit

The Kiikii hydrologic unit spans multiple aquifer systems in the North Shore Aquifer Sector, including the Wahiawa, Waialua, and Mokuleia aquifer systems. The 2019 update to the Water Resources Protection Plan kept the sustainable yield of the Wahiawa Aquifer System at 23 million gallons per day (mgd) but revised the sustainable yield of the Mokuleia aquifer system from 8 mgd to 17 mgd and revised the sustainable yield of the Waialua aquifer system from 25 mgd to 17 mgd based on updated information regarding the modeling of spillover water from the Wahiawa Aquifer System and its allocation among other systems (State of Hawaii, 2019). Also in the North Shore Aquifer Sector, the Kawailoa aquifer system sustainable yield was revised from 29 mgd to 22 mgd. The location of wells in the Kiikii hydrologic unit are depicted in Figure 3-4 and detailed information for each well is specified in Table 3-2.

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: Izuka et al., 2018)

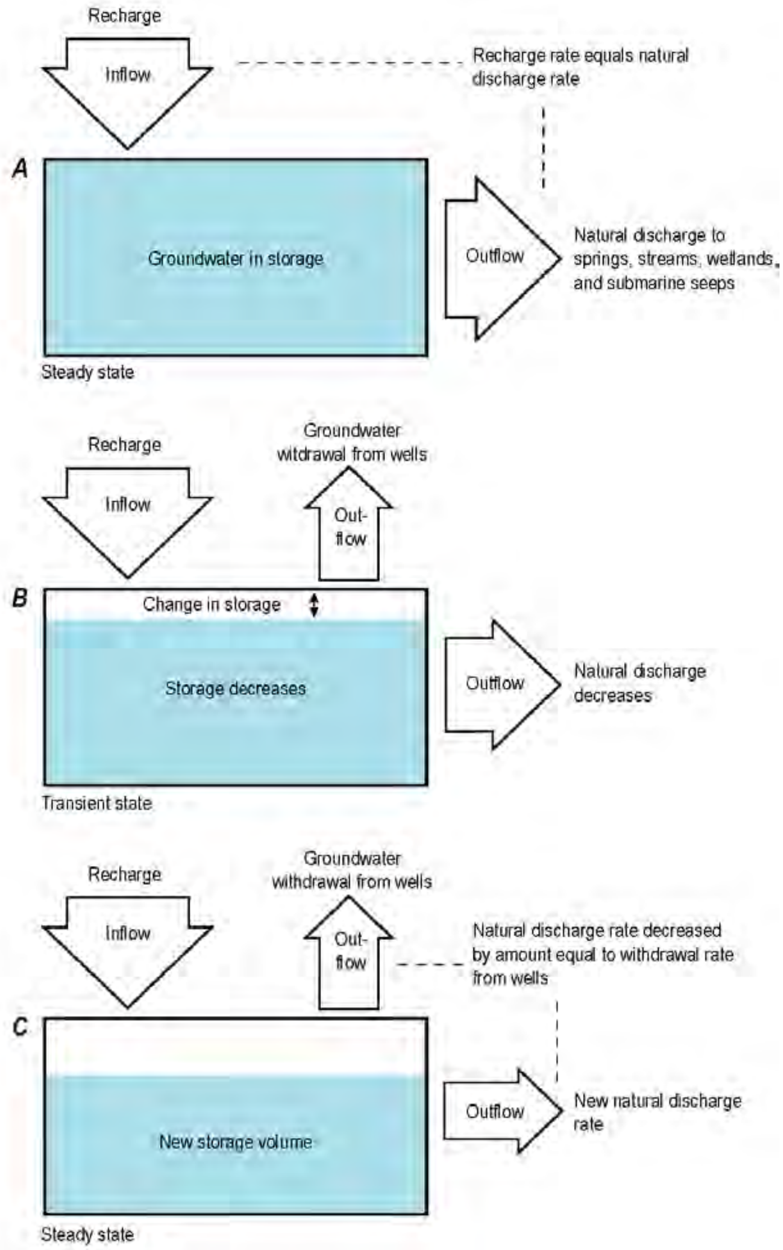


Table 3-2. Information of wells located in the Kiikii hydrologic unit (Source: State of Hawaii, Commission on Water Resource Management, 2020c).

[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)
2900-002	Schofield MW2-1	U S Army	1994	OBS	902	796	0.036
2901-008	Wahiawa I-3	Honolulu BWS	1941	OBSWL	870	880	2.16
2901-009	Wahiawa I-2	Honolulu BWS	1947	UNU	873	990	0
2901-011	Wahiawa I-1	Honolulu BWS	1962	MUNCO	873	821	3.456
2901-012	Wahiawa I-2	Honolulu BWS	1983	MUNCO	874	858	3.456
2902-001	Wahiawa II-1	Honolulu BWS	1974	MUNCO	866	986	3.024
2902-002	Wahiawa II-2	Honolulu BWS	1996	MUNCO	868	861	2.52
2903-001	Schofield MW2-2	U S Army	1994	OBS	862	743	0.036
2959-001	Schofield MW2-5	U S Army	1995	OBS	910	816	0.036
3001-001	Alii Turf	Alii Turf Co., LLC	2010	AGRLI	972	850	0.288
3004-001	Schofield MW4-1	U S Army	1993	OBS	854	645	0.036
3004-002	Schofield MW4-2	U S Army	1993	OBSWL	945	711	0
3004-003	Schofield MW4-3	U S Army	1993	OBS	883	649	0
3004-004	Schofield MW4-4	U S Army	1995	OBS	828	770	0.036
3004-005	Schofield MW4-2A	U S Army	1994	OBS	945	815	0.036
3059-001	Wahiawa	Wahiawa Water	1940	ABNSLD	986	209	0
3059-002	Wahiawa	Wahiawa Water	1941	ABNSLD	986	765	0
3100-001	Wahiawa	U S Navy NAVFAC	1941	UNU	1145	548	0
3100-002	NAVFAC Wahiawa Deep	U S Navy NAVFAC	1942	MIL	1145	970	1.296
3102-001	Helemano	Waialua Sugar	1972	ABNSLD	965	960	0
3102-002	Helemano Pump 24		1973	AGRCP	960	977	4.5
3103-001	Del Monte Pump 5		1988	AGRCP	965	1066	3.168
3104-002	HEP-1		2015	IRR	949.23	750	0.778
3104-003	Brent's		2017	IRR	896	925	0
3104-004	Villa Rose		2015	AGRLI	932	913	0.331
3105-001	Kaukonahua Ho'ola		2017	DOM	820.5	878	0.209
3203-001	Helemano Pump 25	Kelena Farms, Inc.	1974	AGRCP	860	1070	4.464

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)
3203-002	Waialua Pump 26		1975	AGRCP	927	1123	4.5
3204-001	Kaheaka Obs.	USGS	1994	OBS	740	795	0
3205-001	Kamananui		1938	ABNLOS	274	292	0
3205-002	Poamoho A	Poamoho Venture	1994	AGRCP	589	672	1.44
3205-003	45 LLC		2017	DOM	516	560	0.008
3206-001	Pelayo		2016	DOM	145	210	0.012
3206-002	Henderson		2016	DOM	184	280	0.017
3306-001	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	50	380	11.999
3306-002	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	52	377	0
3306-003	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	53	376	0
3306-004	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	56	400	0
3306-005	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	50	377	0
3306-006	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	47	381	0
3306-007	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	49	376	0
3306-008	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	46	375	0
3306-009	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	45	375	0
3306-010	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	49	379	0
3306-011	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	47	378	0
3306-012	Waialua P10 Batt	Waialua Sugar	1927	ABNSLD	50	377	0
3306-013	NSLF-015	North Shore Land & Farming, LLC	2008	DOM	142.3	190	0.015
3306-014	NSLF-023	Valley Well Drilling	2008	DOM	144	180	0.019
3306-015	Barels Springs	Barels O R	2008	DOM	0	180	0.004
3306-016	Hamamoto 2006		2008	AGRCP	0	150	0.014
3306-017	Christensen-01	Christensen K S	2008	DOM	0	190	0.004
3306-018	NSLF-001	Tsuruda, M & M	2008	DOM	80	220	0.024
3306-019	NSLF-024		2008	DOM	0	195	0.01
3306-021	Haleiwa-Saville	Scott Saville	2011	DOM	90	215	0.013
3306-022	Kamalani	Kamalani Ranch Co.	2007	DOM	105.44	160	0.015
3306-023	Payes	Linda L Payes Trust	2008	DOM	92.5	180	0
3306-024	NSLF 11	Falko Partners, LLC	2008	DOM	126	185	0.013
3306-025	NSLF 13		2009	DOM	140	190	0.014
3306-026	Kaala Farms	Kaala Farms LLC	2010	DOM	184	260	0.058
3306-027	Haviland-Partlon	Colleen Haviland & Teryy Partlon	2012	DOM	92	200	0.017
3306-028	Cherry 2012		2013	DOM	162	220	0
3306-030	NST		2014	DOM	128	185	0.014
3306-031	KOHL 010		2016	DOM	88	105	0

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)
3307-001	Waialua P2 Battery Well D	Dole Food Company Hawaii	1899	UNU	29	319	9.999
3307-001	Waialua P2 Battery E		1899	UNU	27	300	0
3307-002	Waialua P2 Battery F		1899	MUNPR	26	275	0.259
3307-003	Waialua P2 Battery G		1899	MUNPR	26	276	0.72
3307-004	Waialua P2 Battery H		1899	UNU	26	277	0
3307-005	Waialua P2 Battery I		1899	UNU	27	277	0.216
3307-006	Waialua P2A Battery N		1899	ABN	26	294	6.998
3307-007	Waialua P2 Battery A		1915	UNU	29	305	0
3307-008	Waialua P2 Battery B		1915	UNU	28	309	0
3307-009	Waialua P2 Battery C		1915	UNU	28	300	0
3307-010	Waialua P2A Battery K		1917	AGRCP	26	300	0
3307-011	Waialua P2A Battery L		1917	AGRCP	26	306	0
3307-012	Waialua P2A Battery M		1917	AGRCP	25	308	0
3307-013	Waialua P2A Battery J	Dole Foods	1924	AGRCP	28	307	0
3307-014	Waialua		1939	AGRCP	108	122	0
3307-015	Waialua		1947	ABNLOS	185	317	0
3307-016	T-116	Dole Foods	1963	OBS	221	323	0
3307-017	T-117	Dole Foods	1964	OBS	221	423	0
3307-018	Waialua-Mauka	Dole Foods	1984	AGRLI	201.77	302	0.03
3307-019	Thompson Corner 1	USGS	1993	OBS	99	181	0
3307-020	Thompson Corner 2	USGS	1993	OBS	100	180	0
3307-021	NSLF-03		2007	DOM	0	220	0
3307-022	NSLF-08	William L Sutton	2007	DOM	105	160	0.016
3307-023	NSFL-09		2007	UNU	0	163	0
3307-024	NSLF-02		2008	AGRCP	0	220	0
3307-025	CL CL 009		2016	DOM	103	260	0
3307-027	CL CL 011		2016	DOM	57	69	0
3307-028	CL CL 017		2016	DOM	68	75	0
3307-029	Pietsch		2016	AGR	138	205	0.071
3307-030	Waialua	Sakuoka S	1957	UNU	28	100	0
3406-005	Gilman	Gilman, Hannah K Trust Estate	1957	ABNLOS	12	100	0
3406-006	Kamooloa Obs.	USGS	1994	OBS	41	51	0
3406-013	Kemoo Camp Bat A	Waialua Sugar	0	ABNSLD	9	326	0
3407-001	Lopez 2	Lopez Family Estate	0	AGRCP	8	180	0.144

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)
3407-002	Pump 1	Dole Foods	1898	AGRCP	12	300	5.999
3407-005	Pump 1	Dole Food Co, Inc	1898	AGRCP	12	280	0
3407-006	Pump 1	Dole Food Co, Inc	1898	AGRCP	12	280	0
3407-007	Mill Pumps	Waialua Sugar	1899	ABNSLD	30	261	9.999
3407-008	Mill Pumps	Waialua Sugar	1899	ABNSLD	30	236	0
3407-009	Mill Pumps	Waialua Sugar	1899	ABNSLD	30	259	0
3407-010	Mill Pumps	Waialua Sugar	1900	ABNSLD	30	296	0
3407-011	Pump 7 B	Dole Food Co Inc	1913	AGRCP	16	206	5.544
3407-012	Pump 7 C	Dole Food Co Inc	1913	AGRCP	15	231	0
3407-013	Waialua II Batt	Waialua Sugar	1920	ABNSLD	34	273	0
3407-014	Pump 1	Dole Food Co, Inc	1920	AGRCP	12	320	0
3407-015	Pump 1	Dole Food Co, Inc	1920	AGRCP	12	320	0
3407-016	Mill Pumps	Waialua Sugar	1923	ABNSLD	33	265	0
3407-017	Mill Pumps	Waialua Sugar	1923	ABNSLD	34	267	0
3407-018	Pump 7 D		1923	AGRCP	17	204	0
3407-019	Pump 7 E		1923	AGRCP	18	208	0
3407-020	Mill Pumps	Waialua Sugar	1933	ABNSLD	34	242	0
3407-021	Mill Pumps	Waialua Sugar	1933	ABNSLD	33	270	0
3407-022	Waialua	Dole Food Co, Inc	1939	ABNLOS	15	0	0
3407-023	Waialua	Dole Food Co, Inc	1939	ABNSLD	45	81	0
3407-024	Waialua	Dole Food Co, Inc	1939	ABNLOS	45	81	0
3407-028	Waialua	USGS	1962	ABNLOS	15	40	0
3407-037	Kiikii Cap Mon 2	USGS	1994	OBS	5	140	0
3407-038	Paradise Shrimp	Paradise Shrimp Farm	2003	AGRAQ	8	61	0

The HBWS total installed pump capacity in the Kiikii hydrologic unit is 14.616 mgd. A number of wells support agricultural irrigation in the region. The HBWS operates two batteries of wells in the Wahiawa aquifer system for potable water supply (Figure 3-5). Each battery consists of two wells and their combined pumpage is reported to CWRM. Monthly pumpage since 1990 has been reported consistently for HBWS Wahiawa II-1 and II-2 wells, while reporting has been less consistent for Wahiawa I-1 and I-2. The mean, median, and maximum monthly pumpage from each battery reported from 1990 to 2020 is provided in Table 3-3.

Dole Food Company currently owns, operates, and reports for five wells, of which two (3407-004 Pump 1 and 3407-011 Pump 7B) continue to supplement surface water sources used to irrigating agriculture (Table 3-4). Both pumps are used well below their historic capacity.

Pural Water Supply also operates six wells in the Kiikii hydrologic unit of which two have been actively used since 2017 (Table 3-5).

Figure 3-4. Well locations by well type and well numbers in the Kiikii hydrologic unit with aquifer boundaries and current systainable yields identified, Oahu. (Source: State of Hawaii, Commission on Water Resource Management, 2018c).

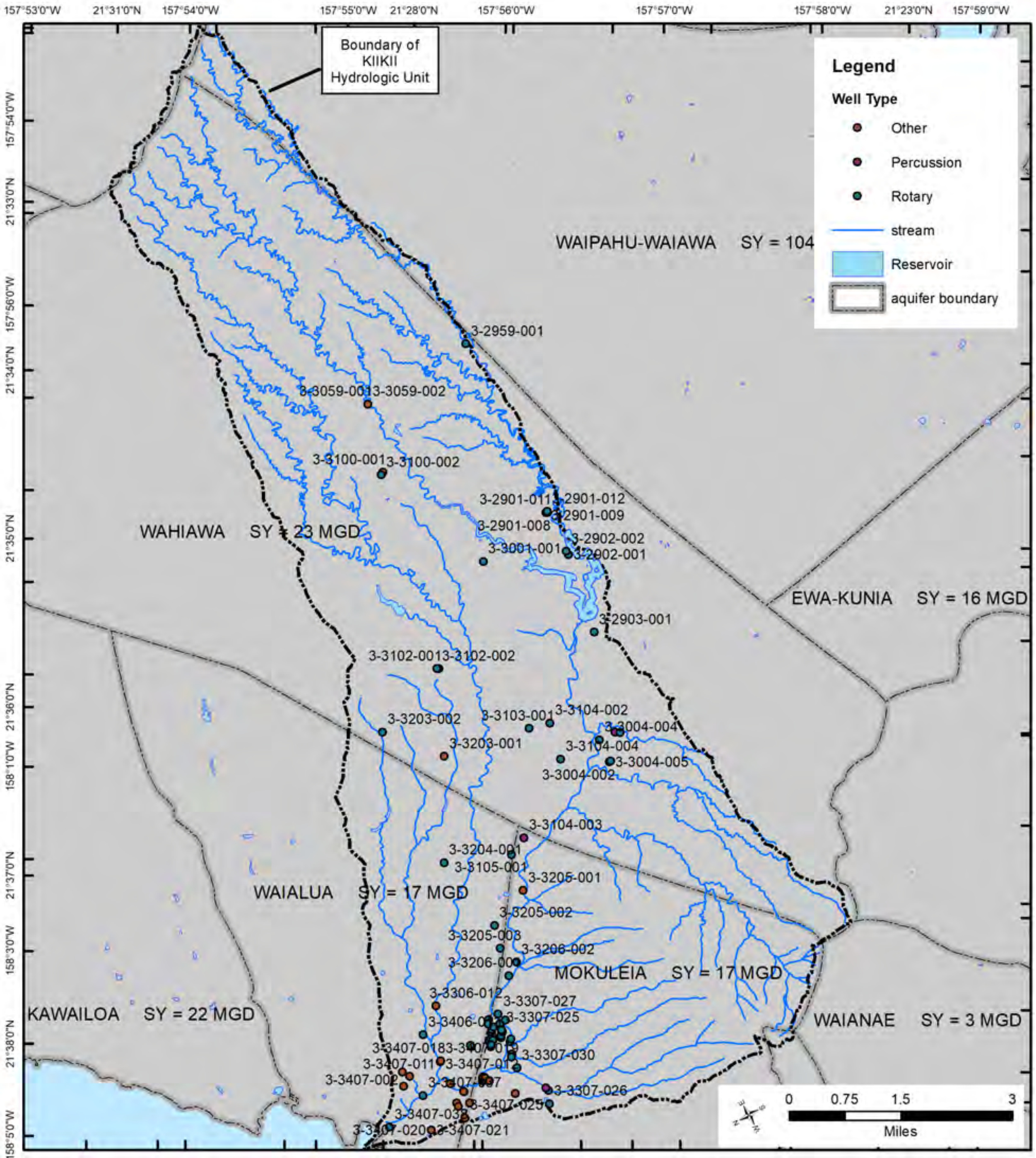


Table 3-3. Groundwater pumpage from source wells for the Honolulu Board of Water Supply from the Wahiawa Aquifer System from January 2013 to June 2020. (Note: -- value is unknown , n/a = not applicable) [Flows iin million gallons per day, mgd]

well ID	well name	Pump capacity (mgd)	average monthly pumpage (mgd)	median monthly pumpage (mgd)	maximum monthly pumpage (mgd)
2901-011	Wahiawa I-1	3.456	1.417	1.948	3.644
2901-012	Wahiawa I-2	3.456			
2902-001	Wahiawa II-1	3.024	1.249	1.326	2.525
2902-002	Wahiawa II-2	2.520			

Figure 3-5. Total reported monthly pumpage (million gallons per day, mgd) and 12-month moving average for Honolulu Board of Water Supply (BWS) wells in the Wahiawa aquifer system, Oahu. (Source: Source: State of Hawaii, Commission on Water Resource Management, 2020c).

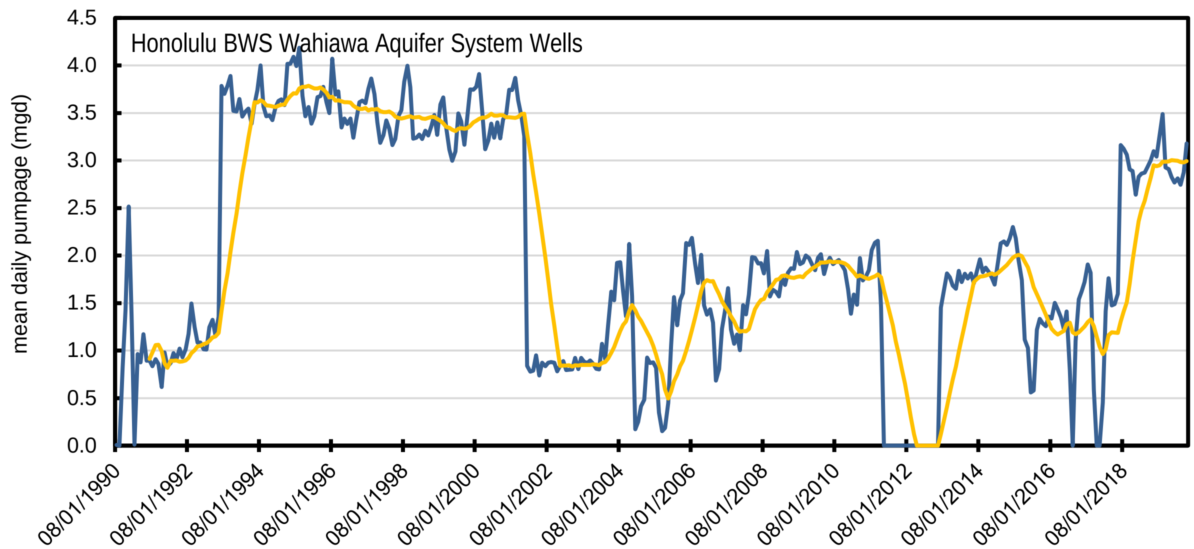


Table 3-4. Groundwater pumpage from wells operated by Dole Foods Company Hawaii in the Kiikii hydrologic unit for different periods of time. [Flows iin million gallons per day, mgd]

		average monthly pumpage (mgd)		median monthly pumpage (mgd)		maximum monthly pumpage (mgd)	
well ID	well name	1980-1995	1995-2020	1980-1995	1995-2020	1980-1995	1995-2020
3102-002	Helemano Pump 24	1.544	0.000	0.934	0.000	6.446	0.000
3203-002	Waialua Pump 26	1.752	0.000	1.103	0.000	5.852	0.001
3408-004	Pump 1	1.749	0.512	1.579	0.351	5.682	5.492
3407-001	Pump 7B	2.222	0.543	1.416	0.059	1.416	0.059
3404-001	Waialua Pump 17	5.390	0.000	3.272	0.000	24.625	0.000

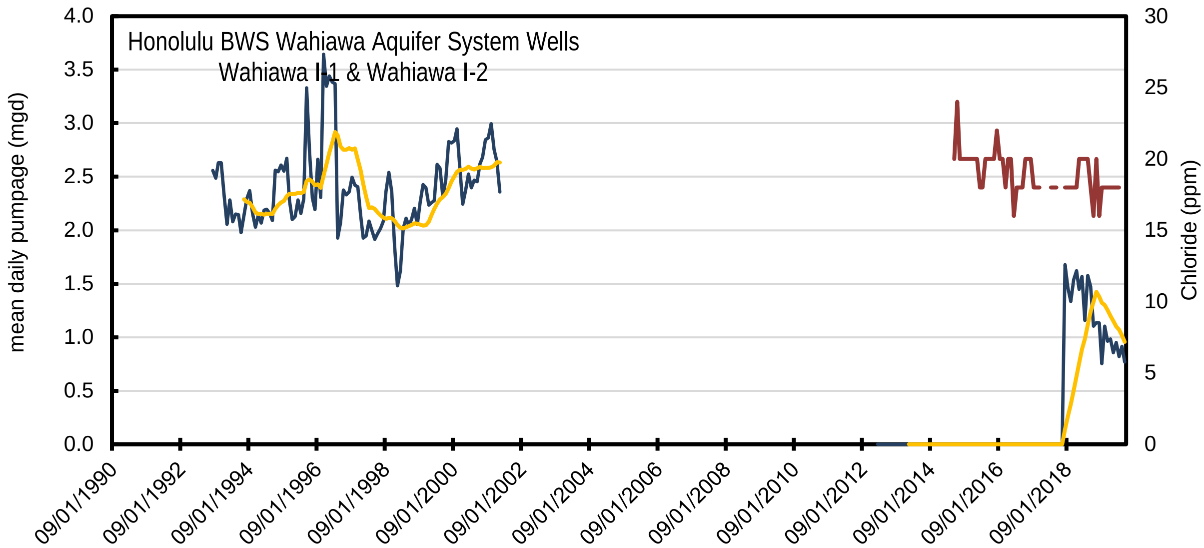
Table 3-5. Groundwater pumpage from wells operated by Pural Water Company Hawaii in the Kiikii hydrologic unit from 2017-2020. [Flows iin million gallons per day, mgd]

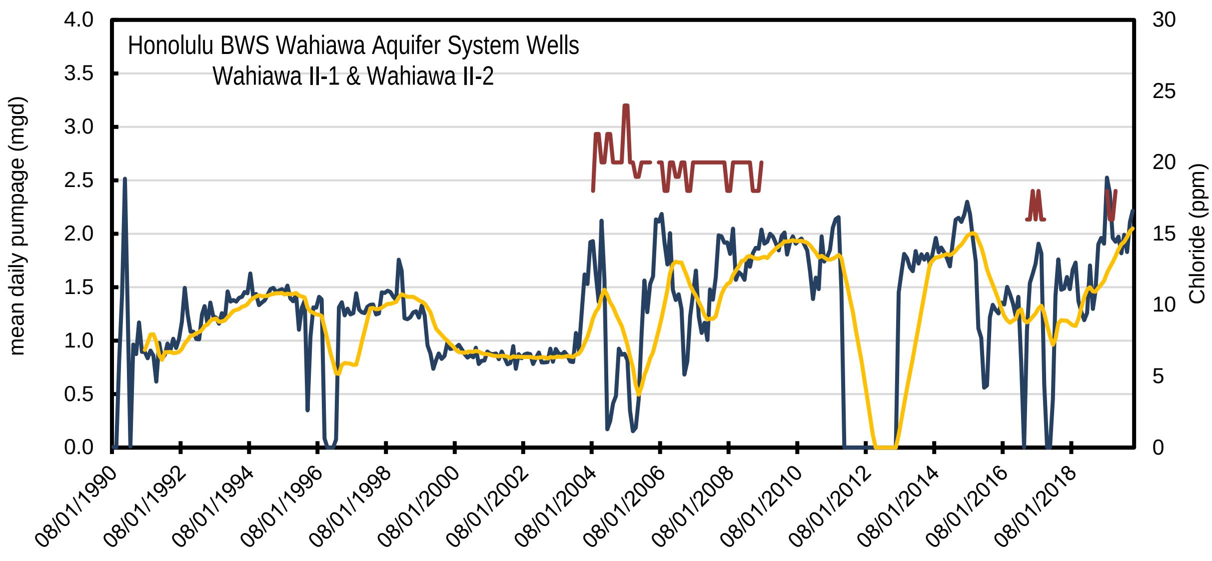
well ID	well name	average monthly pumpage (mgd)	median monthly pumpage (mgd)	maximum monthly pumpage (mgd)
3307-002	Waialua P2 Battery F	0.147	0.182	0.264
3307-003	Waialua P2 Battery G	0.082	0.047	0.294

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 Kiikii hydrologic unit, 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 inconsistent reporting.

Figure 3-6. Reported monthly mean daily pumpage (mgd) and chloride levels for the two Honolulu Board of Water Supply well batteries in Wahiawa.

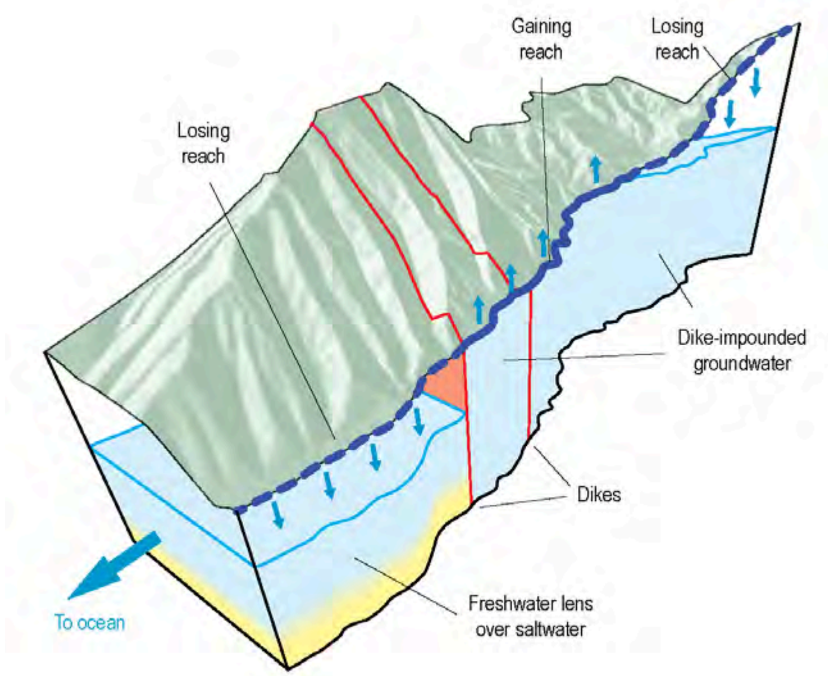




Streamflow Characteristics

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 3-7 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.

Figure 3-7. Depiction of the groundwater table along the stream course in the upper reaches of Kaukonahua Valley in relation to dike-impounded groundwater and losing reaches. (Source: Izuka et al., 2018)



Streamflow conditions have been monitored continuously in the Kiikii hydrologic unit on the North (NF) and South Fork (SF) Kaukonahua streams for varying lengths of time. Mean annual flow for complete water years are provided for various stations on the North (Figure 3-9) and South (Figure 3-10) forks of Kaukonahua stream. Station 16204000 on the NF Kaukonahua Stream monitored the combined flow of water from the NF Kaukonahua Stream and inflow from Poamoho Tunnel measured at USGS 16210900. The difference between these stations for the overlapping period of record (7/1/1958 to 9/29/1968) provides an estimate of low flow characteristics on the NF Kaukonahua Stream at the 920-foot elevation (Figure 3-11). The natural median (Q_{50}) flow for the period of record is 12.0 cfs, the Q_{70} flow is 6.3 cfs, and the Q_{90} flow is 2.1 cfs. For the current climate period (1984-2013), Cheng (2020) estimated low-flow characteristics at four locations (Table 3-6).

Wahiawā Reservoir is located at the confluence of the NF Kaukonahua and SF Kaukonahua streams in central O‘ahu, Hawai‘i. Below this reservoir, two stations have monitoring Kaukonahua Stream for short periods of time, providing some indication of the relative gains and losses of streamflow from upstream to downstream and differences in the size of peak flows (Figure 3-12).

Table 3-6. Selected flow duration discharge exceedance values for the current climate period (1984-2013) in the Kiikii hydrologic unit, Oahu, Hawaii. (Source: USGS 2016, except where noted) [Flows are in cubic feet per second (million gallons per day]

		discharge (Q) for a selected percentage (xx) discharge was equaled or exceeded			
station ID	station name	Q_{50}	Q_{70}	Q_{90}	Q_{95}
16200000	NF Kaukonahua abv RB	6.3 (4.07)	3.7 (2.39)	1.7 (1.10)	1.0 (0.65)
16201000	NF Kaukonahua	4.0 (2.59)	2.6 (1.68)	1.3 (0.84)	0.84 (0.54)
16204000	NF Kaukonahua[a]	11.4 (7.35)	5.2 (3.34)	1.05 (0.65)	--
16208000	SF Kaukonahua at Pump E	8.2 (5.30)	4.6 (2.97)	1.8 (1.16)	0.95 (0.61)
16211003	Poamoho Stream	2.8 (1.81)	1.6 (1.03)	0.65 (0.42)	--

[a] data derived from USGS 16204000 minus USGS 16109000 (Poamoho Tunnel) from 1958-1968 and adjusted to the 1984-2013 climate period using the percent change in flow for the concurrent period of record at USGS 16208000.

Seepage Gains and Losses

During stream channel development, surface flow from the Waianae Range diminished upon reaching the younger and more porous Koolau lava, losing water to the groundwater recharge. The resulting debris deposits continued to develop due to changes in stream grade even when Waianae surface flows eventually crossed the Koʻolau lavas and joined surface flows emanating from the larger and wetter Koolau range (Stearns and Vaksvik 1935). Over time, the Koolau streams, and to some extent the Waianae streams, cut deep gulches, exposing the underlying layers of ash, debris, and lava flows. These stream channels have exposed subsurface water flows including that contribute to surface flow gains now observed in these streams.

Seepage runs have never been made on Kaukonahua or Poamoho streams, although gaining stream reaches can be inferred from surface geology and the amount of stream channel incision into the underlying geology. For example, both the North Fork and South Fork branches of Kaukonahua Stream cut through Koolau Basalt 1.8 to 3 million years old in the marginal dike zones of the southeast to northwest rift zone, which tends to result in gaining stream reaches. During periods of constant outflow from Waihiawa Reservoir, measured at USGS station 16210200, estimates of streamflow gains can be made at Waialua (USGS station 16210500), 8.5 miles downstream (Table 3-7).

Table 3-7. Selected flow duration discharge exceedance values for flow between successive locations on Kaukonahua Stream in the Kiikii hydrologic unit, Oahu, Hawaii. (Source: USGS 2020) [Flows are in cubic feet per second (million gallons per day]

					discharge (Q) for a selected percentage (xx) discharge was equaled or exceeded		
upstream station ID	elevation (ft)	distance (mi)	downstream station ID	elevation (ft)	Q_{50}	Q_{70}	Q_{90}
16210200	760	8.5	16210500	15	0.38 (0.25)	0.24 (0.16)	0.10 (0.066)
16210000	1200	6.3	16204000	940	1.05 (0.68)	0.82 (0.53)	0.41 (0.26)

Figure 3-8. USGS and CWRM gaging stations in streams in the Kiikii hydrologic unit, Oahu (Source: USGS, 2020).

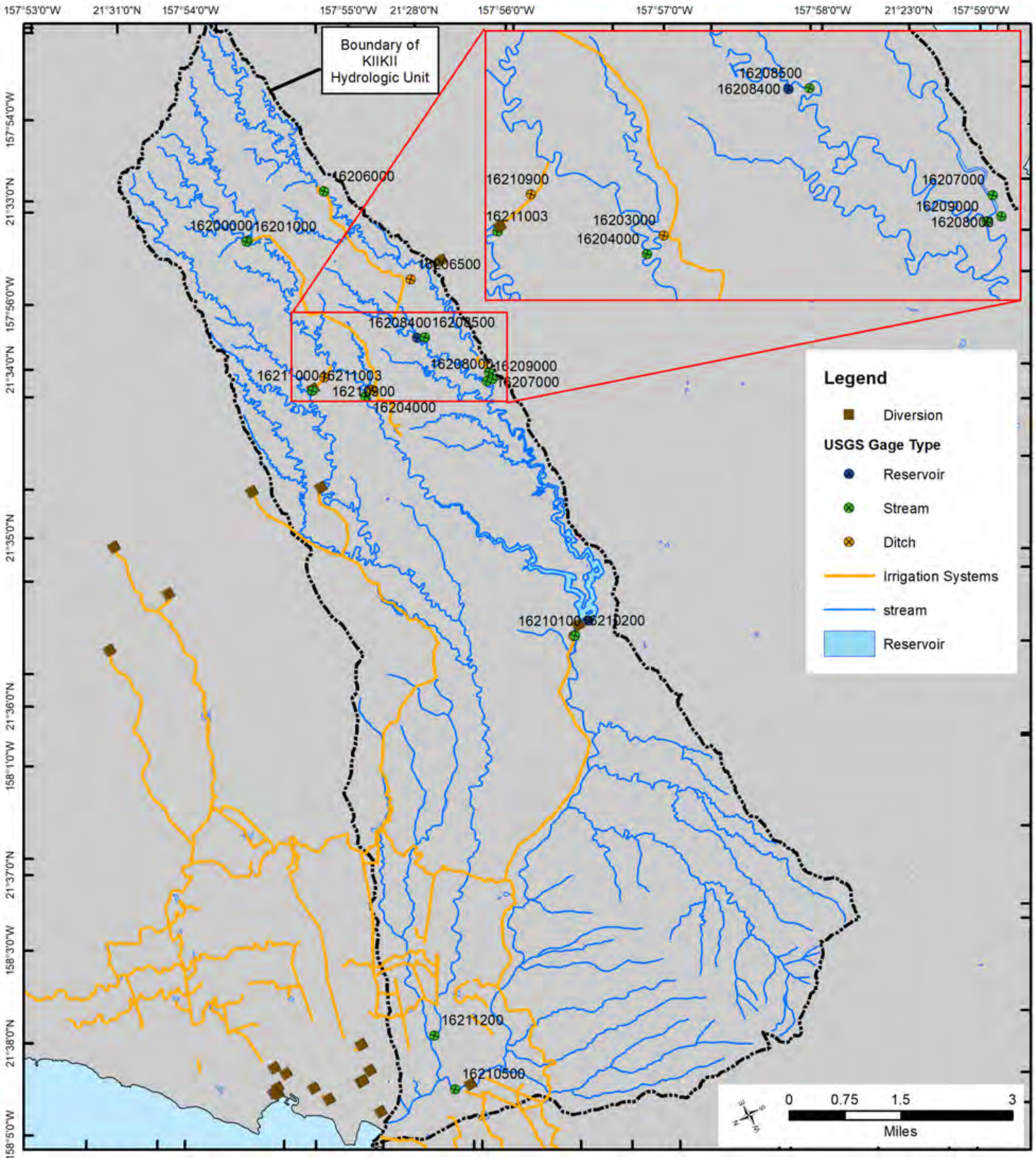


Figure 3-9. Mean annual flow (in cubic feet per second, cfs) for complete years at USGS stream gaging stations on the NF Kaukonahua, Oahu.

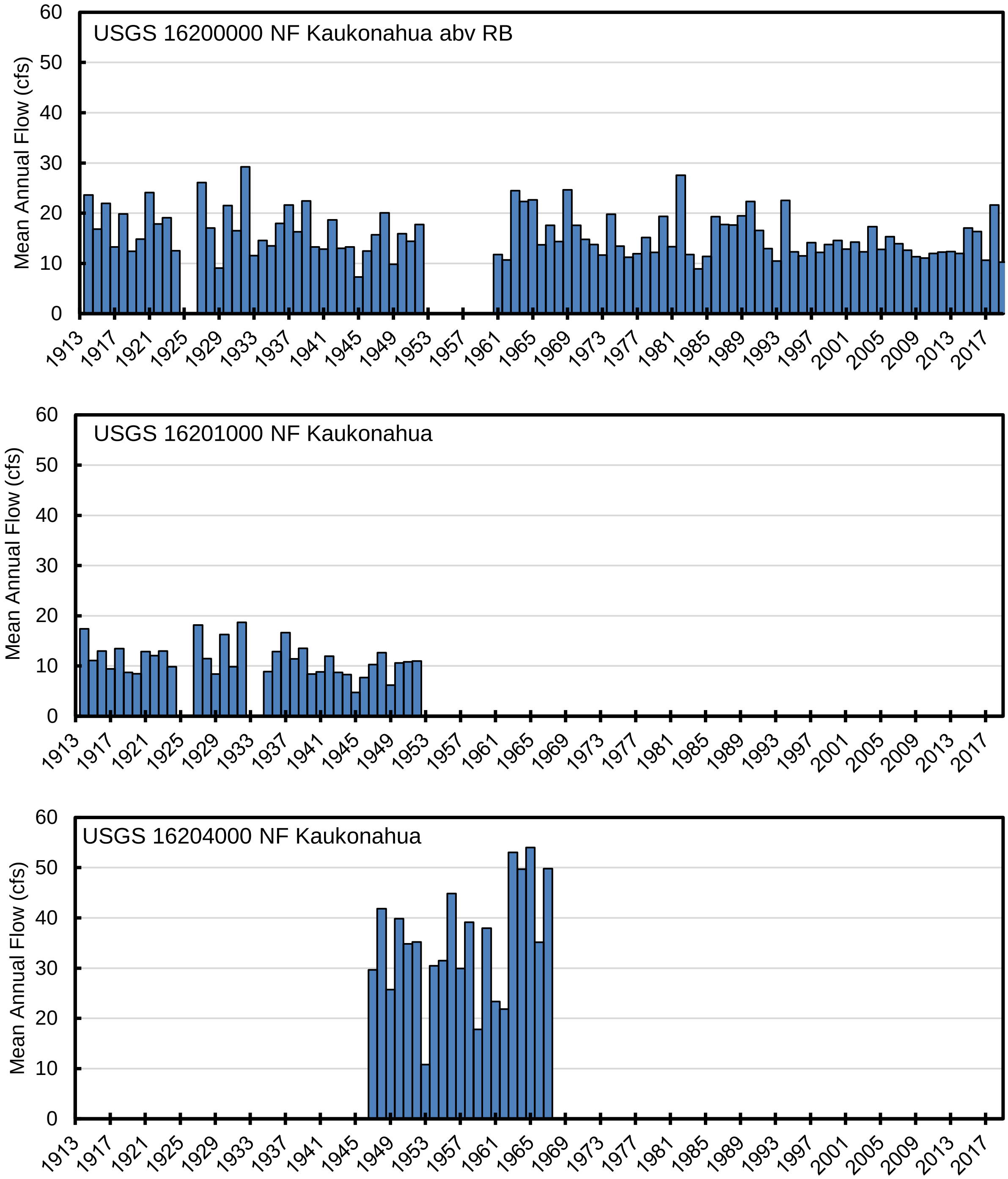


Figure 3-10. Mean annual flow for complete years at USGS stream gaging stations on the SF Kaukonahua, Oahu.

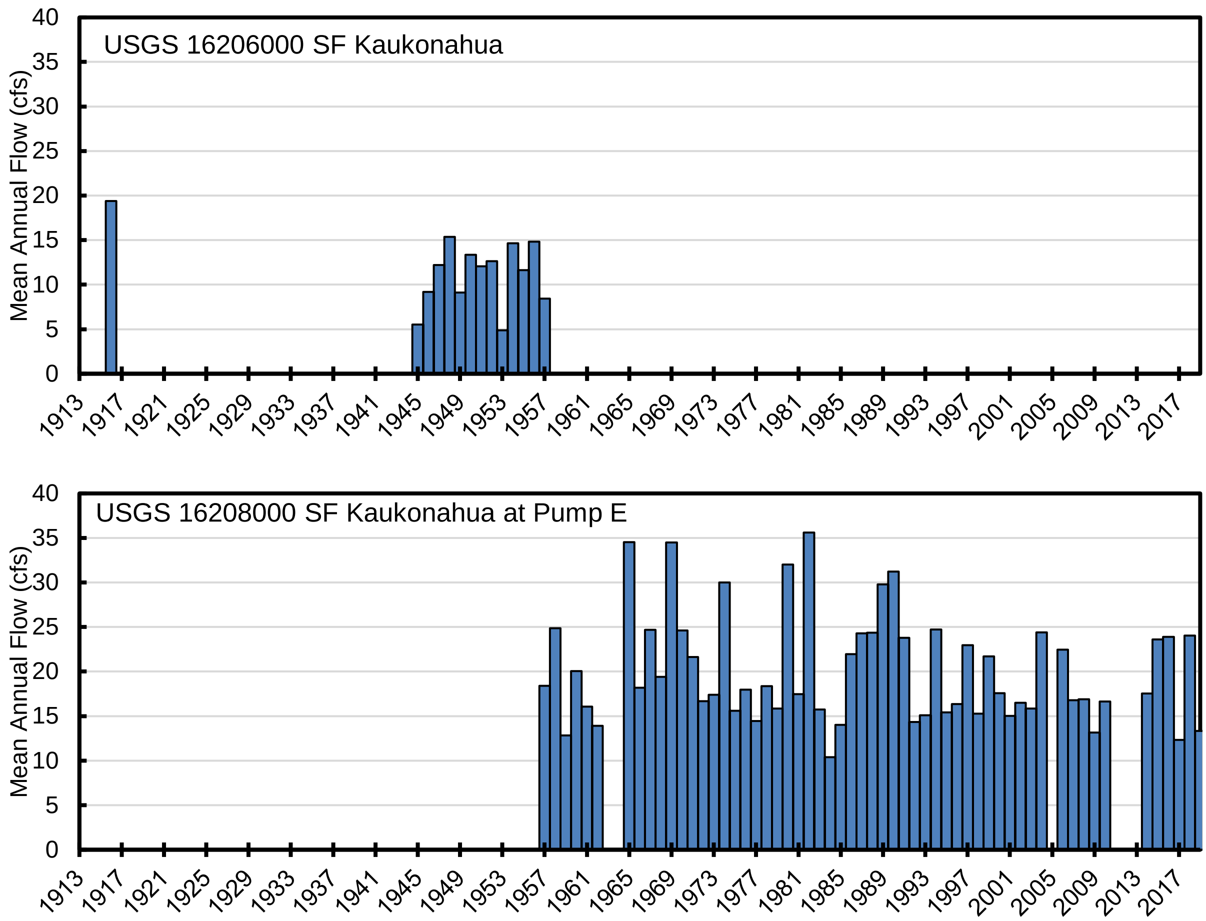


Figure 3-11. Mean daily flow at USGS 16204000 on NF Kaukonahua Stream minus mean daily flow at USGS 16109000 Poamoho Tunnel inflow from Poamoho Stream to NF Kaukonahua Stream, Oahu.

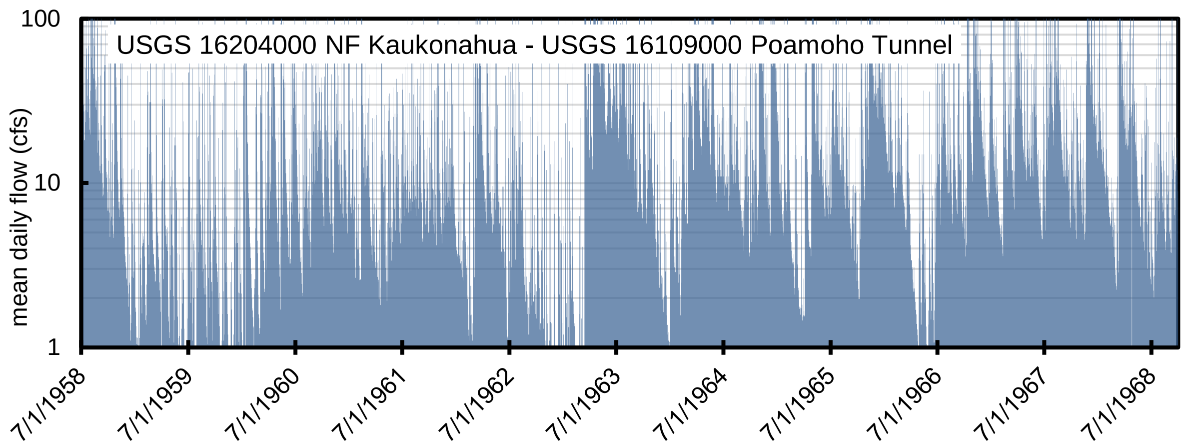
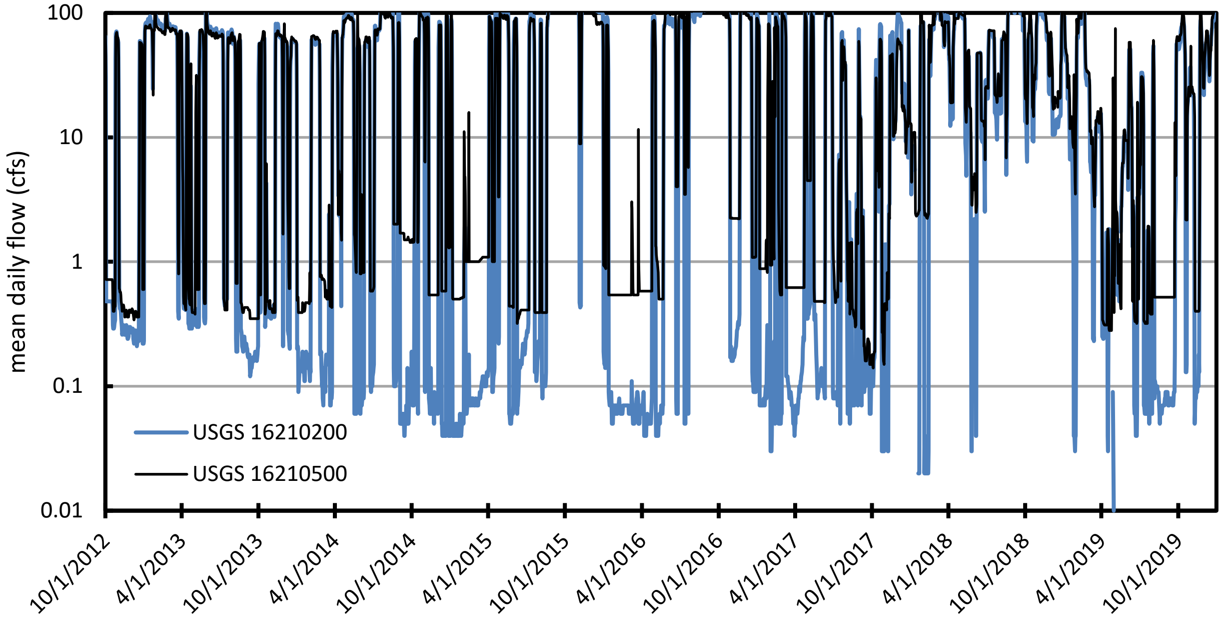


Figure 3-12. Mean daily flow (cubic feet per second, cfs) on Kaukonahua Stream below Waihiawa Reservoir (USGS station 16210200) and on Kaukonahua Stream at Waialua (USGS station 16210500) from 2012 to 2019.



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 large 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).

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 3-13. 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)

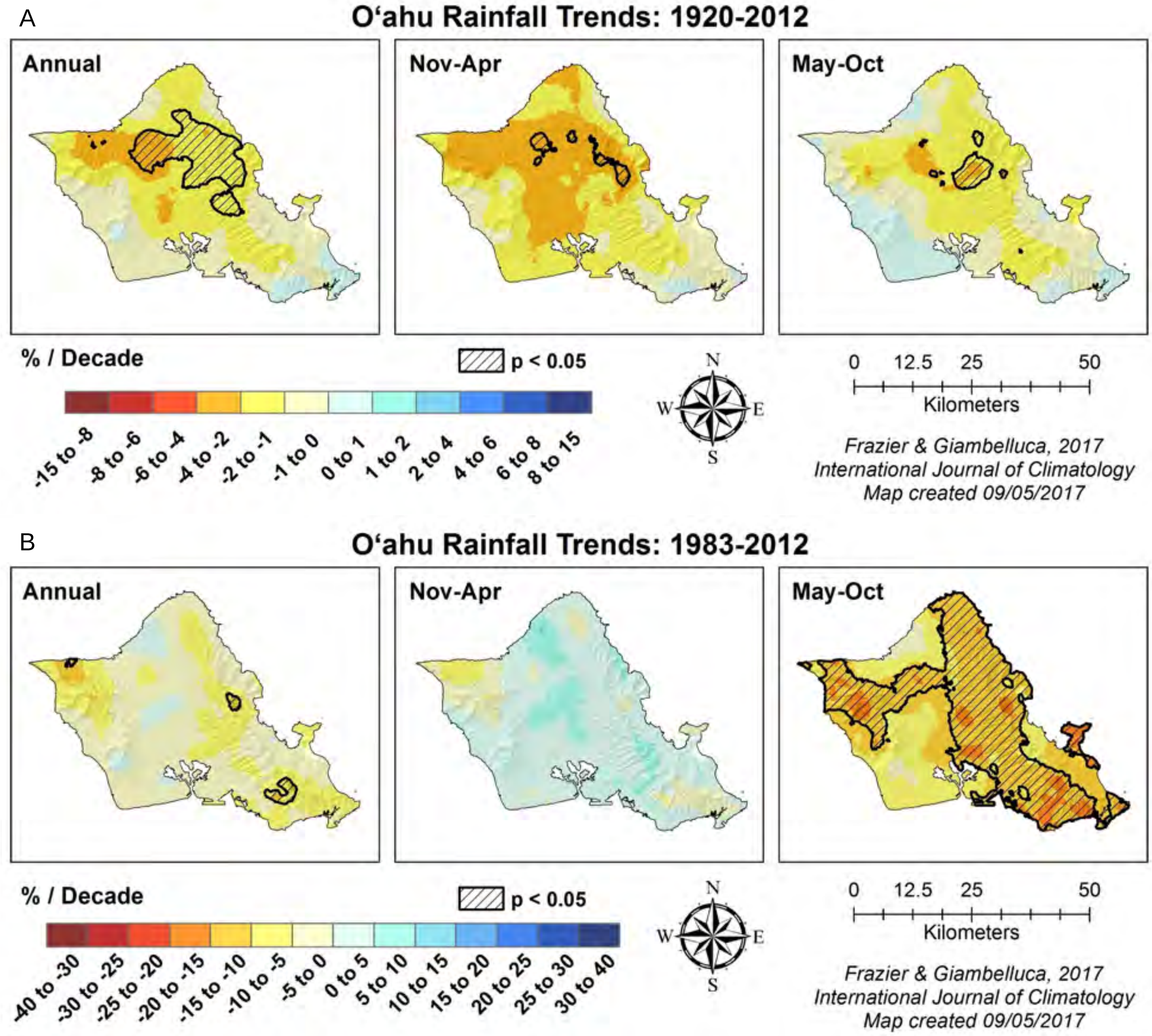
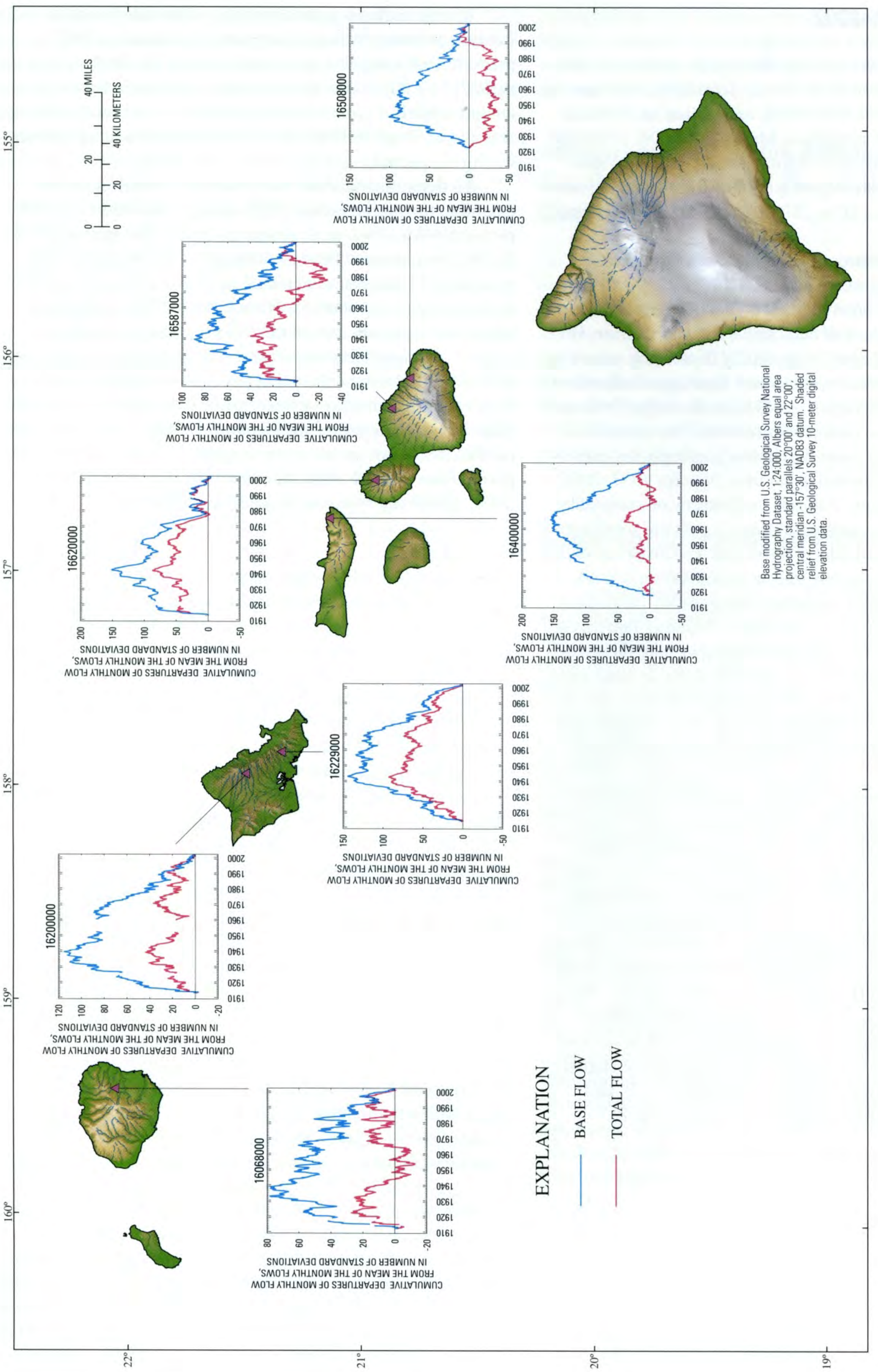


Figure 3-14. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii. This data is based on complete water years from 1913 through 2002. (Oki, 2004, Figure 4)



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.

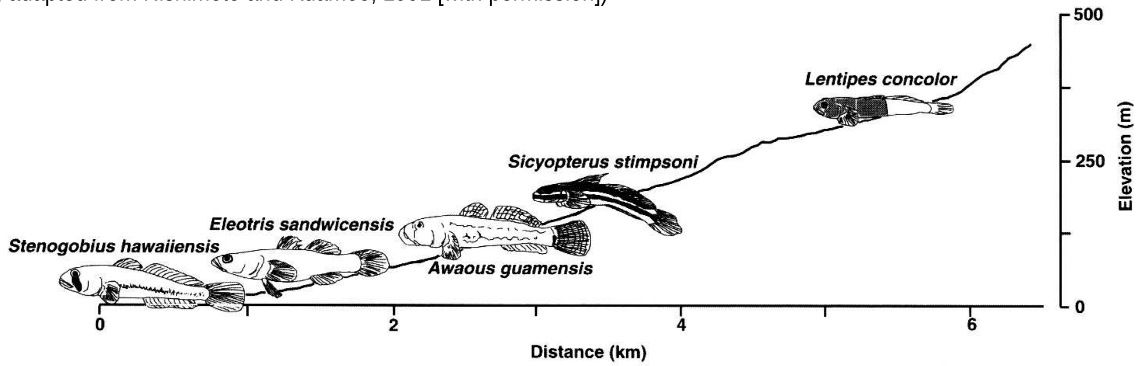
Table 4-1. List of commonly mentioned native stream organisms. (Source: State of Hawaii, Division of Aquatic Resources, 1993)

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 recommended that the Kiikii hydrologic unit streams be listed as candidate streams for protection based on its Blue Ribbon recreational resources. The HSA identified the Kiikii watershed as having moderate aquatic resources.

DAR Atlas of Hawaiian Watersheds

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

- **Point Quadrat Survey.** In the Kiikii watershed, stream surveys were conducted in 1931, 1932, 1945, 1959, 1961, 1962, 1969, 1976, 1977, 1978, 1979, 1990, 1995, 1996, 1997, 1998, 2000, 2002, and 2006 by the Hawaii Division of Fish and Game, Division of Forestry and Wildlife, the Division of Aquatic Resources, or US Fish and Wildlife. Few native species have been identified in Kaukonahua 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). Streamflow restoration would likely benefit recruitment and survival of native species in the estuary, lower, and middle reaches.

- **Insect Survey.** Multiple native insect species have been identified in the Kiikii hydrologic unit, including A*nax strenuous*, *Campsicnemus biocoloripes*, and *Megalagrion sp*. such as *M. Hawaiiense*, *M. leptodemas, M. nigrohamatum nigrolineatum*, and *M. oceanicum*. and the watershed met the criteria as a biotic stream of importance for native macrofauna diversity (>5 spp.). Some of these species are candidate endangered species. However, the watershed did not meet the DAR qualification for native insect diversity (>19 spp).

- **Watershed and Biological Rating.** The Kiikii watershed has a medium land cover rating for Oahu and statewide due to the percentage of conservation land. The watershed supports wetland and estuarine reaches giving it a high rating for shallow waters on Oahu and statewide. However, the watershed rates poorly for stewardship due to the degree of urbanization, channelization, and invasive species. Kaukonahua and Poamoho streams have a high rating for stream size and reach diversity, but a low rating for wetness, resulting in a high 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 a poor total biological rating for the island and the state. These scores combined gave Kiikii watershed a medium overall watershed rating with a high rating strength.

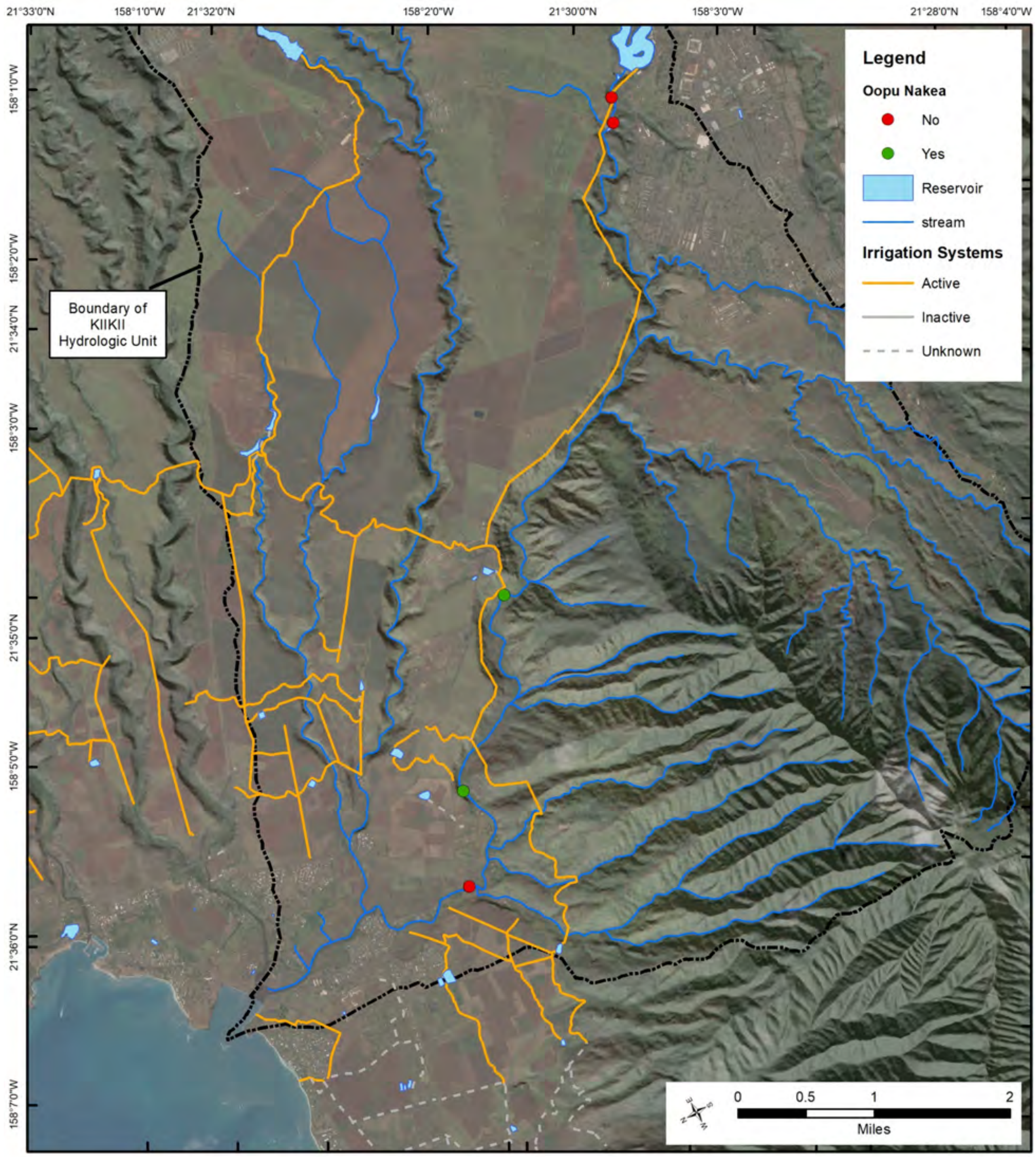
Table 4-2. Present (P) of native species by stream reach for the Kiikii Hydrologic unit, Oahu. (Source: DAR, 2008)

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

Recent Biota Surveys

In 2021, staff from DAR and CWRM conducted a cursory survey of Kaukonahua Stream from Wahiawa Reservoir to its confluence with Poamoho Stream (Figure 4-2). At two elevations, staff observed recent (< 5 months old) recruits of *A. stamineus* (70 ft a.s.l. and 280 ft a.s.l.). Water samples were also gathered at each location for eDNA analysis to identify the spatial distribution of aquatic biota. At this time, that data are not available for analysis.

Figure 4-2. Biota survey locations and presence (yes) or abasence (no) of A. stamineus (Oopu Nakea) in Kaukonahua Stream below Wahiawa Reservoir on June 2, 2021.



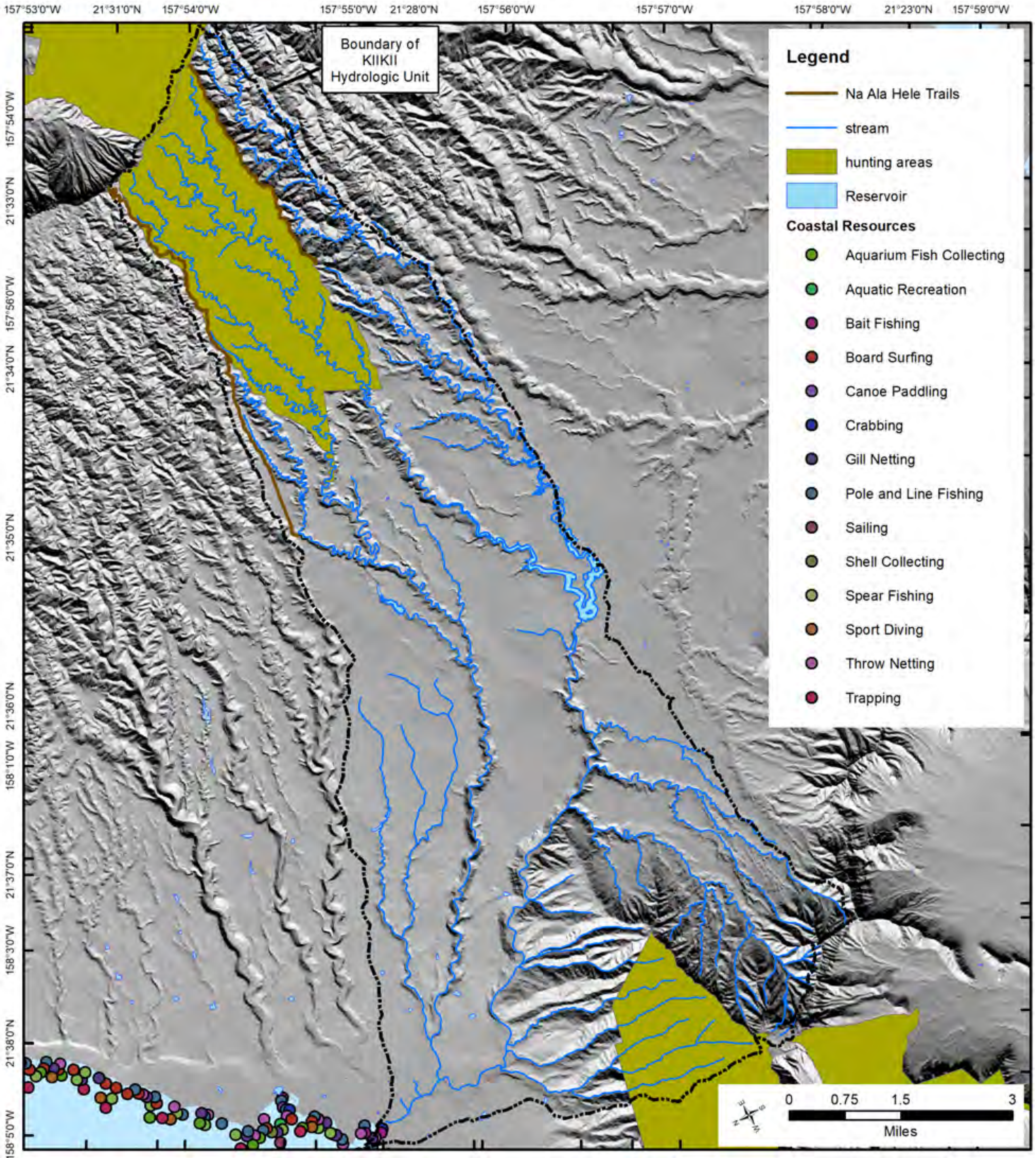
5.0 Outdoor Recreational Activities

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, swimming, boating, parks, hunting, and science views as recreational opportunities in the Kiikii hydrologic unit and classified the watershed as having "outstanding" recreational resources and including it as a Candidate Stream for Protection based on its "Blue Ribbon" recreational resources (National Park Service, 1990). Boatingand fishing on Lake Wilson (Wahiawa Reservoir) are particularly popular activities. 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 Ewa Forest Reserve Poamoho Section and the Kaala Natural Area Reserve, but not in the rest of the hydrologic unit. The Wahiawa Freshwater State Recreation Area supports hiking, aesthetic values, and recreational fishing.

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 Kaukonahua 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 Kiikii include: crabbing, canoe paddling, pole and line fishing, and throw netting (Figure 5-1).

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

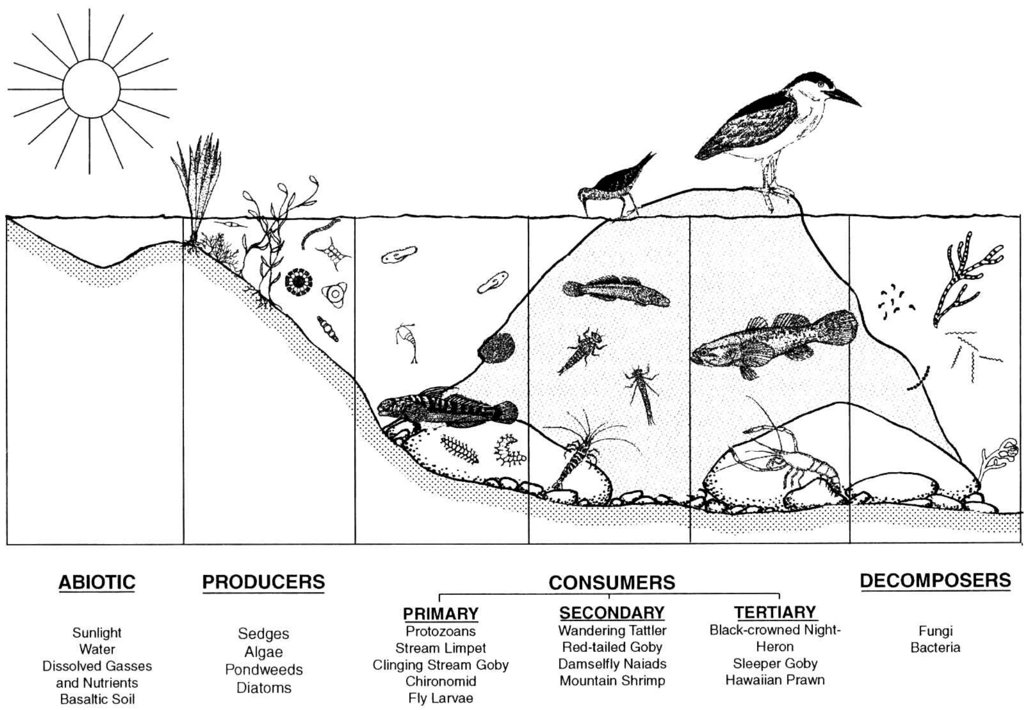


6.0 Maintenance of Ecosystems

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 Kiikii watershed did not deserve to be a candidate stream for protection based on its riparian resources. The Kaukonahua and Poamoho Valleys are heavily degraded by invasive species. Restoration of cultural practices along the stream, including the cultivation of food resources, would help manage riparian vegetation.

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 Kiikii Stream were classified as “substantial” (3 out of 4) 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 Kiikii 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.	2
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.	--
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.	2
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.	1
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
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.	30%
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, California Grass; 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 Kiikii, 8.145 square miles (13.9 percent) is in Forest Reserves (Ewa Forest Reserve Poamoho Section and Mokuleia Forest Reserve) and 1.635 square miles (2.8 percent) is located Kaala Natural Area Reserve, both under the jurisdiction of the Department of Land and Natural Resources Division of Forestry and Wildlife. The Department of Land and Natural Resources Division of State Parks also manages the Wahiawa Freshwater State Recreation Area (0.105 square miles, 0.18 percent).

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. In addition to the individual management areas outlined above, portions of Kiikii fall within two watershed partnerships on Oahu. Table 6-2 provides a summary of the partnership area, partners, and management goals of the Koolau Mountains Watershed Partnership and Waianae Mountains Watershed Partnership.

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

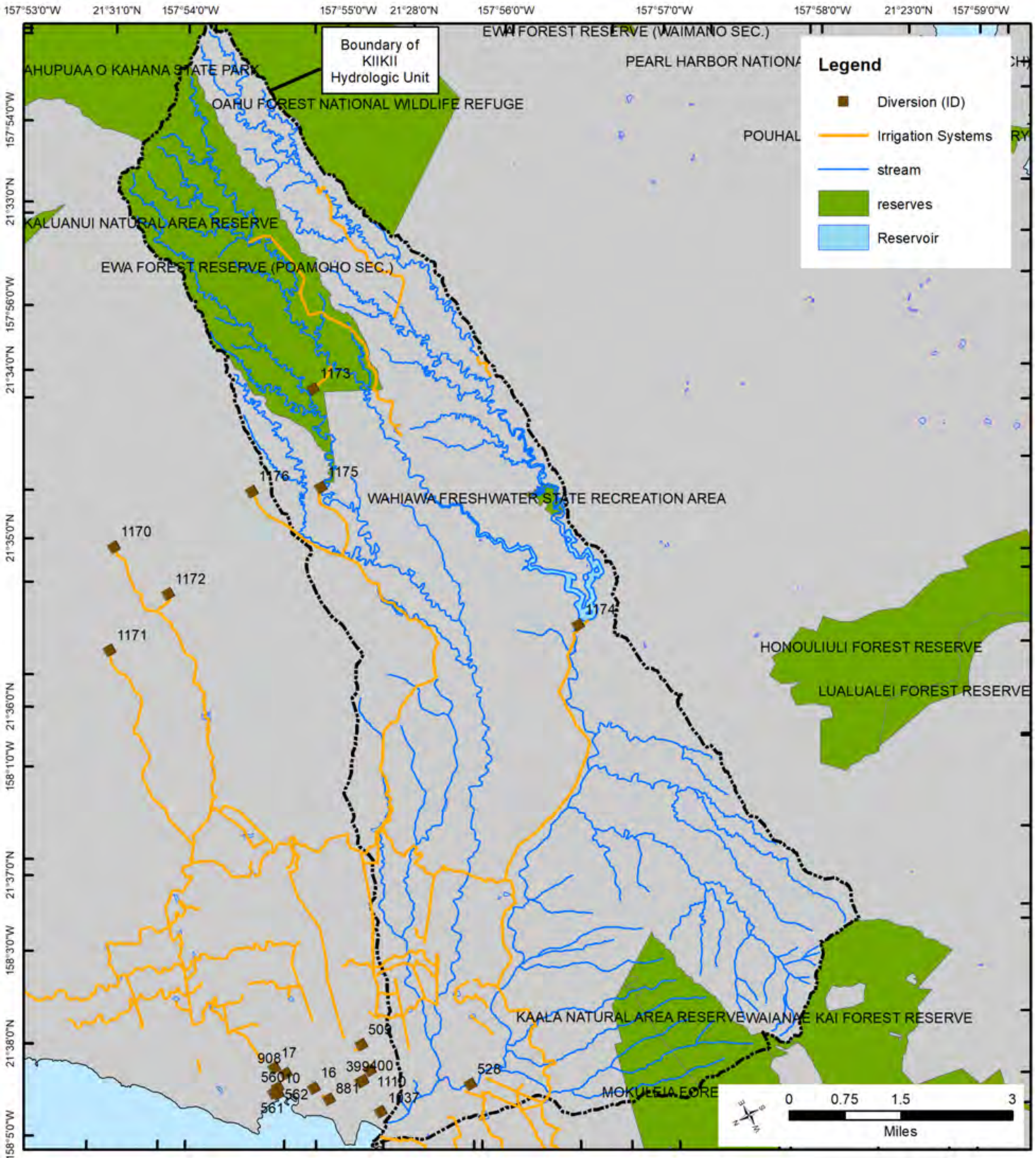
Management Area	Year Established	Total Area (mi^2)	Area of Unit (mi^2)	Percent of Unit
Koolau Mountains Watershed Partnership	1999	174.07	13.819	23.7
The Koolau Mountains Watershed Alliance (KMWA) is comprised of the City and County of Honolulu Board of Water Supply, Dole Food Company Inc, Hawaii Reserves Inc, Waimea Valley (Hiipaka LLC), Kamehameha Schools, Kualoa Ranch, Oahu Country Club, Ohulehule Forest Conservancy LLC, Queen Emma Land Company, State Agribusiness Development Corp, State Department of Hawaiian Home Lands, the State Department of Land and Natural Resources, US Army, and US Fish and Wildlife Service. The management priorities of the KMWP 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) light restoration activies.				
Waianae Mountains Watershed Partnership	2010	72.68	13.175	22.6
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 Kiikii 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 Kiikii hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015n)

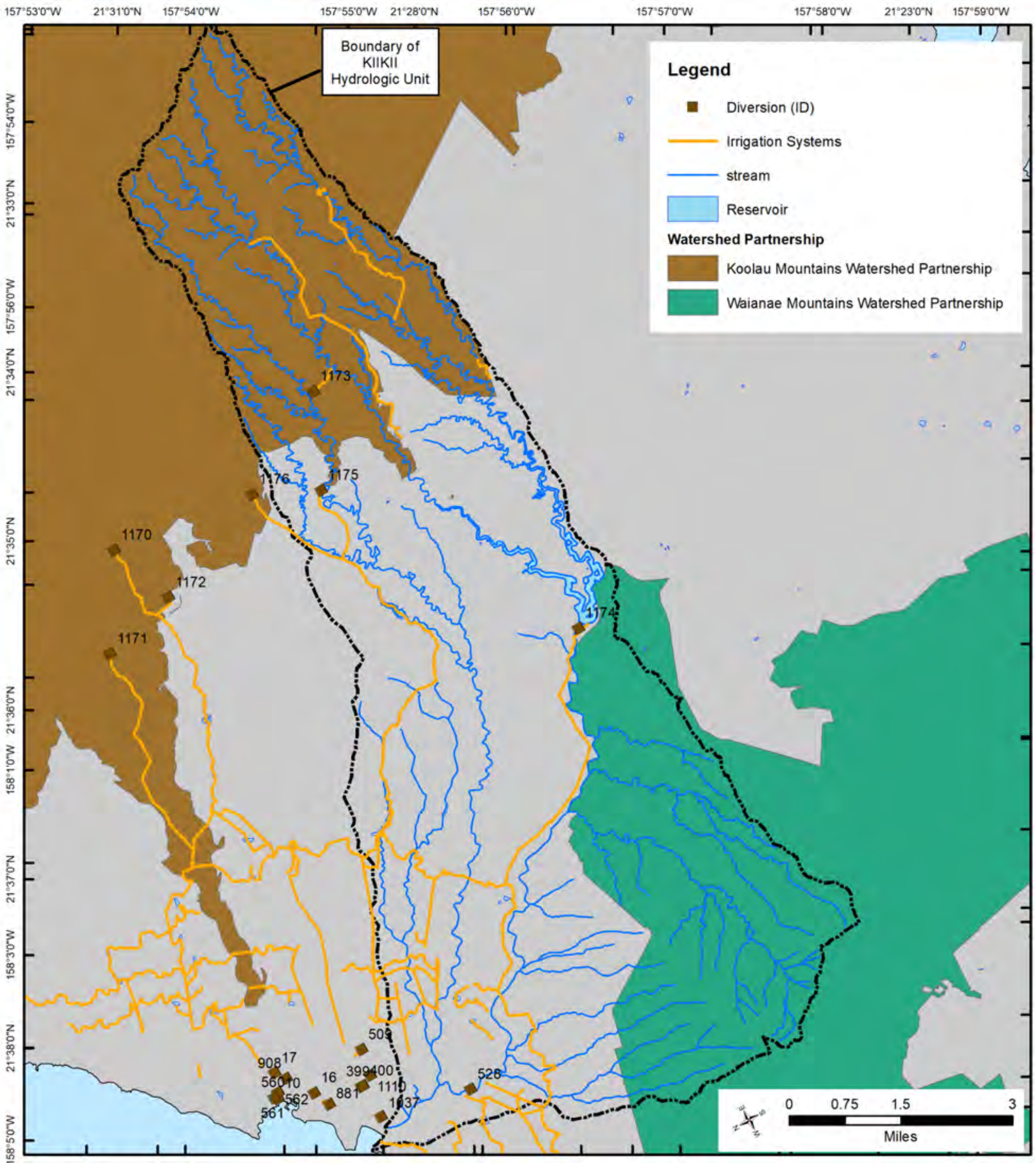
System Type	Class	Area (mi^2)	Percent of Unit
Palustrine	Lake	0.357	0.6%
Palustrine	Freshwater Forested/Shrub Wetland	0.313	0.5%
Palustrine	Riverine	0.290	0.5%
Palustrine	Freshwater Emergent Wetland	0.105	0.2%
Palustrine	Freshwater Pond	0.065	0.1%
Marine	Estuarine and Marine Deepwater	0.018	<0.1%
Marine	Estuarine and Marine Wetland	0.002	<0.1%

Figure 6-2. Reserves in and near the Kiikii 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 Kiikii. 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 Kiikii (Table 6-4, Figure 6-6).

Figure 6-3. The Koolau Mountains Watershed Partnership boundaries in the the Kiikii hydrologic unit, Oahu.



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.

Table 6-4. Distribution of threatened and endangered plant species for Kiikii 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	4.128	7.06%
High concentration of threatened and endangered species	11.896	20.36%
Medium concentration of threatened and endangered species	6.102	10.44%
Low concentration of threatened and endangered species	10.264	17.56%
Little or no threatened and endangered species	26.049	44.57%

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. Some of Kiikii provides critical habitat for native forest birds except in the uppermost elevations near Mt Kaala, in the Ewa Forest Reserve or Oahu Forest Wildlife Refuge. Further, native cliff vegetation supports endangered plants and 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 6-4. Wetlands in the Kiikii hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2007b; 2015c)

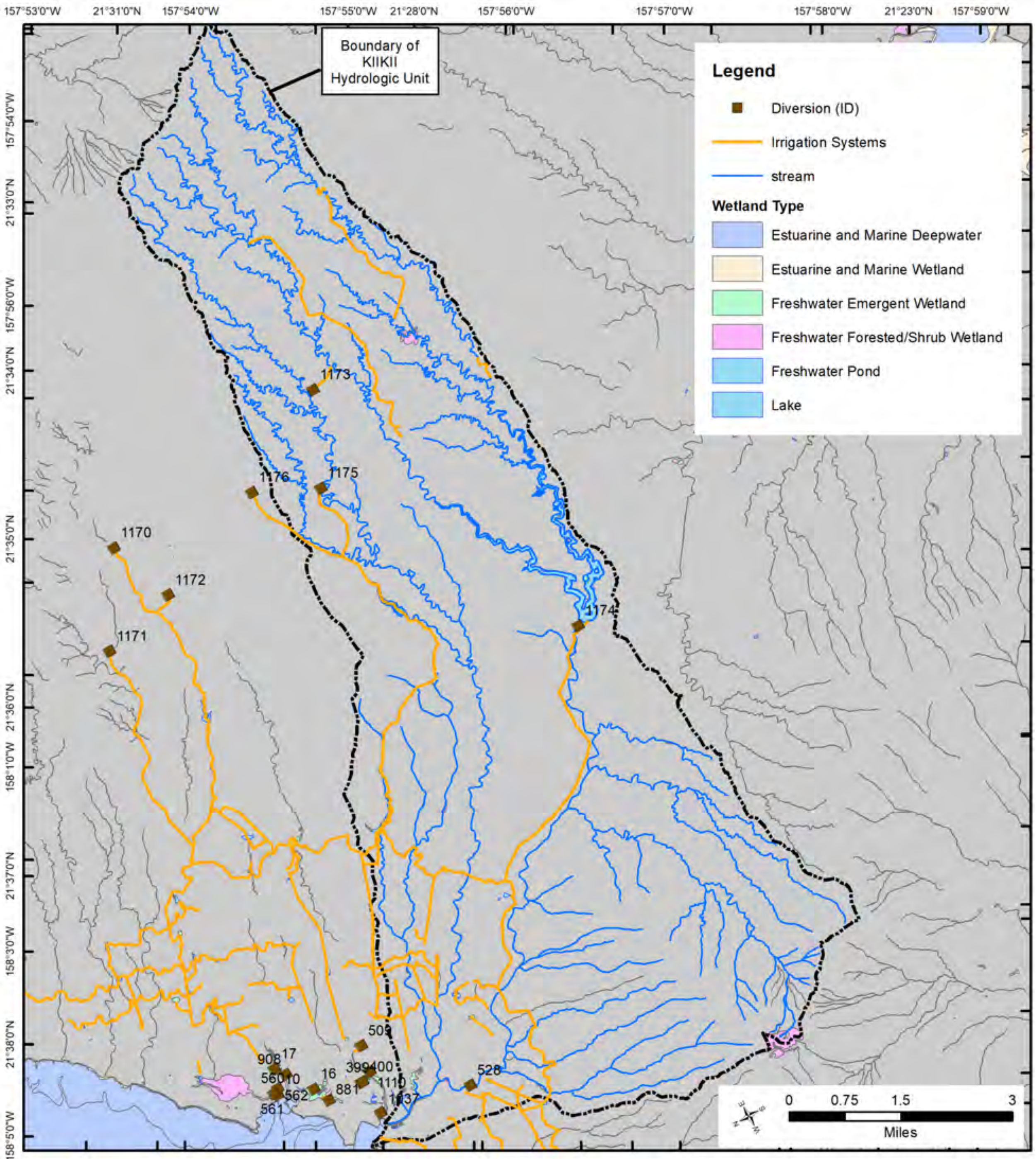


Figure 6-5. Distribution of critical ecosystem habitat in Kiikii hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2004b)

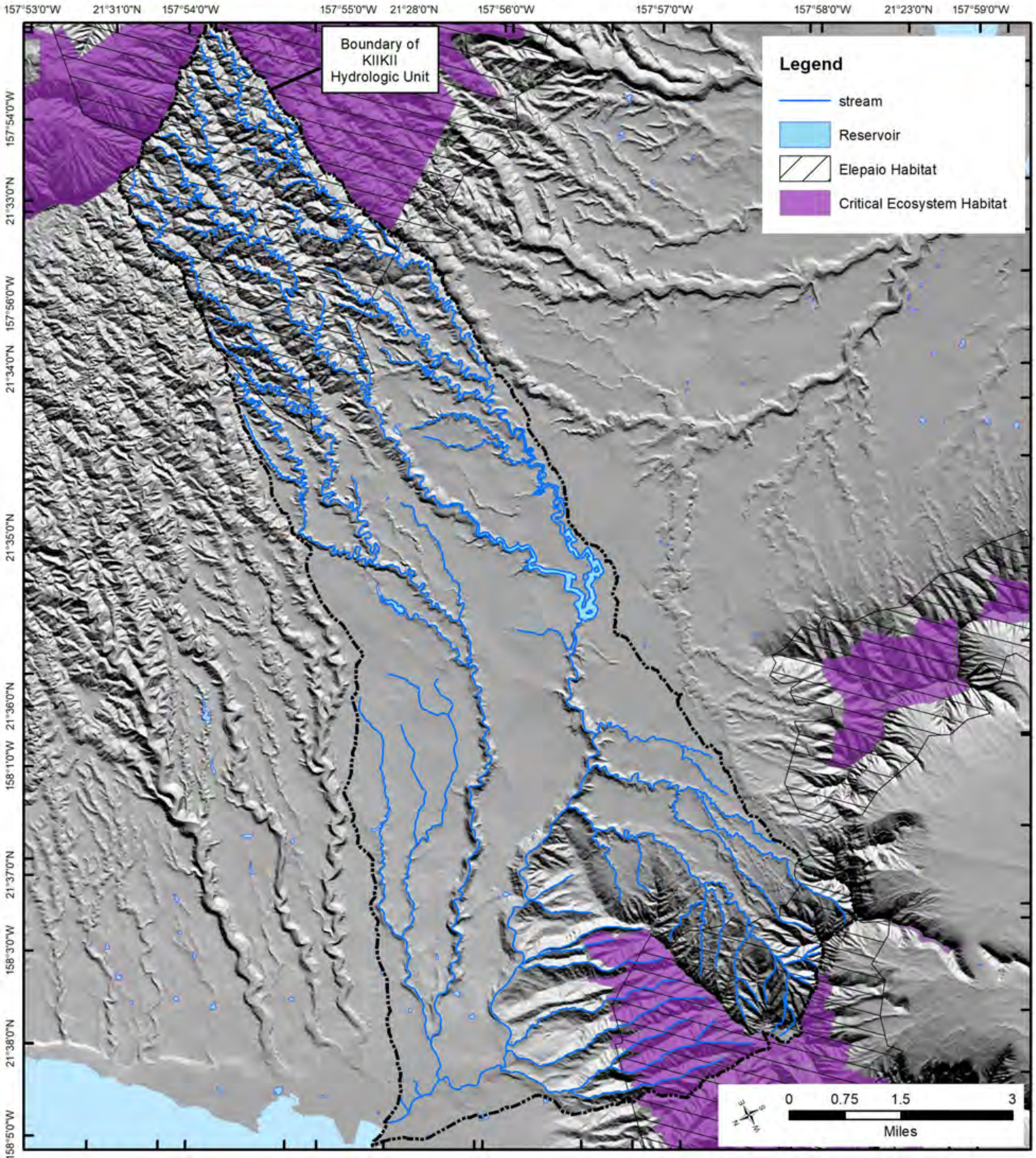
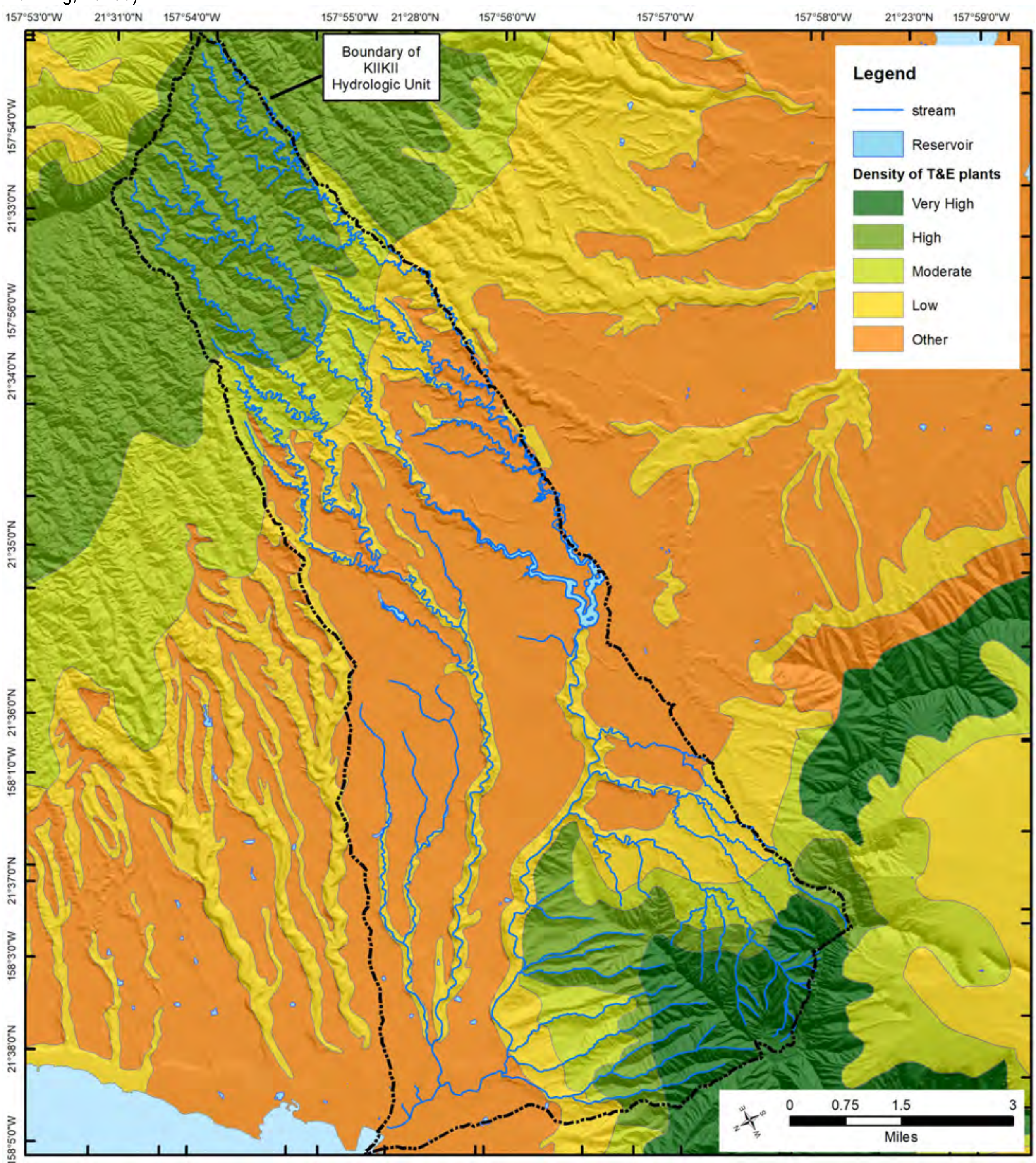


Figure 6-6. Density of threatened and endangered plants in Kiikii hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015d)



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 Kiikii hydrologic unit supports substantial hiking and aesthetic viewpoint opportunities, mostly restricted to high elevation areas or near Wahiawa Reservoir. There are few wildlife opportunities except in the native forest there.

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.

Navigation by boats in the Kiikii hydrologic unit is limited to Wahiawa Reservoir.

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 Kiikii hydrologic unit, although pumped-storage hydropower using water from Wahiawa Reservoir has been proposed. Historically, there was a run-of-the river hydropower plant on the South Fork of Kaukonahua Stream above Wahiawa Reservoir.

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 Kiikii hydrologic unit which likely contribute to the high levels of contamination in surface waters at lower elevations (Figure 10-2). Of the 614 onsite sewage disposal systems in the hydrologic unit, 472 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. 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)."

Kaukonahua Stream is classified as Class 1a inland waters from its headwaters to approximately the 1,200 feet elevation as the surrounding land is in the conservation subzone "protective." It should be noted that the conservation subzone map utilized for this interpretation is general and elevations are not exact. It should also be noted that there is no direct relationship between elevation and attainment of water quality standards. Figure 10-1 shows the Kiikii hydrologic unit, including inland and marine (coastal) water classifications. Water quality data collected from four locations in Kiikii 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. The marine waters of Kaiaka Bay are classified as Class A waters. Kaiaka Bay did not meet the current standards for enterococci, total nitrogen, nitrate-nitrite, ammonium, turbidity, or chloraphyl *a* in the 2018 DOH report. In the 2018 DOH report, Kaukonahua Stream was identified as not meeting inland wet and dry season water quality standards for total nitrogen, nitrate-nitrite, and turbidity, although it met the standards for total phosphorus and total suspended solids. North and South Fork Kaukonahua streams visually obtained the total nitrogen standard (TMDL standards approved in 2010) and turbidity standard (TMDL standards approved in 2010) and attained the nitrate-nitrite, total phosphorus and total suspended solids standards standards.

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

station ID		**station name**		**elevation (ft):** 80							
21HI-3-6-06.01		Poamoho Stream near Waialua									
Ammonium		Dissolved Oxygen		Nitrate		ORP		pH		Salinty	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
3	0.78 (0.79)	3	5.58 (1.05)	3	1.05 (0.10)	3	315.7 (3.06)	3	7.74 (0.51)	3	0.14 (0.05)
Sp Conductance		Temperature		Turbidity							
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
1	0.25	3	21.26 (0.51)	5	18.1 (31.8)						

station ID		**station name**		**elevation (ft):** 80							
21HI-3-6-06.02		Kaukonahua Stream near Waialua									
Ammonium		Dissolved Oxygen		Nitrate		ORP		pH		Salinty	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
5	0.24 (0.18)	8	5.52 (2.77)	6	0.41 (0.31)	7	309.6 (62.6)	8	7.53 (0.28)	8	0.16 (0.19)
Sp Conductance		Temperature		Turbidity							
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
5	0.27 (0.35)	8	23.10 (2.40)	11	9.65 (7.52)						

station ID		**station name**		**elevation (ft):** 1,150							
16200000		NF Kaukonahua Stream									
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)
12	7.08 (3.40)	12	8.58 (4.10)	12	1..36 (1.12)	12	4.97 (4.39)	11	0.0 (0.0)	24	9.60 (1.33)
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)
4	0.1 (0.0)	12	8.83 (4.69)	12	2.00 (3.33)	8	60.0 (62.1)	12	1.35 (0.50)	2	0.0 (0.0)
Nitrate		Orthophosphate		Phosphorus		Potassium		Silica		Sodium	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
5	0.074 (0.130)	14	0.017 (0.017)	2	0.0 (0.0)	12	0.34 (0.12)	12	6.29 (3.32)	12	5.18 (0.76)
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)
91	48.77 (9.96)	2	15.0 (21.2)	11	1.68 (0.67)	119	20.95 (1.88)	36	10.41 (15.02)	2	0.0 (0.0)

Table 10-1. continued.

station ID		station name		elevation (ft): 860							
16208000		SF Kaukonahua Stream									
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)
13	8.62 (2.79)	13	10.69 (3.45)	14	1.83 (1.14)	13	5.42 (2.76)	10	0.0 (0.0)	24	11.19 (1.42)
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)
6	0.05 (0.06)	13	12.28 (3.93)	13	3.46 (2.73)	11	234 (180)	14	1.70 (0.51)	8	170.8 (336.0)
Nitrate		Orthophosphate		Phosphorus		Potassium		Silica		Sodium	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
10	0.10 (0.18)	11	0.033 (0.048)	4	0.29 (0.30)	14	0.44 (0.14)	13	5.09 (1.39)	14	5.94 (1.79)
Sp Conductance		Strontium		Sulfate		Temperature		TDS		pH	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
95	57.17 (9.76)	4	24.83 (24.14)	13	2.07 (1.04)	101	21.90 (1.93)	40	12.63 (16.96)	92	6.53 (0.40)

Figure 10-1. Water quality standards and water quality sample sites for the Kiikii 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.

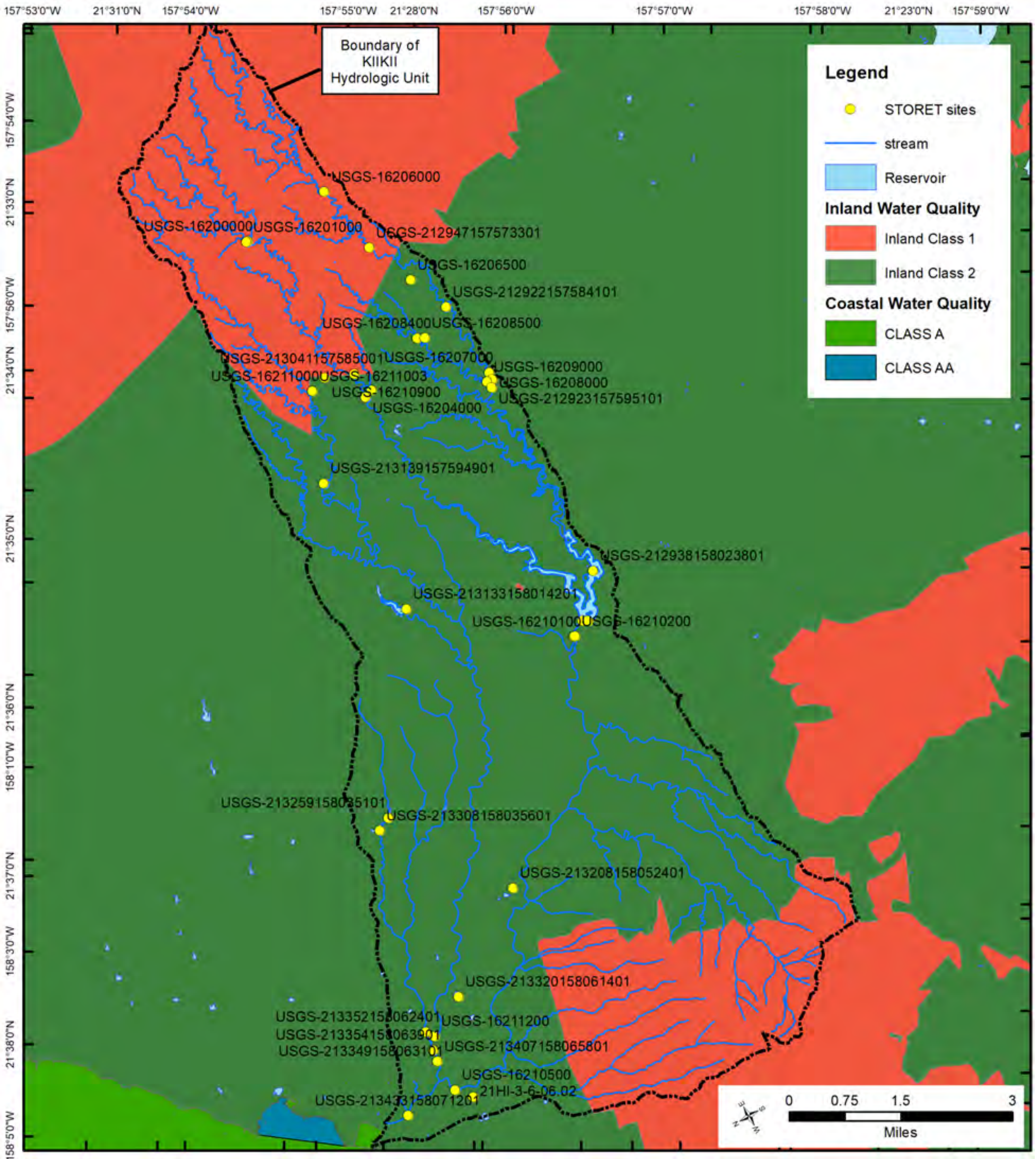
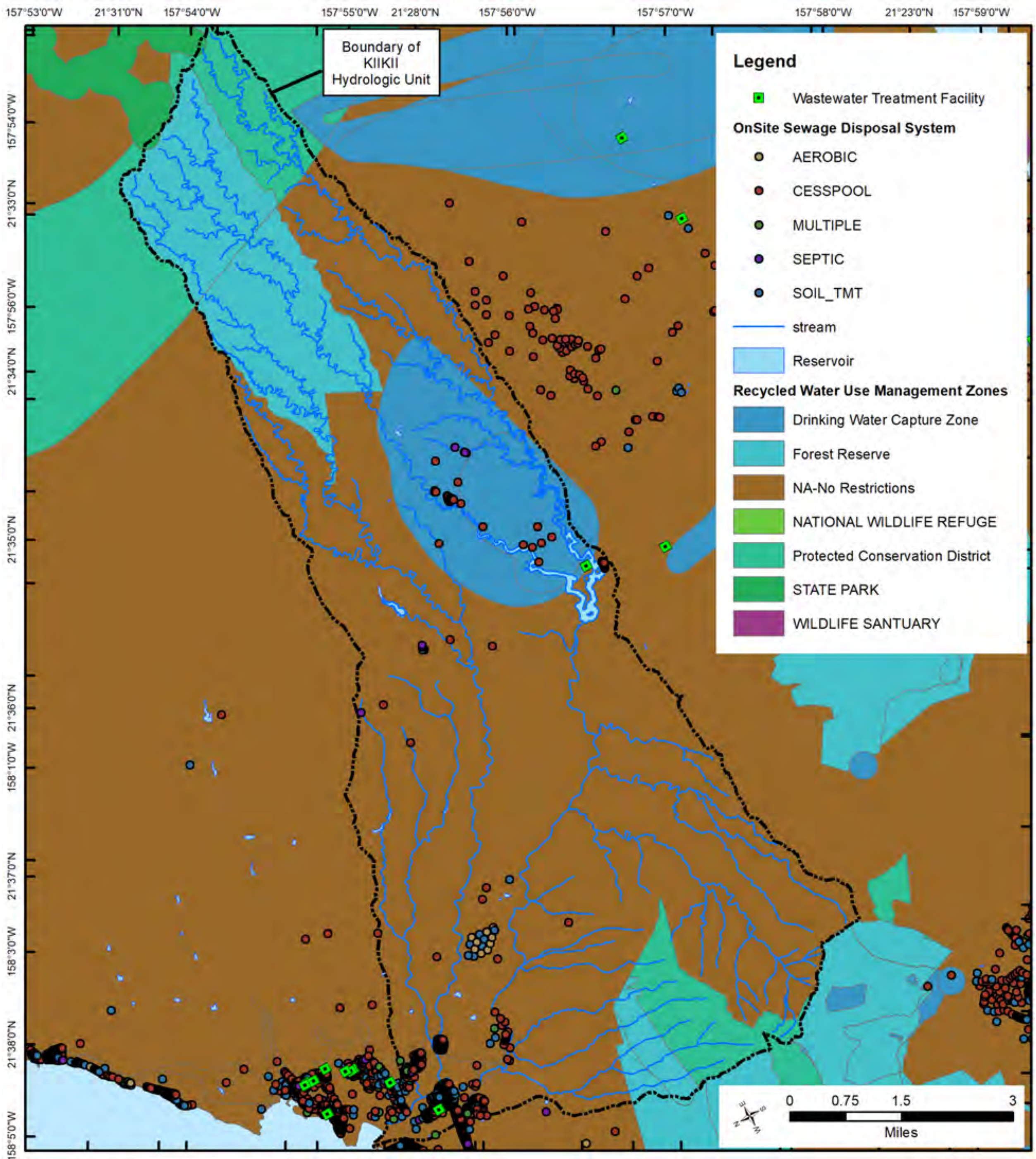


Figure 10-2. On-site sewage disposal systems and wastewater treatment facilities in the Kiikii hydrologic units, Oahu. (Source: State of Hawaii Department of Health, 2020)



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. The Department of Defense operates their own potable water system to serve the potable water needs of the various military installations that exist in and near the Kiikii hydrologic unit. Dole Food Company operates their own potable and non-potable private water systems in the Kiikii hydrologic unit, with the potable one using approximately 0.1 mgd groundwater for the general public regulated by the DOH, Safe Drinking Water branch.

12.0 Protection of Traditional and Customary Hawaiian Rights

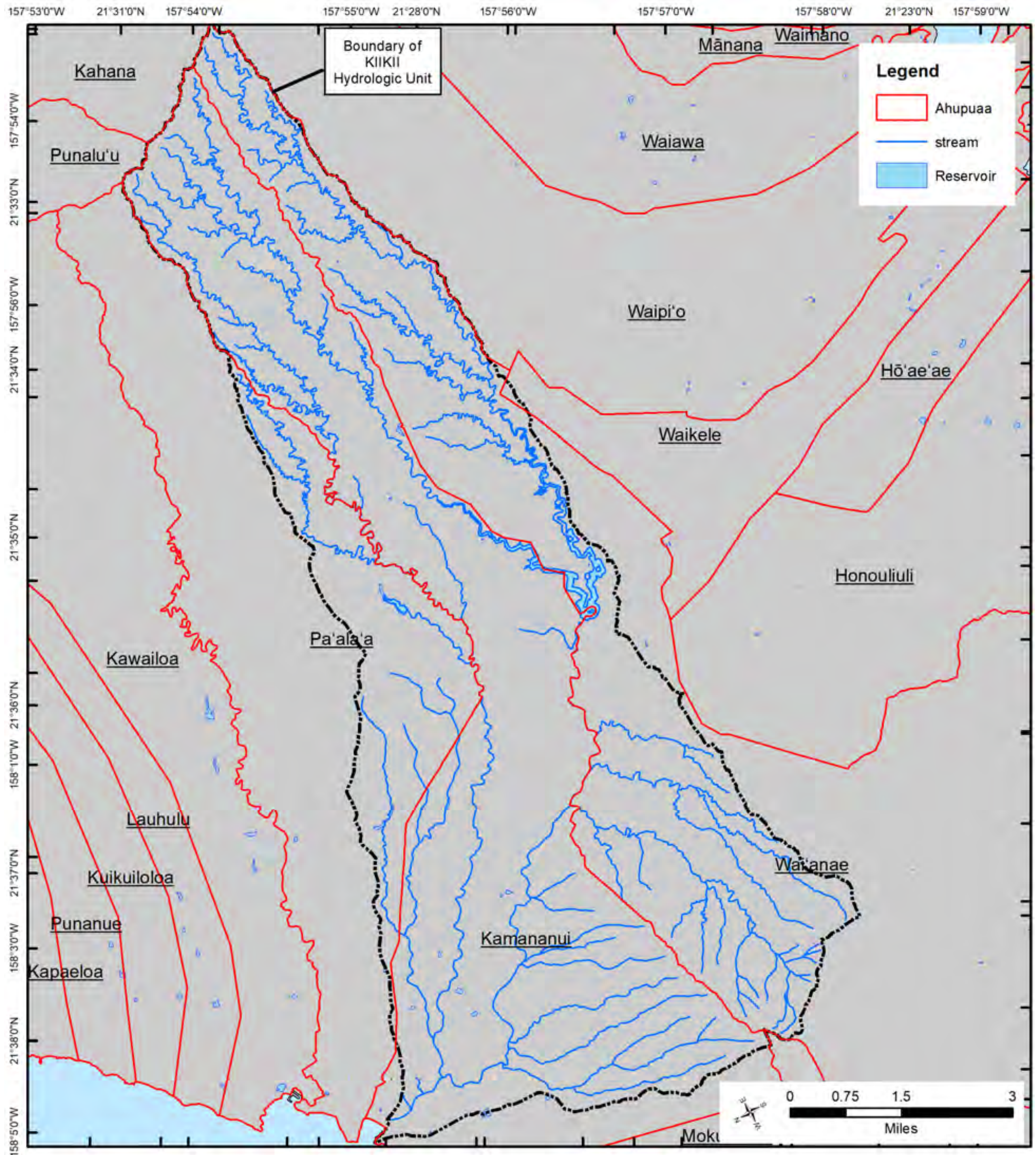
The maintenance of instream flows is important to the protection of traditional and customary Hawaiian rights, as they relate to the maintenance of stream resources (e.g., hihiwai, opae, oopu) for gathering, recreation, and the cultivation of taro. Article XII, Section 7 of the State Constitution addresses 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 Kiikii is included in the ahupuaa of Waianae as shown in Figure 12-1 and also includes the ahupuaa of Kamananui, Paalaa, and a small portion of Waikele. The ahupuaa boundaries are delineated based on the USGS Digital Line Graphs. These boundaries may be different from the information listed on legal documents such as deeds.

Figure 12-1. Traditional ahupuaa boundaries in the Kiikii 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 Kiikii. Table 12-1 presents the results of the Commission's assessment. A lack of land commission awards suggest little cultivation of the riparian areas of Kaukonahua Gulch. However, in the lowlands around Kaiaka Bay, historically there was much wetland kalo cultivation and dryland agriculture, with some continuing today.

[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.

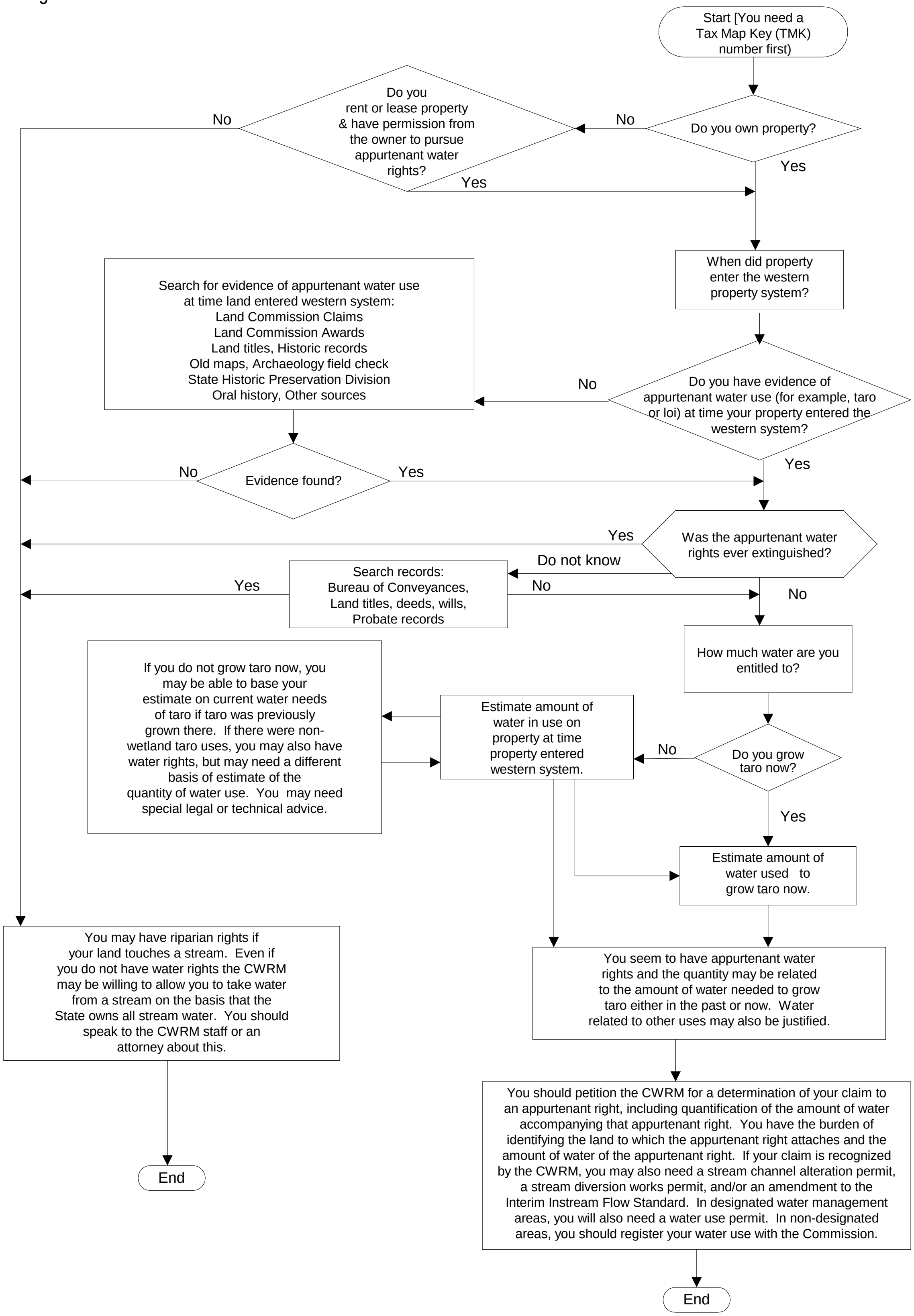


Table 12-1. Land Awards, claimants, associated tax map key (TMK) parcels, and landowners for the Kiikii hydrologic unit, Oahu. [LCA is Land Commission Award; Gr. is Grant; por. is portion; and G.L. is Government Lease]

Land Award	TMK	Landowner	Claimant
Gr. 263	multiple	multiple	Ile
Gr. 647:1	multiple	multiple	Smith, Joseph H
Gr. 477	166014002	Bryant, Harold V Jr	Wana et al
Gr. 475	166014002	Bryant, Harold V Jr	Wahapaa et al
Gr. 1976:3	166014004	Dole Food Co Inc	Halilo
Gr. 559	multiple	multiple	Anderson, John F
Gr. 236:1	multiple	multiple	Davis, John O
Gr. 570:2	166021005	Gamioa. Derek K	Imaui
Gr. 581:2	166021005	Gamioa. Derek K	Kiekie
Gr. 1091	multiple	multiple	Kukea et al
Gr. 479	multiple	multiple	Naukana et al
Gr. 480	multiple	multiple	Kaiaikawaha
Gr. 476	multiple	multiple	Kalimahuamoa et al
Gr. 579:2	multiple	multiple	Naukana
Gr. 573:2	multiple	multiple	Kapahu
Gr. 580:3	166022001	Dole Food Co Inc	Kukea
Gr. 577	166022001	Dole Food Co Inc	Kailweuweu
Gr. 569:2	166022001	Dole Food Co Inc	Kuhi
Gr. 590:2	166022001	Dole Food Co Inc	Kahinapoo
Gr. 574:2	166022001	Dole Food Co Inc	Kahawaii
Gr. 575:4	166022001	Dole Food Co Inc	Hapo & Kahula
Gr. 582:2	166022001	Dole Food Co Inc	Mahiai
Gr. 628:2	166022001	Dole Food Co Inc	Kalimahuamoa
Gr. 570:3	166022001	Dole Food Co Inc	Imaui
Gr. 564 :2	166022001	Dole Food Co Inc	Kupahu
Gr. 571:3	166022001	Dole Food Co Inc	Kauahi & Kauohanui
Gr. 586	166022001	Dole Food Co Inc	Ehu
Gr. 589	166022001	Dole Food Co Inc	Haalou
Gr. 587	166022001	Dole Food Co Inc	Kaiaikawaha & Lono
Gr. 588	166022001	Dole Food Co Inc	Kealiihuluhulu
Gr. 578	166022001	Dole Food Co Inc	Kahoeka & Koiniho
Gr. 721:1	multiple	multiple	Chamberlain, Warren
Gr. 262	multiple	multiple	Kupohu
Gr. 721:2	multiple	multiple	Chamberlain, Warren
Gr. 461	multiple	multiple	Keaa
Gr. 460	multiple	multiple	Nauluahi
Gr. 463	multiple	multiple	Thomas, Joseph
Gr. 229	multiple	multiple	Kamakaokalae
Gr. 277	multiple	multiple	Keoehu & Kaaiolohua
LCA 248	multiple	multiple	Thomas, Joseph
Gr. 1847	multiple	multiple	Collins, Charles W

Table 12-1. continued.

Land Award	TMK	Landowner	Claimant
Gr. 3766	multiple	multiple	Halstead, Edgar & Frank
Gr. 1631	167003019	Flying R Livestock Co Ltd	Komo
Gr. 1338:3	167003019	Flying R Livestock Co Ltd	Kaiaikawaha
Gr. 347	167003005	Kaala Ranch LLC	Naukana
Gr. 346	multiple	multiple	Hanapule
Gr. 345	multiple	multiple	Kaha
Gr. 344	multiple	multiple	Kalimahuamoa
Gr. 716	167004001	Dole Food Co Inc	Niho
Gr. 717 & 840	167004001	Dole Food Co Inc	Kanoulu
Gr. 718	167004001	Dole Food Co Inc	Kauikapu
Gr. 719 & 842	multiple	multiple	Pea
Gr. 720 & 839	167004003	Lopez, Theodore J P Trust	Kanekapu
Gr. 841	167004001	Dole Food Co Inc	Kuhoomanana
Gr. 1628:3	multiple	multiple	Polu
Gr. 609	166027010	Dole Food Co Inc	Emerson, John S
Gr. 1338:1	166027010	Dole Food Co Inc	Kaiaikawaha
Gr. 1326:2	166027010	Dole Food Co Inc	Gulick, Peter J
Gr. 1795:1	166027010	Dole Food Co Inc	Pule
Gr. 1670:3	166027010	Dole Food Co Inc	Kealiihuluhulu
Gr. 1935	166027010	Dole Food Co Inc	Alauka
Gr. 610	multiple	multiple	Haleki
Gr. 1794	166027010	Dole Food Co Inc	Napohaku
Gr. 1650	166027010	Dole Food Co Inc	Kaakau
Gr. 1798	166027010	Dole Food Co Inc	Kealohi
Gr. 1778	166027010	Dole Food Co Inc	Pule
Gr. 1795:2	166027010	Dole Food Co Inc	Pule
Gr. 1670:2	166027010	Dole Food Co Inc	Kealiihuluhulu
Gr. 1936	166027010	Dole Food Co Inc	Kuoho
Gr. 1793.5	166027010	Dole Food Co Inc	Owali
Gr. 1624	166027010	Dole Food Co Inc	Nihoa
Gr. 1666	166027010	Dole Food Co Inc	Mamua & Ioane
Gr. 1623:2	166027010	Dole Food Co Inc	Kahalau
Gr. 1801	166027010	Dole Food Co Inc	Kehao
Gr. 1796:2	166027010	Dole Food Co Inc	Naahalama
Gr. 1796:1	166027010	Dole Food Co Inc	Naahalama
Gr. 1625	166027010	Dole Food Co Inc	Lono
Gr. 1793	166027010	Dole Food Co Inc	Kaioe
Gr. 2019:4	166027010	Dole Food Co Inc	Maigret, Louis
Gr. 2019:1	166027010	Dole Food Co Inc	Maigret, Louis
Gr. 2019:3	166027010	Dole Food Co Inc	Maigret, Louis
Gr. 1790	166027010	Dole Food Co Inc	Mamua 2
Gr. 1803:2	166027010	Dole Food Co Inc	Paele

Table 12-1. continued.

Land Award	TMK	Landowner	Claimant
Gr. 1793	166027010	Dole Food Co Inc	Kaioe
Gr. 1791	166027010	Dole Food Co Inc	Kuikekala
Gr. 1623:1	166027010	Dole Food Co Inc	Kahalau
Gr. 1792	166027010	Dole Food Co Inc	Kaui
Gr. 2019:2	166027010	Dole Food Co Inc	Maigret, Louis
Gr. 1809:1	166027010	Dole Food Co Inc	Haiku
Gr. 1620	166027010	Dole Food Co Inc	Kawaaeae
Gr. 1628:1	multiple	multiple	Polu
Gr. 1622:1	166028022	Hamamoto, Mark H	Kuemanu
Gr. 1337:2	166028009	Wang, Han-Chow	Kaiaikawaha
Gr. 1667:1	166028027	Willenborg Estates	Nalei
Gr. 1808:1	166028027	Willenborg Estates	Hanapule
Gr. 1645	multiple	multiple	Piliko & Kaia
Gr. 1810:1	166028015	Beaman, Bert D Trust	Kanekapu
Gr. 1321:2	166028023	Valley Well Drilling Inc	Niho
Gr. 1648	multiple	multiple	Mano
Gr. 1646	multiple	multiple	Peahi
Gr. 1644:1	166028017	Cherry, Robert L	Hoonani
Gr. 1325:2	multiple	multiple	Kuahiwilau
Gr. 1322:2	165001042	Kaukonahua	Kahunawaa
Gr. 1090:2	165001040	Pioneer Hi-Bred	Chamberlain, Warren
Gr. 547:3	multiple	multiple	Smith, Joseph H
Gr. 851	multiple	multiple	Laumana
Gr. 1336	multiple	multiple	Kuoha & Haiku
Gr. 1335	multiple	multiple	Paele & Puu
Gr. 1334	multiple	multiple	Naalaa
Gr. 846	multiple	multiple	Haapou
Gr. 10113:1	multiple	multiple	Waialua Agriucultural Co Ltd
Gr. 9946	multiple	multiple	Waialua Agriucultural Co Ltd
Gr. 8550:3	multiple	multiple	Waialua Agriucultural Co Ltd
Gr. 1330	165001010	Kaala View Farm Lots #1	Kuahiwilau
Gr. 1333	165001046	Dole Food Co Inc	Kealohi
Gr. 1331	165002006	Dole Food Co Inc	Kea & Kahui
Gr/ 1332	165002027	Dole Food Co Inc	Nauluhao & Koa
Gr. 1128	165002028	Dole Food Co Inc	Kekio
Gr. 849	multiple	multiple	Kekela
Gr. 850	multiple	multiple	Lauhulu & Keuwai
Gr. 845	multiple	multiple	Polu
Gr. 1127	multiple	multiple	Kuemanu
Gr. 1126	multiple	multiple	Kauikapu
Gr. 848	multiple	multiple	Kahoeka

Table 12-1. continued.

Land Award	TMK	Landowner	Claimant
Gr. 1125	multiple	multiple	Kaiaikawaha & Lono
Gr. 682	multiple	multiple	Castle, Samuel N
Gr. 1124	multiple	multiple	Kalaikoa & Kaula
Gr. 847	multiple	multiple	Haleki
Gr. 604	multiple	multiple	Bishop, Artemas
Gr. 527	177001001	United States of America	Bishop, A
LCA 16	177001001	United States of America	Pahoa
Gr. 1626	166027010	Dole Food Co Inc	Kaakua
Gr. 1628:2	166027010	Dole Food Co Inc	Polu
Gr. 1338:2	166027010	Dole Food Co Inc	Kaiaikawaha
Gr. 1621	166027010	Dole Food Co Inc	Puuilio
Gr. 647:2	166027010	Dole Food Co Inc	Smith, Joseph H
Gr. 1629:1	166027010	Dole Food Co Inc	Kamai
Gr. 1622:2	multiple	multiple	Kuemanu
Gr. 1337:1	multiple	multiple	Kaiaikawaha
Gr. 1667:2	multiple	multiple	Nalei
Gr. 1808:2	multiple	multiple	Hanapule
Gr. 1810:2	multiple	multiple	Kanekapu
Gr. 1643	multiple	multiple	Piliko
Gr. 1649	multiple	multiple	Kahuenui
Gr. 1647	166028002	Agustin, William Trust	Mano & Peahi
Gr. 1324:2	167003019	Flying R Livestock Co Ltd	Oiki & Kauaua
Gr. 1325:1	167003010	Akamata LLC	Kuahiwilau
Gr. 1324:1	167003009	Sober, Jeffrey	Oiki & Kauaua
Gr. 1323	167004001	Dole Food Co Inc	Kaha
Gr. 1809:2	167003008	Flying R Livestock Co Ltd	Haiku
Gr. 1322:1	167004001	Dole Food Co Inc	Kahunawaa
Gr. 1808:3	167004001	Dole Food Co Inc	Hanapule
Gr. 1670:1	167004001	Dole Food Co Inc	Kealiihuluhulu
Gr. 1321:1	167004001	Dole Food Co Inc	Niho
Gr. 1320	165001042	Kaukonahua	Poo
Gr. 1116	167004001	Dole Food Co Inc	Makaiki
Gr. 1115	165001043	Kaukonahua Hoola LLC	Poikamauna
Gr. 1114	165001043	Kaukonahua Hoola LLC	Kanoulu
Gr. 1113	165001043	Kaukonahua Hoola LLC	Kahuawaa
Gr. 1112	167004001	Dole Food Co Inc	Pea
Gr. 1111	167004001	Dole Food Co Inc	Kapali
Gr. 1110	165001043	Kaukonahua Hoola LLC	Kauikapu
Gr. 858:2	167004001	Dole Food Co Inc	Mamaki
Gr. 859	165001043	Kaukonahua Hoola LLC	Hopemanu

Table 12-1. continued.

Land Award	TMK	Landowner	Claimant
Gr. 858:1	167004001	Dole Food Co Inc	Mamaki
Gr. 854:3	167004001	Dole Food Co Inc	Kaliuna
Gr. 857	167004001	Dole Food Co Inc	Piowa
Gr. 856	167004001	Dole Food Co Inc	Kekio
Gr. 854:2	167004001	Dole Food Co Inc	Kaliuna
Gr. 853:2	167004001	Dole Food Co Inc	Mahiai
Gr. 855	167004001	Dole Food Co Inc	Kupahu
Gr. 854:1	167004001	Dole Food Co Inc	Kaliuna
Gr. 853:1	167004001	Dole Food Co Inc	Mahiai
Gr. 852	167004001	Dole Food Co Inc	Loloole
Gr. 843	167004001	Dole Food Co Inc	Poekamaona & Kapali
Gr. 1122	167004001	Dole Food Co Inc	Mamaki & Kauikapu
Gr. 1121	167004001	Dole Food Co Inc	Piowa
Gr. 973	multiple	multiple	Robinson, James, Lawrence, Robert & Holt, Robert W
Gr. 606	multiple	multiple	Cook, Amos S
LCA 7713:34.1	multiple	multiple	Kamamalu, Victoria

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

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:

> There was quite a sizable population there if we can judge from the various areas of *lo'i* northwest of the present town of Wahiawa. There must have been extensive sweet-potato and yam plantations here. It is one of the few places where sweet potatoes are known to have been irrigated.
>
> (p. 464)

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

The extensive terracing and irrigation ditches in the uplands around Wahiawa validates the idea of abundant agriculture supporting a large population center which extended beyond the Kaukonahua tributaries:

> Water was brought to the northern *lo'i* from Helemano Stream. Inland along that stream there were terraces. There were extensive terraces that drew water from Wahiawa Stream, both above and below the present town. There were many small terrace areas along the sides of the valleys of all the streams of this general area. These streams tap the southwest slopes fo the Ko'olau range where it begins to lose altitude but is still very wet in the hinterland. The peculiarity of this area, apart from distance from the sea, is that it is the only extensive level area on this island that is quite high.
>
> (p. 465)

The region also supported much religious activity, as evidence of the various Heiau, kapu (sacred) and royal locations. Upslope and west of the present day town, is Kukui-o-Lono, a place made famous by the legend of Kukaniloko, who was the ancient high chief of Oahu and made the first *lo'i* here. This location was one of two sacred places which *kapu* chiefesses went to give birth to their children.

> There are many loi developments Wahiawa was from very ancient times identified with the ruling *ali'i* of Oahu.
>
> (p. 465)

Archaeological Evidence for Hawaiian Agriculture

There are many identified archaeological sites throughout the Kiikii hydrological unit. In the upper elevations, especially to the southeast along the Waianae Range, there is much terracing along the stream channels which indicate historical kalo loi was grown here. The lowlands also likely supported wetland agriculture due to its geology and shallow groundwater. 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, mounds, and walls consistent with irrigated agricultural complexes and cultural practices (Table 12-4).

Individual cultural resources of Kiikii 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 Kiikii 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.

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 Kiikii hydrologic unit (DHM, Inc., 1990). The closest fishpond is at Loko Ea, in Kawailoa.

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

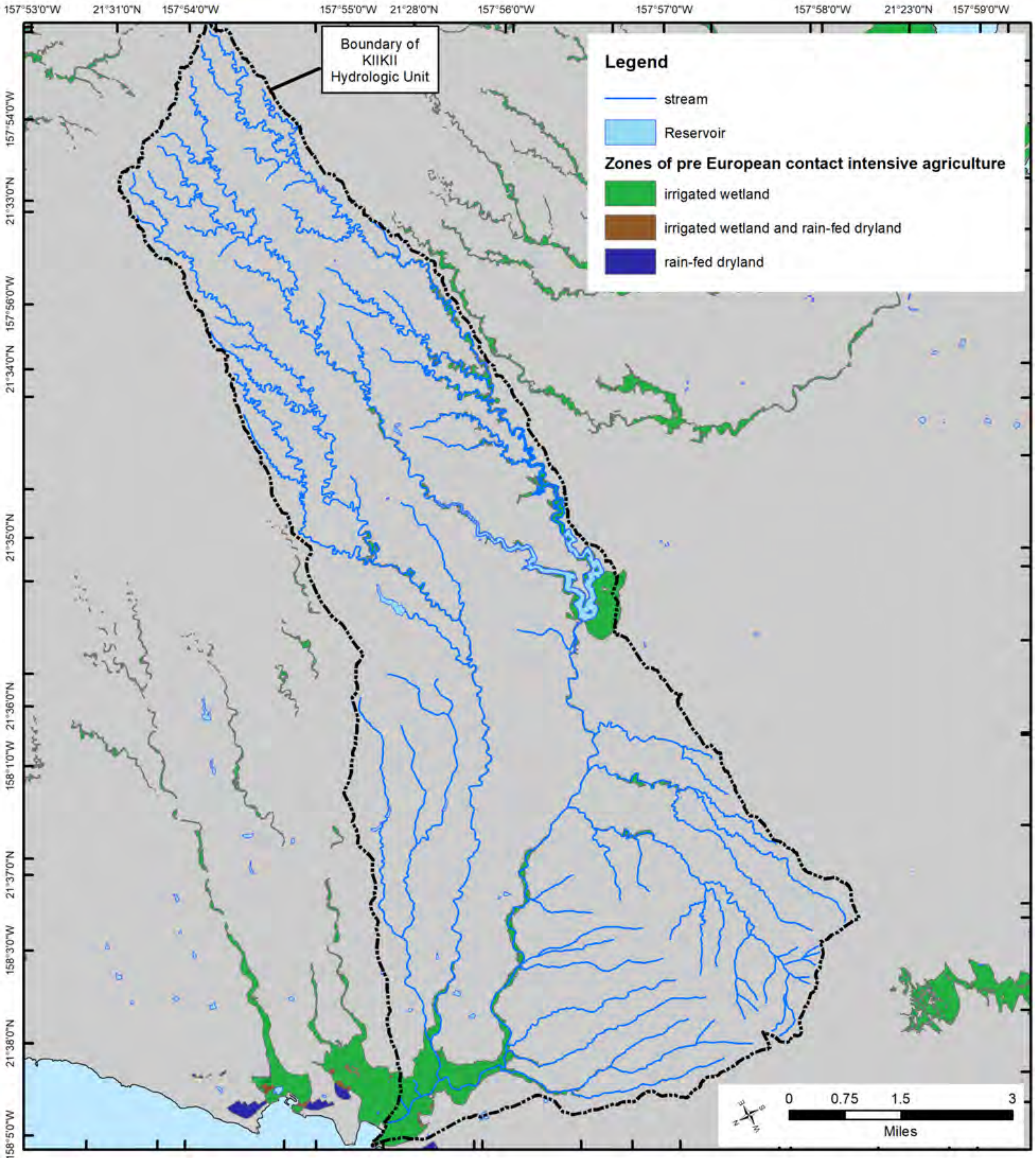
Historic Site #	State Site #	SHPD Library	Land Award	Description
00491			Gr. 1110	none
00218	50-80-04-00218	O-00409	Gr. 606	Sones of local origin in large depressions on surface with natural backrests behind; known to be sit-spots for mother-to-be high-ranking chiefesses from prehistoric period
01605	50-80-04-01605	O-00778	Gr. 973	Poamoho Heiau; none
00197	50-80-04-00197	O-00242	Gr. 350	2 or more terraces with smaller internal divisions in good condition; main heiau platform terraces; of sacrificial class pre-1778
05411	50-80-09-05411	O-02126	none	Pecked boulder
05511	50-80-08-05511	O-02125	none	Concrete platform with three square depressions on surface from WWII
05508	50-80-08-05508	O-02125	none	Concrete structure from WWII
05461	50-80-09-05461	O-02126	none	Concrete foundation from WWII
05501	none	none	none	none
05509	50-80-08-05509	O-02125	none	Ku Tree Reservoir
05384	50-80-09-05384	O-02126	none	Koolau Reservoir
05502	50-80-08-05502	O-02125	none	Stone wall on south side of Kaukonahua Stream
05503	50-80-08-05503	none	none	Complex of terraced and walled fields, auwai, railroad berm
05442	50-80-0-05442	O-02126	none	Modified slope for agriculture
00217	50-80-04-00217	O-00163	none	Kalena Gulch Heiau destroyed in 1933
05379	50-80-04-05379	O-02126	none	Exavated ditch, prehistoric auwai for irrigation of site 5380
05380	50-80-04-05380	O-02126	none	Field 5380; complex of terraces within Mohiakea Gulch
00215	50-80-04-00215	O-00163	none	Haleauau Heiau destroyed in 1977
05513	50-80-08-05512	O-02125	none	Oahu Sugar Ditch
05518	50-80-08-05518	O-02125	none	Wall forming half of a rectangle constructed in historic/military period
05517	50-80-08-05517	O-02125	none	2 mounds used for agriculture attributed to traditional Hawaiian use
05445	50-80-08-05445	O-2126	none	Mounds, terraced fields
05405	50-80-04-05405	O-02126	none	Four terraces compex and clearing mound
05404	50-80-04-05404	O-02126	none	Three field terraces with irrigated or pondfield agriculture
03723	50-80-04-03723	O-00443	Gr. 607	Boulder 1.7m x 2.8m x 1.0m high, with several subangular basalt rocks between 20cm x 20cm x 35cm & 40cm x 40cm x 50cm. No midden, artifacts or other evidence of human activity.

Table 12-5. Cultural resource elements evaluated as part of the Hawaii Stream Assessment for Kiikii 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.	None
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.	Little or no information
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.	--
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.	--
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.	--
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.	--
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.	--

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.	--
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.	No

Figure 12-3. Zones of pre-contact intensive agriculture in Kiikii 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 Kiikii 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 specific wells used by the Honolulu BWS municipal system that provide potable water in and nearby the hydrologic unit was covered in Chapter 3. Additional information related to the Honolulu BWS is provided here followed by an analysis of reservations of water for Hawaiian Home Lands.

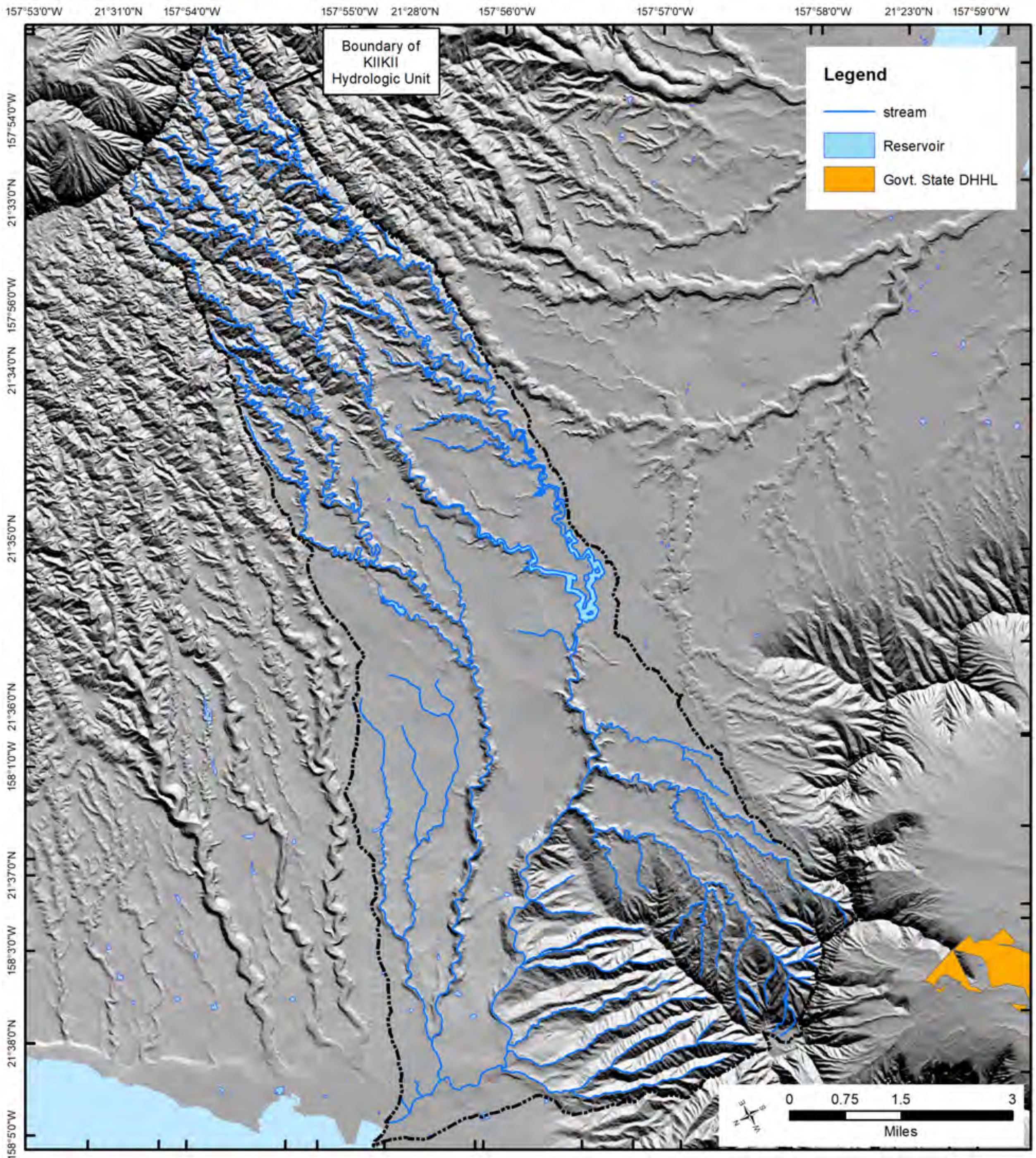
Public Water Supply

In 2010, the Honolulu BWS potable water demand for the North Shore District was 2.8 mgd. The most probable future growth scenario is the mid-growth scenario which projects an increase in potable demand to 3.0 mgd by 2035, assuming a 10% increase in population growth (Honolulu Board of Water Supply, 2016).

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 does not manages any land within or near the Kiikii hydrologic unit (Figure 13-1).

Figure 13-1. Hawaiian Home Lands development parcels identified near the Kiikii 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 1889, Castle & Cooke incorporated the Waialua Agricultural Company and purchased a sugarcane plantation in Waialua initially started by Levi and Warren Chamberlain in 1865 (Wilcox 1996). Immediately, Castle & Cooke began to invest and upgrade the plantation, constructing a new mill, expanding acerage, building a railway, and investing in groundwater and surface water resources. Between 1900 and 1906, Castle & Cooke had constructed four surface water systems to provide storage and distribution of diverted stream water to all areas of the plantation (Figure 14-1). As the Company developed water resources, more acreage was planted and sugar production increased from 5,000 tons per year to 20,000 tons per year by 1905. The use of mechanical harvesting further increased the harvestable acreage.

Renamed Waialua Sugar Company, the plantation's four surface water systems were interconnected to reservoirs, the largest being Lake Wilson, or Wahiawa Reservoir. Storage was particularly important since historically, streamflow was extremely unreliable. The 2.5 billion gallon reservoir was constructed in just two years and became the largest reservoir in Hawaii. It's notable for being an instream reservoir at such a high elevation (1000 feet a.s.l) that it can provide water to almost all of Waialua's fields. The various ditches constructed as part of Waialua Sugar Company's water supply are summarized in Table 14-1.

James Dole formed the Hawaiian Pineapple Company in 1901, growing pineapples on 64 acers of land purchased from savings he brought from Boston. In 1913, Dole purchased a new machine that increased the rate of pineapple processing to 35 pineapples per minute, and subsequently increased the potential acerage that could be harvested. In 1932, Castle & Cooke purchased a 21% interest in the Hawaiian Pineapple Company and in 1960, purchased the remaining shares, with Waialua Sugar Company remaining a subsidiary of Dole Corporation. In 1985, Castle & Cooke merged with FlexiVan Corp, becoming the Dole Food Company. The Waialua Sugar Company closed in 1996 due to economic pressure from international competition. Following the end of sugarcane production, Dole Food Company converted much of the land into diversified agriculture, growing a variety of products, mostly for local consumption, that continue today.

Table 14-1. Surface water irrigation systems constructed by Waialua Sugar Company on Oahu.

System Description	System Details
Oahu Ditch/Mauka Ditch Collected Kaukonahua branches above Wahiawa Reservoir for storage	2 diversions 4.125 miles of ditch, mostly tunnel Served Ku Tree Reservoir 90.5 mgd capacity
Koolau Sourced water on the south fork Kaukonahua Stream for a small hydropower built in 1916, but closed in 1960	1 diversion 2.278 miles of ditch, mostly tunnel
Wahiawa Ditch Sourced water from Wahiawa Reservoir at the confluence of the north and south forks of Kaukonahua stream	1 diversion (Wahiawa Reservoir) 9.52 miles of ditch and laterals Served upper fields at 730 ft elevation 50 mgd capacity
Tanada/Helemano Ditch Sourced water from Poamoho and Helemano streams to feed Helemano reservoirs/upper fields	2 diversions 2.378 miles of ditch and laterals, some tunnel
Opaeula/Kawainui Ditch Sourced water from Opaeula, Kawainui, and Kawaiiki streams to Upper and Lower Opaeula Reservoirs	3 diversions 3.544 miles of ditch and laterals
Kamananui Ditch Sourced water from Kawainui and Kamananui streams for Kawailoa fields	2 diversions 2.675 miles of ditch and laterals
Ito Ditch Extention of the Wahiawa Ditch across Kaukonahua Gulch to Waialua/Mokuleia fields constructed in 1911	1 diversion (Wahiawa Reservoir) 2.762 miles of ditch and laterals, multiple siphons and some tunnel

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 14-2 provides a description of registed diversions that support instream uses.

Figure 14-1. Registered stream diversions and irrigation systems by sub-system (abandonded and in use) for the many surface water systems utilized by Waialua Sugar Company. (Source: 2004 State of Hawaii Department of Agriculture)

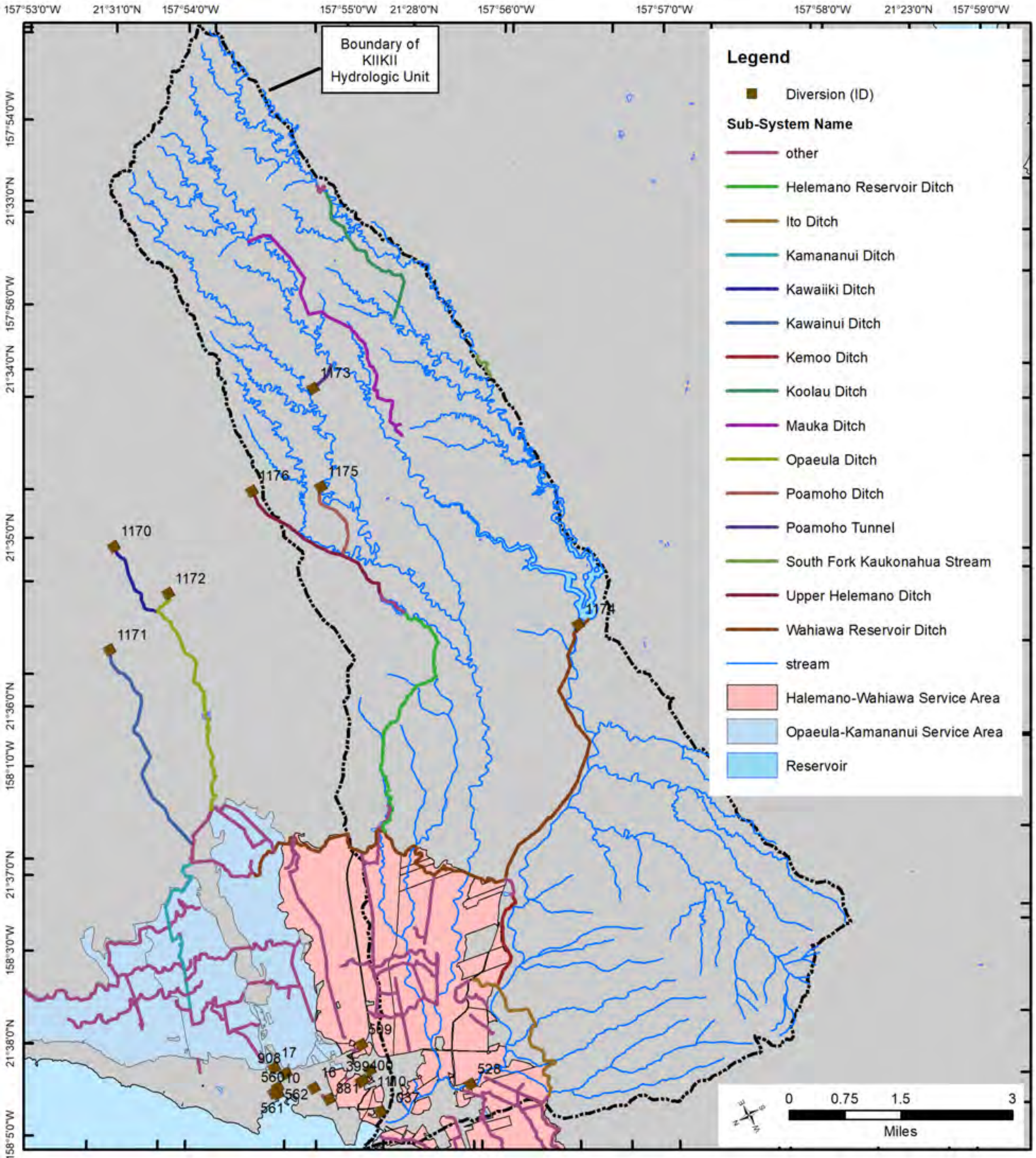


Table 14-2. Registered diversions supporting instream uses in the Kiikii hydrologic unit, Oahu.
[Source of photos are denoted at the end of each description; CWRM, Commission on Water Resource Management; Chevrons ( ) indicate general direction of natural water flow to and out of diversions; Arrows ( ) 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.1173	WAIALUA SUGAR	7-2-001:006	--	Yes	Yes	Yes	Yes

Photos. Poamoho Tunnel from Poamoho Stream to NF Kaukonahua Stream.

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.1176	WAIALUA SUGAR	7-1-002:011	--	Yes	Yes	No	No

Photos. Helemano Ditch intake on Helemano Stream; a) intake structure on left bank (CWRM, 2020); b) diversion dam across channel from left bank (CWRM, 2020); diversion dam from downstream (CWRM, 2020); upstream view from diversion dam (CWRM, 2020); downstream view from diversion dam (CWRM, 2020); Helemano Stream 1000 ft downstream (CWRM, 2020)

a)

b)

c)

d)

e)

f)

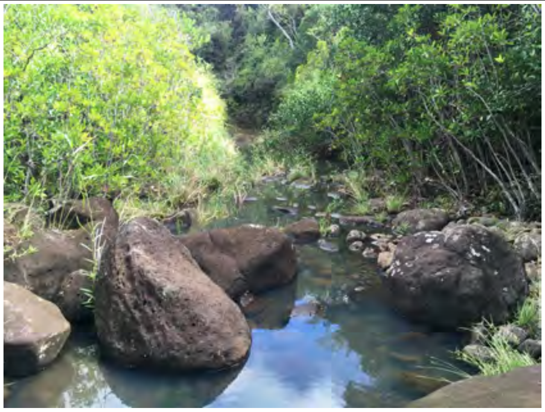


Table 14-1. continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.1175	WAIALUA SUGAR	7-1-002:011	--	No	Yes	No	No

Photos. Helemano Ditch intake on Poamoho Stream; a) intake on right bank (CWRM, 2020); b) inflow at intake on right bank (CWRM, 2020); c) diversion is a pile of rocks within stream channel (CWRM, 2020); d) upstream view of Poamoho from diversion

a)

b)

c)

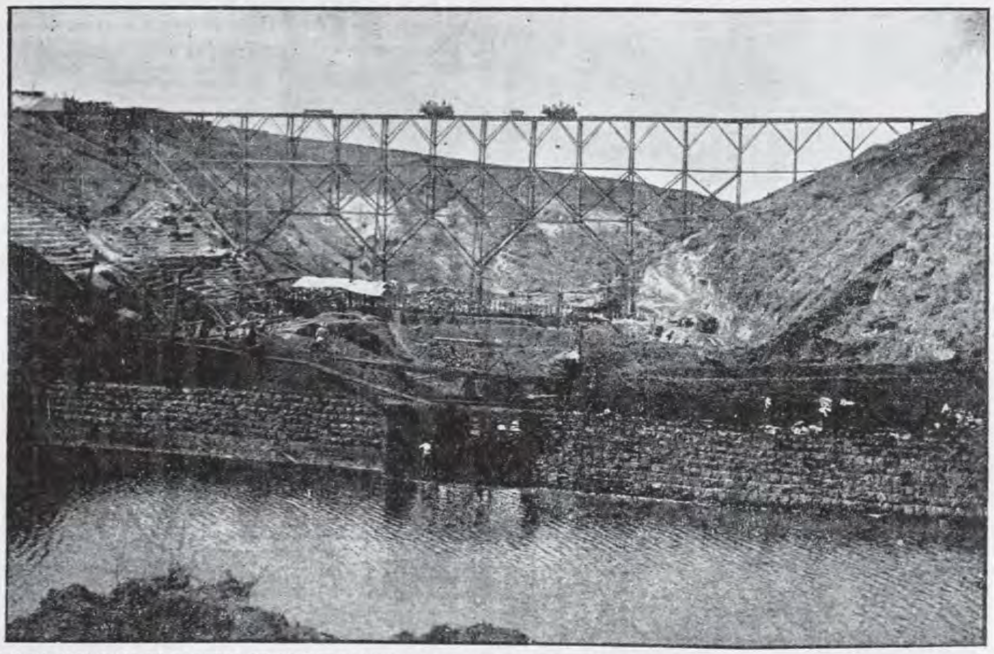
d)

Table 14-2. 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.1174	WAIALUA SUGAR	7-2-001:001	--	Yes	Yes	Yes	Yes

Wahiawa Dam on Kaukonahua Stream (confluence of North and South Forks); Wahiawa ditch from Wahiawa Reservoir
Photos. a) Wahiawa Dam under construction in 1905; b) spillway on Wahiawa Dam from left bank; c) upstream face of Wahiawa Dam from left bank (DLNR 3/2013);

a)



THE WAHIAWA DAM IN PROCESS OF CONSTRUCTION. LOOKING DOWN THE VALLEY AND SHOWING ROCK PROTECTION AT THE FOOT OF THE EARTH FILL, WHICH EXTENDS 500 FEET TO THE RAILROAD TRESTLE.

b)

c)

d) headhouse intake on left bank from dam (DLNR 3/2013); e) intake siphon on headhouse (DLNR 3/2013); f) downstream face of spillway siphon (DLNR 3/2013); g) arial image of Wahiawa Reservoir and dam (DLNR 3/2013); h) ouflow from Wahiawa Reservoir Outlet Tunnel of upper gate siphon and start of Wahiawa Ditch (D. Fahrenwald 9/2015); i) inflow of recycled water from Schofield Barracks into Wahiawa Ditch (D. Fahrenwald 9/2015);

d)

e)

f)

g)

h)

i)

j) Wahiawa Ditch return to Kaukonahua Stream below Wahiawa Reservoir from right bank (CWRM, 2021); k) lower gate siphon release (unused) next to upper gate siphon release to Wahiawa (l); USGS gaging station 16210100 on Wahiawa Ditch (CWRM, 2021); (m) box weir on Wahiawa Ditch at USGS 16210100 (CWRM, 2021).

j)

k)

l)

m)

Table 14-2. 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.528	ISHIDA H	6-6-027:008	0.34	No	No	No	No
Pump from Kaukonahua Stream via 150 gpm pump and a 2inch pvc pipe used to irrigation 0.75 acres of truck crops; registered 700,000 gallons per year; diversion not active per contact with landowner in 2020							

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, much of the land designated as agriculture in the Kiikii hydrologic unit is still used for agriculture. As of 2015, there was approximately 6095 acres (9.524 square miles) of agriculture (Table 14-3). In 2020, a new agricultural baseline survey was published by the Department of Agriculture that identified 7469.4 acres (11.671 square miles) in the Kiikii hydrologic unit as agriculture (Table 14-4). Water diverted from surface water sources in Kiikii supplies much of the irrigation needs, supplemented by one stream source from outside of the hydrologic unit and groundwater wells. While stream flow is highly variable, the ability to deliver consistent water supply via the Wahiawa Ditch was due to the construction of Wahiawa Dam at the confluene of the north and south forks of Kaukonahua Stream (Figure 14-2). One of the largest landowners in the hydrologic unit from 2015-2020, Dole Food Company delivered an average of 1.59 mgd via the Helemano Ditch and 6.3 mgd via the Wahiawa Ditch (Table 14-5). In 2007, 18 commercial farms were relying on the irrigation system ranging in size from eight to 2,000 acres. Large landowners can support the continued maintenance of irrigation systems for the reliable delivery of water for agriculture. In Kiikii, two of the largest landowners are Dole Food Company and Alexander & Baldwin (Figure 14-6).

Figure 14-2. Monthly mean daily flow (million gallons per day, mgd) in the Wahiawa Ditch below Wahiawa Reservoir (diversion 1174), Oahu. (Source: USGS 2020)

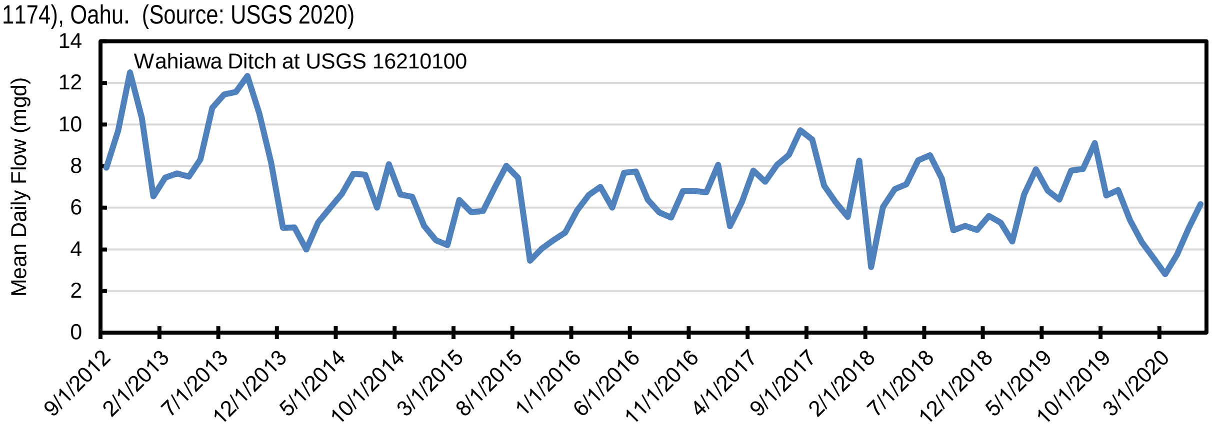


Table 14-3. Crop area from the 2015 agricultural baseline and estimated demand (based on estimated general irrigation requirements in gallons per acre per day, gad) for the Kiikii hydrologic unit, Oahu. (Source: Perroy et al., 2015).

	2015		2020			2015	2020
Crop	Area (acres)	Area (mi²)	Area (acres)	Area (mi²)	General Irrigation Requirement (gad)	Estimated Demand (gpd)	Estimated Demand (gpd)
Pineapple	2987.5	4.668	3130	4.890	2200	6.573	6.885
Coffee	--	--	19.2	0.03	3400		0.065
Diversified Crop	1351.7	2.112	2435	3.804	3400	4.596	8.278
Pasture	1050.9	1.642	1084	1.694	400	0.420	0.434
Seed Production	542.7	0.848	605.4	0.946	3400	1.845	2.058
Tropical Fruits	51.8	0.081	73.0	0.114	3400	0.176	0.248
Papaya	40.3	0.063	40.3	0.063	2200	0.089	0.089
Commercial Forestry	26.2	0.041	26.2	0.041	1800	0.047	0.047
Aquaculture	20.5	0.032	33.3	0.052	--	--	--
Banana	11.5	0.018	11.5	0.018	4000	0.046	0.046
Flowers / Foliage / Landscape	10.9	0.017	10.9	0.017	3000	0.033	0.033
Taro	1.3	0.002	1.3	0.002	300000	0.384	0.384
Total	6095.4	9.524	7469.4	11.671		14.209	18.567

Table 14-4. Minimum, maximum, and average flow estimated for the Upper Halemano Ditch from the Poamoho Stream diversion (diversions 1175 and 1176) and measured for Wahiawa Ditch (diversion 1174) at USGS station 6210100 from 2015 to 2020.

Ditch	Minimum (mgd)	Maximum (mgd)	Mean (mgd)
Upper Halemano from Poamoho Stream	0.720	3.145	1.586
Wahiawa Ditch	0.000	20.682	6.326

In 2010, agricultural water demand was estimated to be approximately 25 mgd, and is projected to increase by 18% by 2035 (~1% per year) to nearly 30 mgd (HBWS, 2016). Food security has become an important issue for islands as increasing reliance on global food markets makes island populations vulnerable to stochastic shifts in the price of raw agricultural commodities and the transportation costs of importing food products (Martinez et al. 2010). At both the policy level and the community level, the local-food movement is pushing grocery stores and restaurants to improve the supply of locally sourced food. In 2007, farm operations in the Wahiawā Ditch service area produced an estimated $37.66 million of crops and paid $14.43 million to household earnings, contributing approximately $28 million to the state's gross domestic product (Southichack 2008). These economic data considered only the use of irrigation water for tree and orchard crops, since Wahiawā WWTF and SB WWTF were discharging R-2 effluent into the system, limiting the crops available for irrigation. With recent upgrades to these facilities to produce R-1 effluent, a larger variety of crops is now being grown, likely further stimulating local food production and economic output. Maintaining a reliable irrigation supply is essential for consistent agricultural operations (Spangler et al. 2017). To increase the system's ability to meet future demands, reservoirs that were discontinued during plantation closure could be rehabilitated to provide additional storage, reducing demand during low water availability (Falinski and Penn 2018). Further, some landowners are digging new wells or rehabilitating older wells as backup water supply to meet their water demands during drought conditions.

Wahiawa Reservoir

The Wahiawa Dam was built in 1906 with a storage capacity of 9.46 million m^3 (2.5 billion gallons), serving agricultural needs as far as 11 km away. The dam rose 98 feet above the stream bed and inundated the gulches of both forks of Kaukonahua Stream, with a total surface area of approximately 725,000 m^2. The elevation at the top of the dam is approximately 843 feet above sea level (asl). In 1927, the City and County of Honolulu’s Wahiawa WWTF began discharging treated effluent into the reservoir. To comply with dam safety regulations, the DLNR Engineering Division funds USGS station 16210000 at the Wahiawa Reservoir spillway (Figure 14-3). The spillway is at an elevation of 79.7 feet and the top of the dam is at an elevation of 88.0 feet. The minimum elevation needed to maintain a fishery in the reservoir is approximately 60.0 feet (State of Hawaii Department of Land and Natural Resources, 2003).

Figure 14-3. Mean monthly elevation of Wahiawa Reservoir at the spillway to Kaukonahua Stream from 2005 to 2020. (Source: USGS 2020)

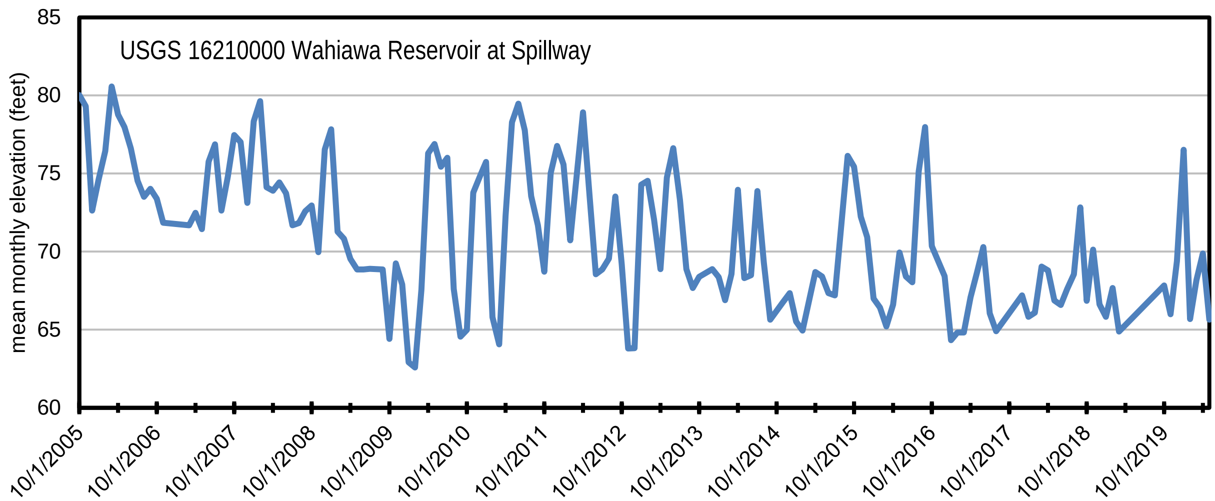


Figure 14-4. Agricultural Lands of Importance to the State of Hawaii (ALISH) for the Kiikii hydrologic unit, Oahu. (Source: State of Hawaii, Office of Planning, 2015g)

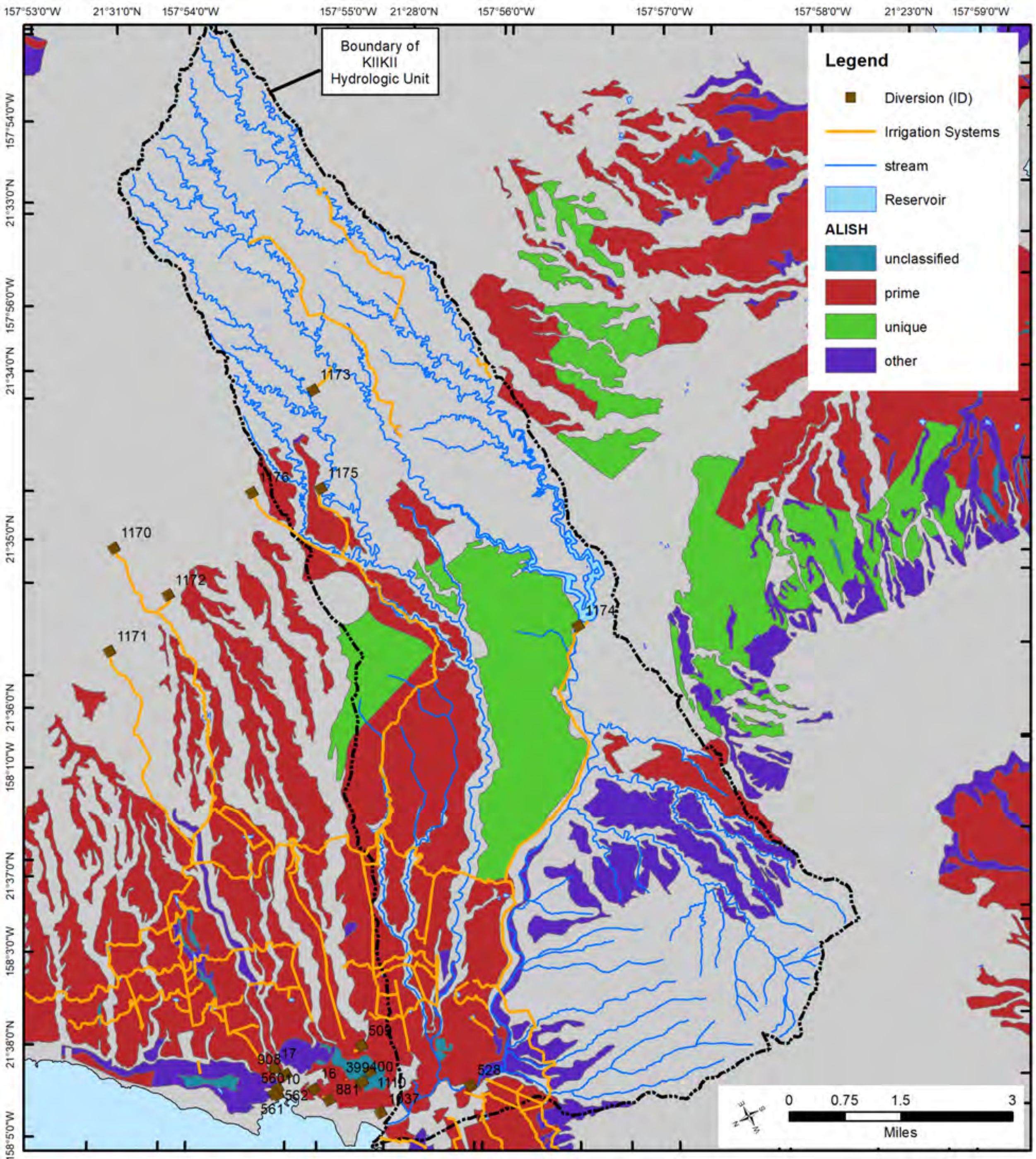


Figure 14-5. 2015 agricultural baseline by crop category in the Kiikii hydrologic unit, Oahu. (Source: Perroy et al., 2015)

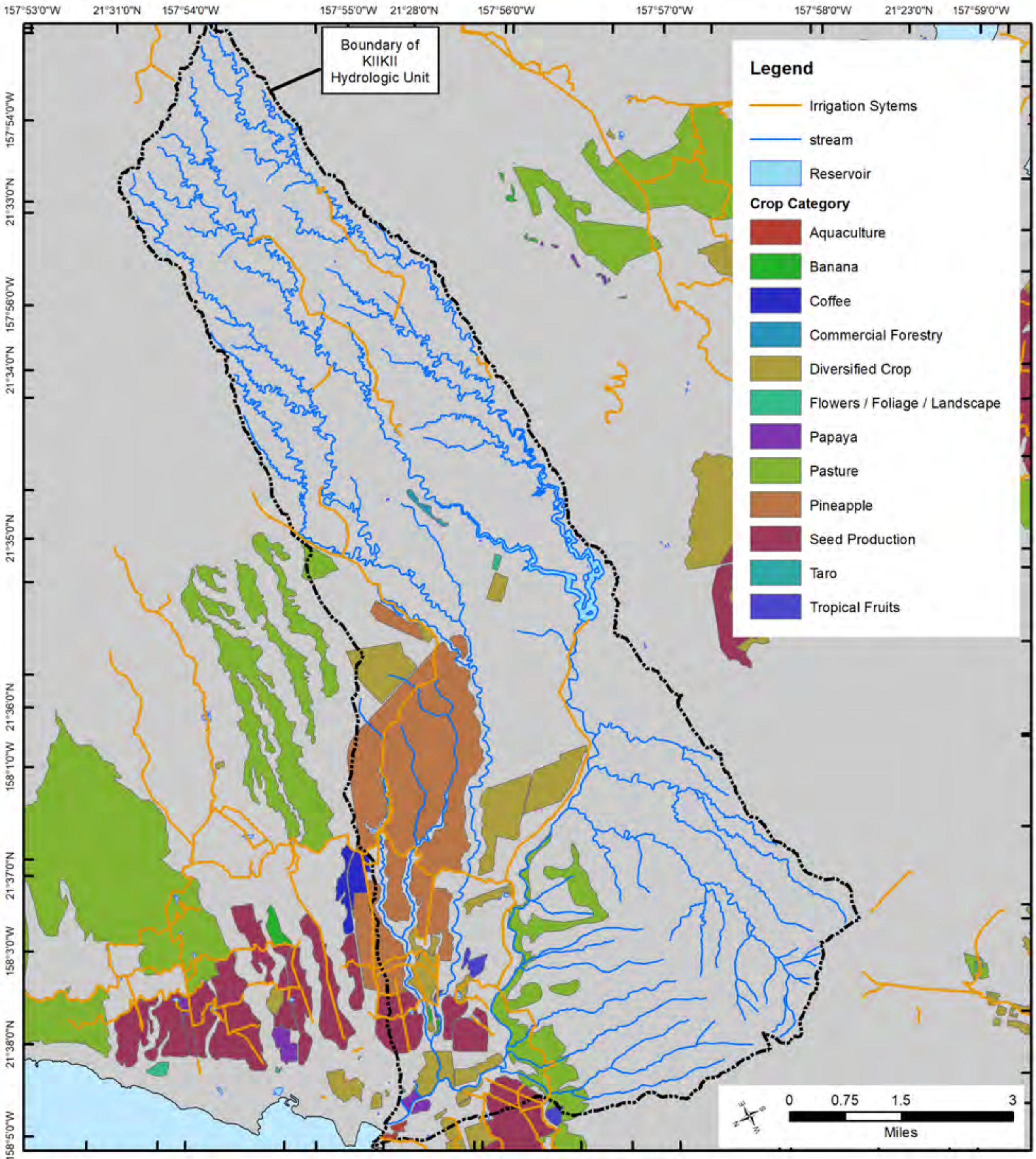


Figure 14-6. 2020 agricultural baseline by crop category in the Kiikii hydrologic unit, Oahu. (Source: DOA, 2021)

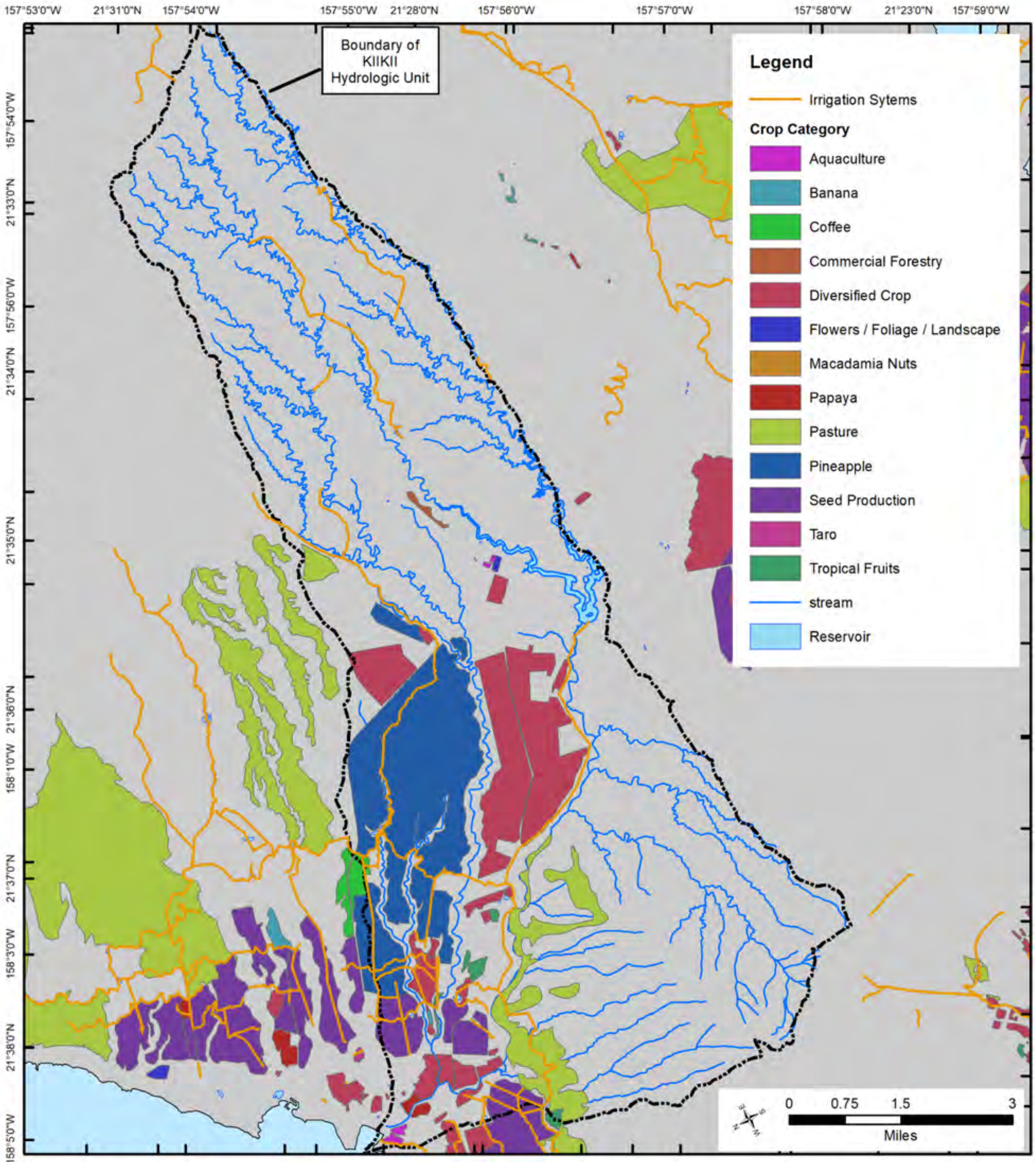
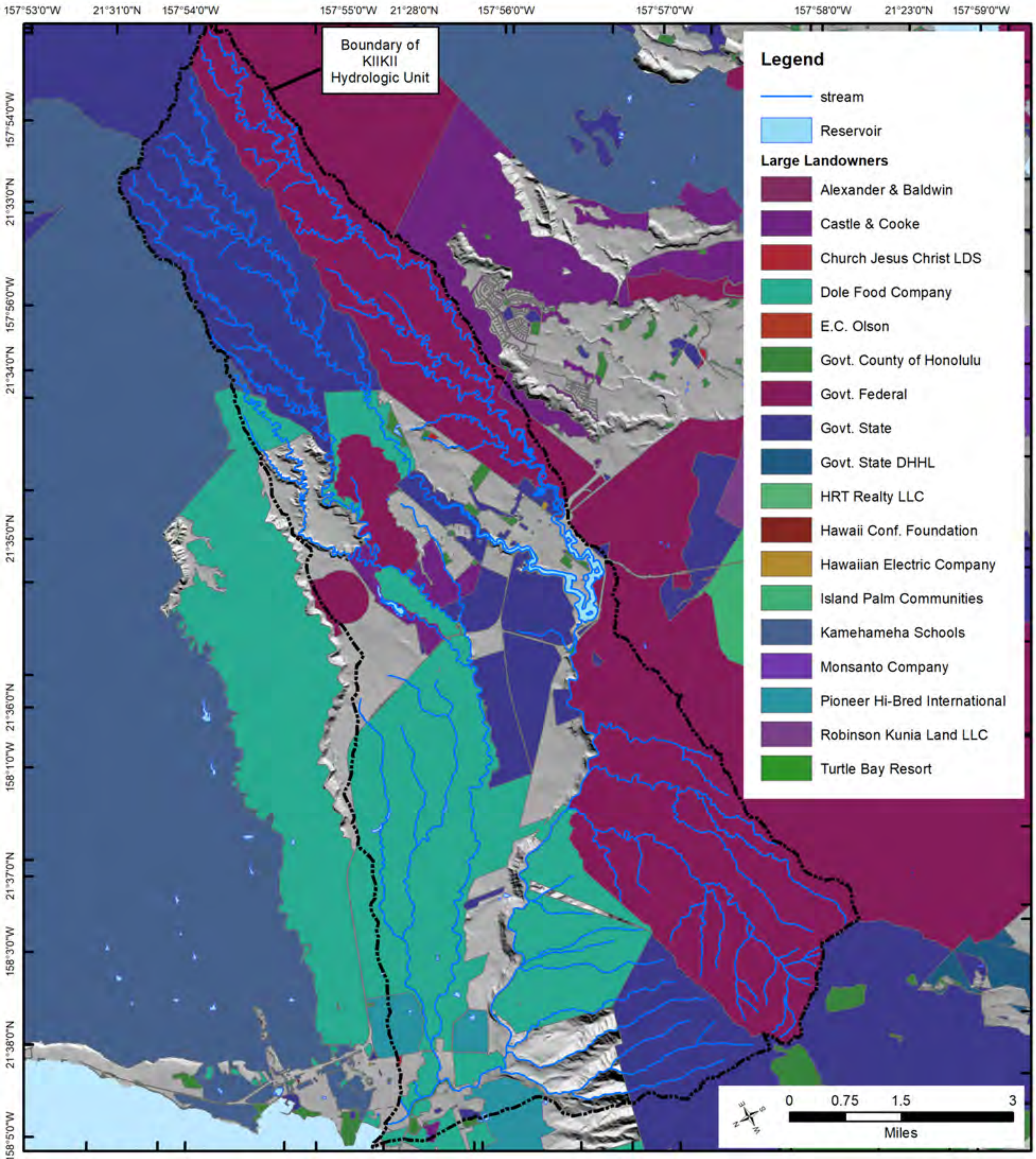


Figure 14-7. Large landowners in the Kiikii hydrologic unit, Oahu



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16.0 Appendices

Appendix A	Kiikii, Oahu, Hawaii. June 2008. DAR Watershed Code: 35006 *State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources.*

APPENDIX A

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

Atlas of Hawaiian Watersheds & Their Aquatic Resources Ki‘iki‘i, O‘ahu