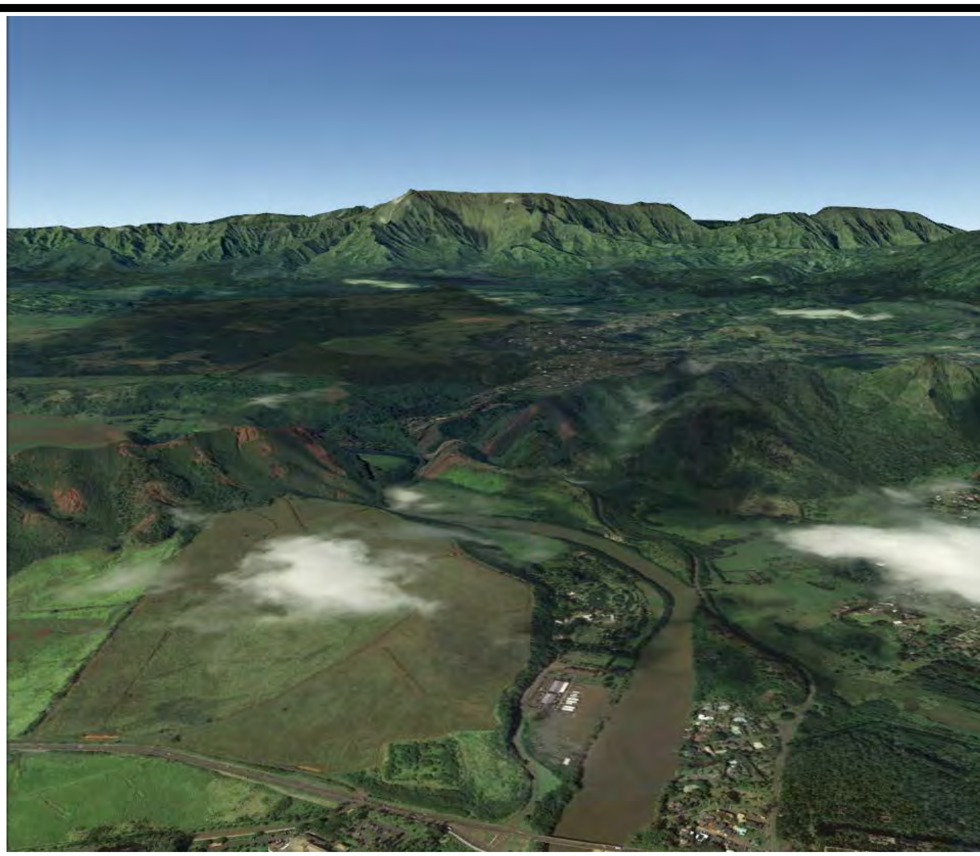
Instream Flow Standard Assessment Report

Island of Kauai
Hydrologic Unit 2040
Wailua

August 2018 **DRAFT PR-2018-06**



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

COVER
Satallite image of Wailua with the Wailua River flowing into the Pacific Ocean, East Kauai [Google Earth, 2004].

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)
DOW	Department of Water (County of Kauai)
EA	Environmental Assessment
EIS	Environmental Impact Statement
EKWUC	East Kauai Water Users Cooperative
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
KIUC	Kauai Island Utility Cooperative
LCA	Land Commission Award
LUC	Land Use Commission (State of Hawaii)
MF	multi-family residential
mgd	million gallons per day
Mgal/d	million gallons per day
mi	mile
MOU	Memorandum of Understanding
na	not available
NAWQA	National Water Quality Assessment (USGS)
NHLC	Native Hawaiian Legal Corporation

NIR	net irrigation requirements
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
NRCS	Natural Resource Conservation Service (USDA)
NVCS	National Vegetation Classification System
por.	Portion
REL	religious
RMT	R.M. Towill Corporation
SCS	Soil Conservation Service (United States Department of Agriculture) Note: The SCS is now called the Natural Resources Conservation Service (NRCS)
SF	single family residential
SPI	Standardized Precipitation Index
sq mi	square miles
TFQ	total flow statistics
TFQ_{50}	50 percent exceedance probability
TFQ_{90}	90 percent exceedance 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 hydrologic unit of Wailua is located in East Kauai, on the east flank of Waialeale Mountain, the primary volcano on the Hawaiian island of Kauai (Figure 1-3 and 1-4). It covers an area of 52.6 square miles from 5,226 feet elevation to the sea with a mean basin elevation of 993 feet and a mean basin slope of 32.4 percent (Figure 1-5). Forty-one percent of the basin has a slope greater than 30 percent. The longest flow path in Wailua is 20.6 miles in length, traversing in an easterly direction from its headwaters to the ocean. The Wailua River is composed of two branches which are fed by numerous large perennial tributaries as well as many small perennial and ephemeral headwater tributaries. While the perennial tributaries are generally fed by spring flow from groundwater sources, the ephemeral ones flow only intermittently in response to rainfall-runoff. Dike-impounded groundwater discharge as well as the slow release of water from the Alakai Swamp supports perennial flow in the upper reaches of the largest tributaries to the Wailua River. The basin has a mean annual precipitation of 138 inches but rainfall ranges from 50 to 400 inches per year. Most of the watershed is owned by the State of Hawaii designated as conservation land in the Lihue-Koloa Forest Reserve or as agricultural land managed by the State of Hawaii Department of Agriculture. The lower elevations are occupied by alien forest and grass species with large areas cleared for agriculture, while the upper regions support native and invaded wet forest vegetation. Certain areas support low to medium density urban development and some rural development. In 2010, the census blocks making up the Wailua hydrologic unit supported 7929 people (U.S. Census Bureau Office of Planning 2011). Many state and county roads exist as well as private roads, providing access to much of the region (Figure 1-6). There are multiple diversion and ditch systems developed by the former Lihue Plantation and currently managed by either Kauai Island Utility Cooperative, East Kauai Water Users Cooperative, or Grove Farm Company. These irrigation systems continue to function to provide hydropower, water for agriculture, recreation, or drinking water supply.

Current Instream Flow Standard

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

> Interim instream flow standard for Kauai. The Interim Instream Flow Standard for all streams on Kauai, as adopted by the commission on water resource management on June 15, 1988, shall be that amount of water flowing in each stream on the effective date of this standard, and as that flow may naturally vary throughout the year and from year to year without further amounts of water being diverted off stream 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 31, 1987. Streamflow was not measured on that date; therefore, the current interim IFS is not a measurable value.

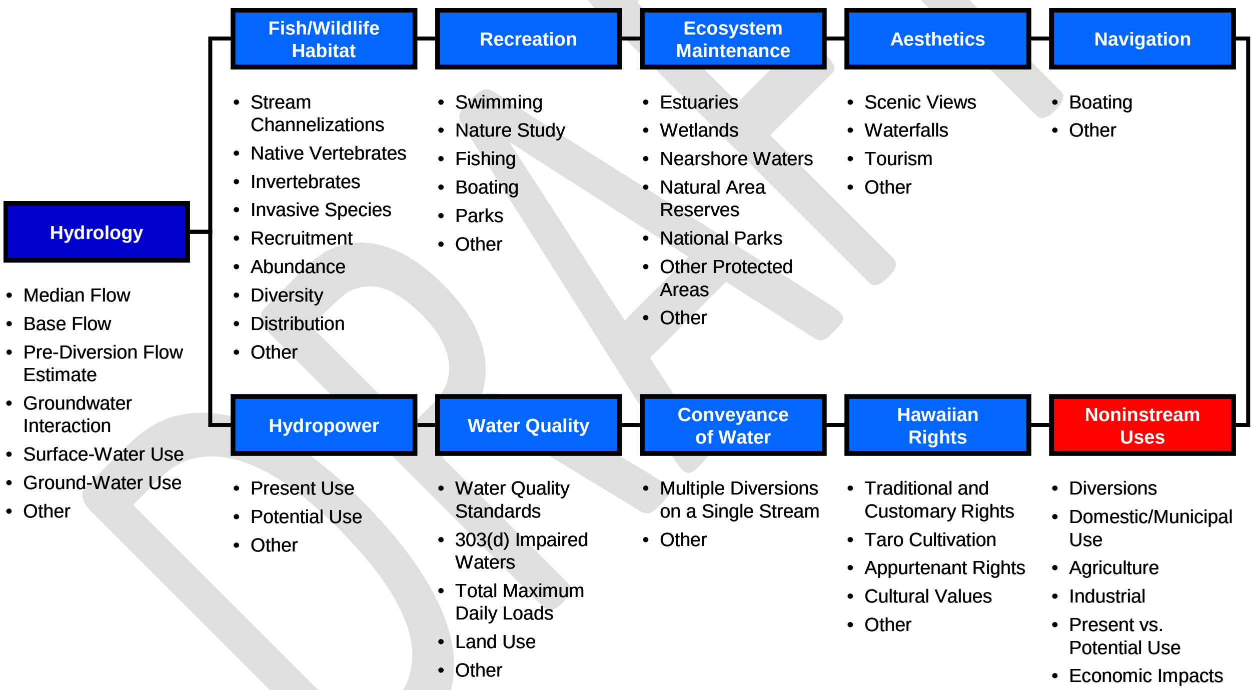
Instream Flow Standards

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

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

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

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

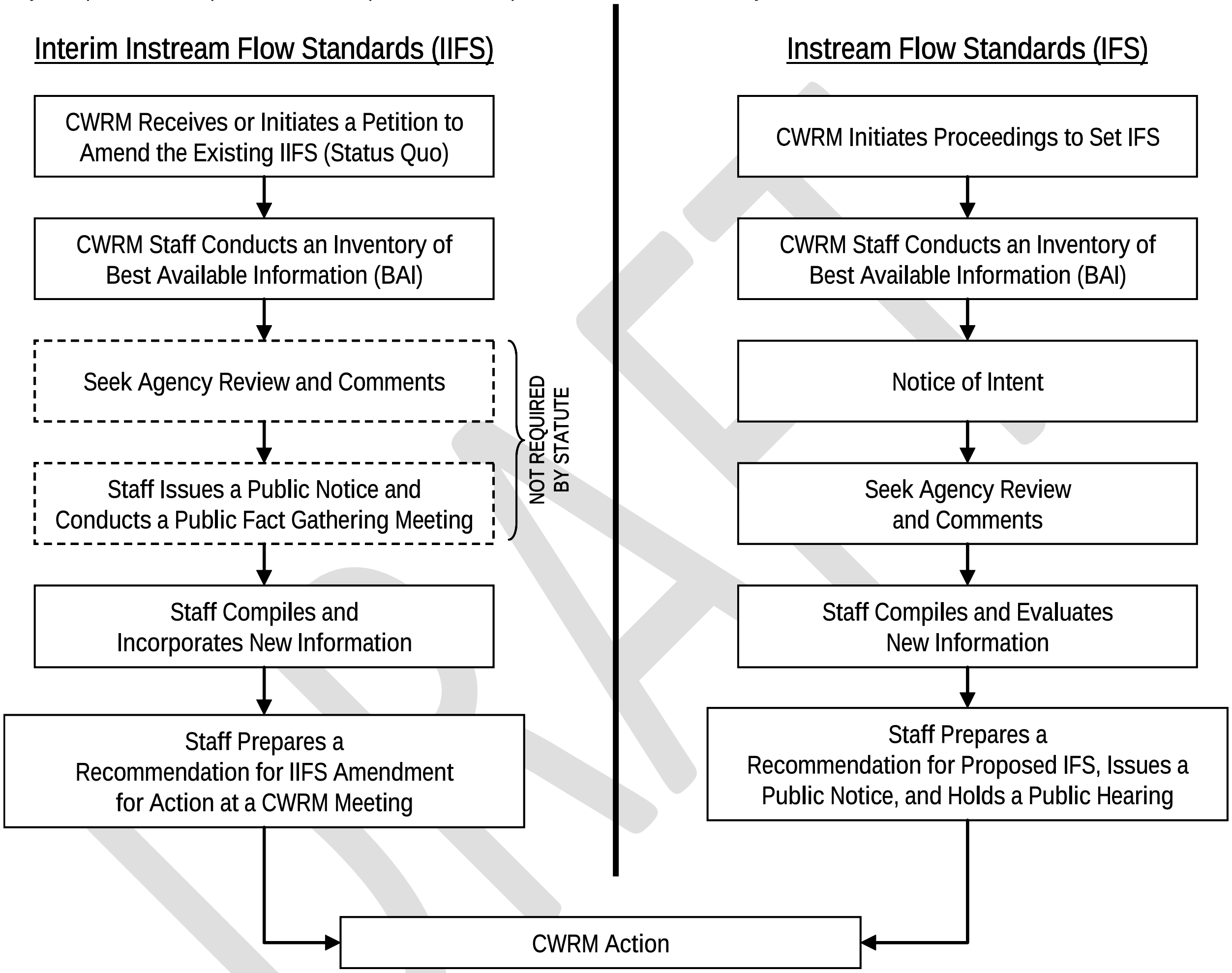


Interim Instream Flow Standard Process

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

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

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.



Instream Flow Standard Assessment Report

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

Each report begins with an introduction of the subject hydrologic unit and the current IFS status. Section 2.0 is comprised of the various hydrologic unit characteristics that, both directly and indirectly, impact surface water resources. Section 3.0 contains a summary of available hydrologic information, while Sections 4.0

through 12.0 summarize the best available information for the nine instream uses as defined by the Code. Noninstream uses are summarized in Section 13.0. Maps are provided at the end of each section to help illustrate information presented within the section's text or tables. Finally, Section 14.0 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. Landsat 7 satellite imagery (1999-2003) of the Wailua hydrologic unit in East Kauai, Hawaii. (Source: State of Hawaii, Office of Planning, 2018a)

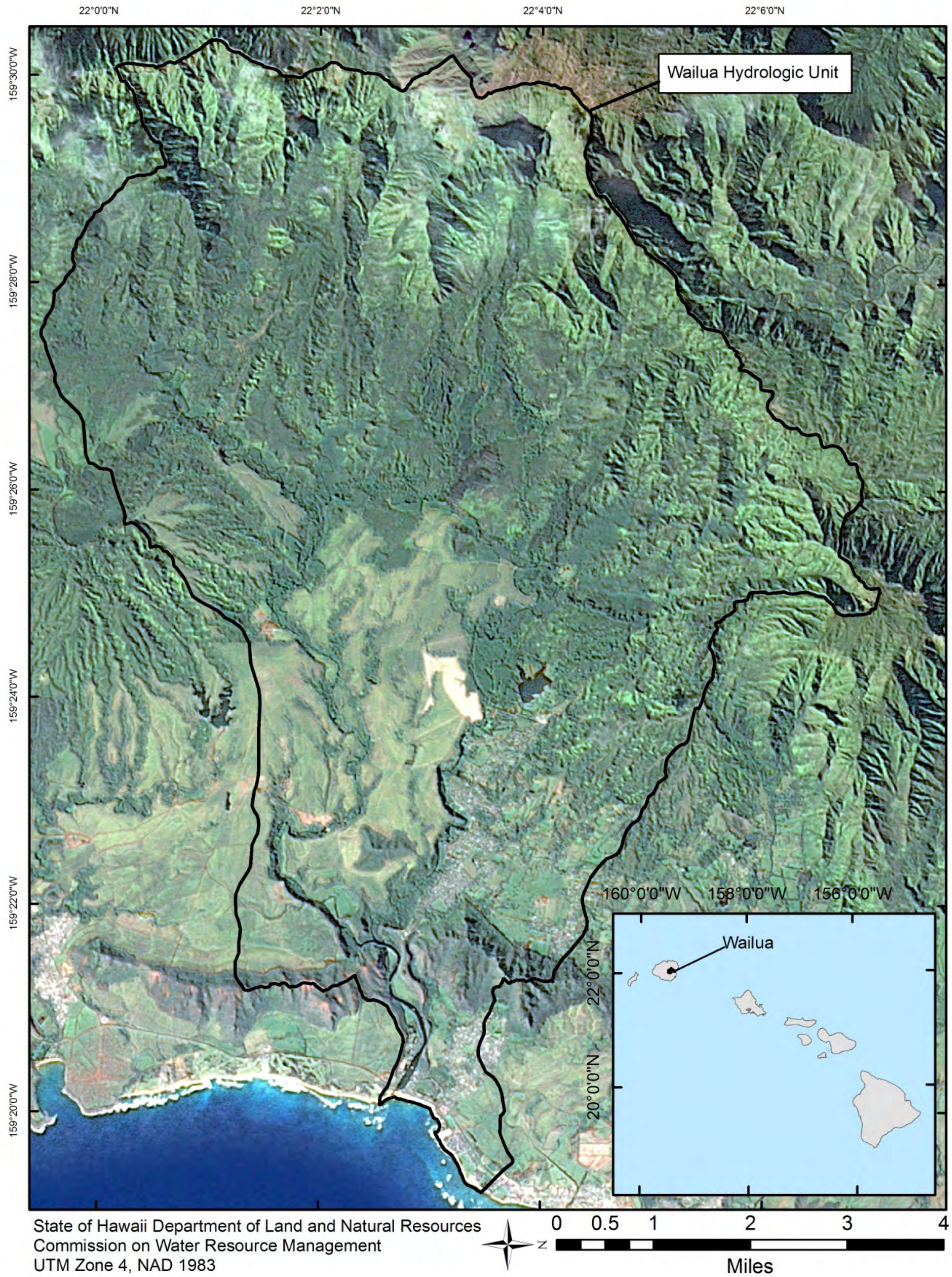


Figure 1-4. Digital elevation model and elevation range with 500 ft contours of the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2004e; USGS, 2001a; 2001b)

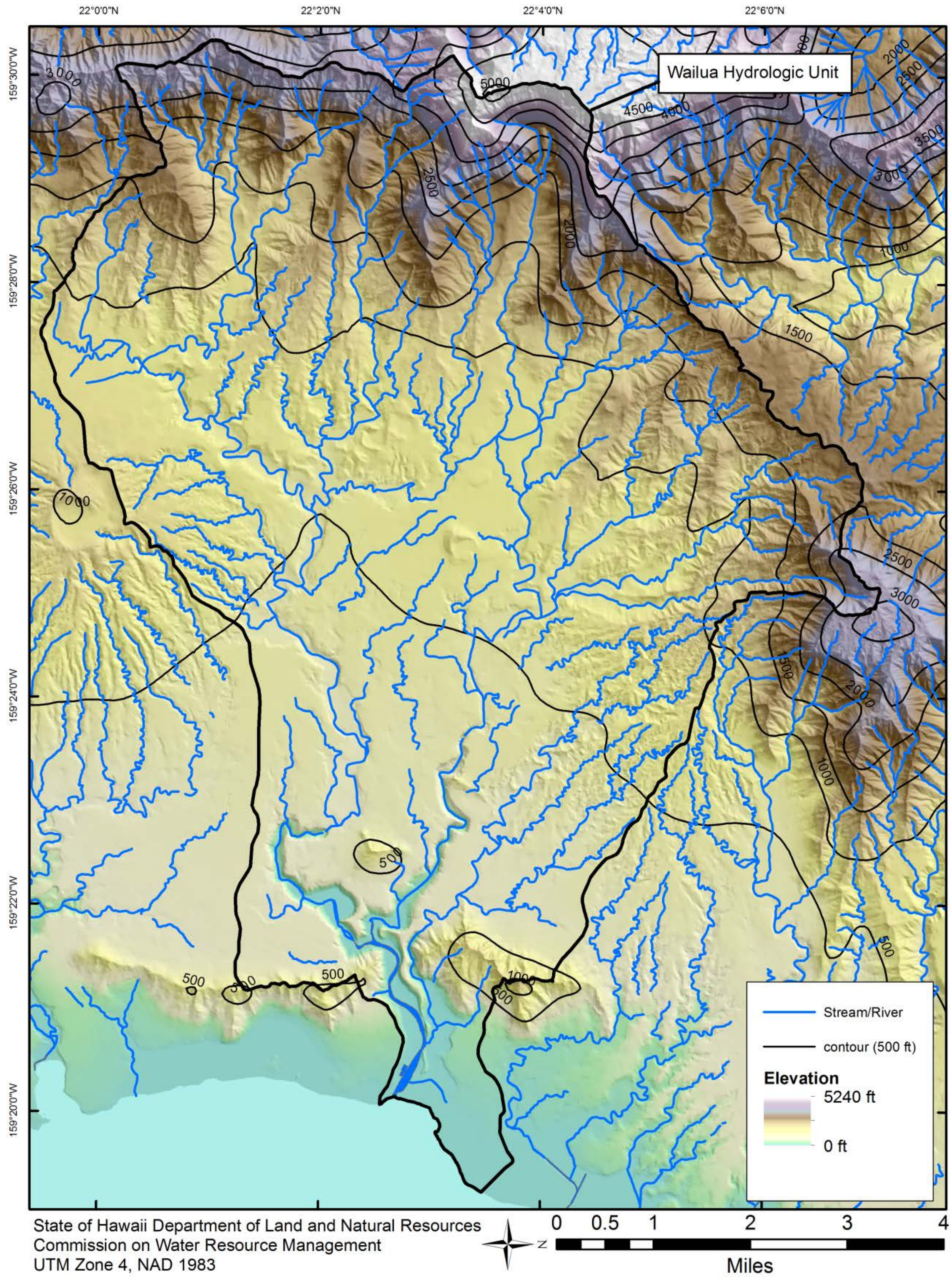


Figure 1-5. USGS topographic map of the Wailua hydrologic unit, Kauai. (Source: USGS, 1996; 2001b)

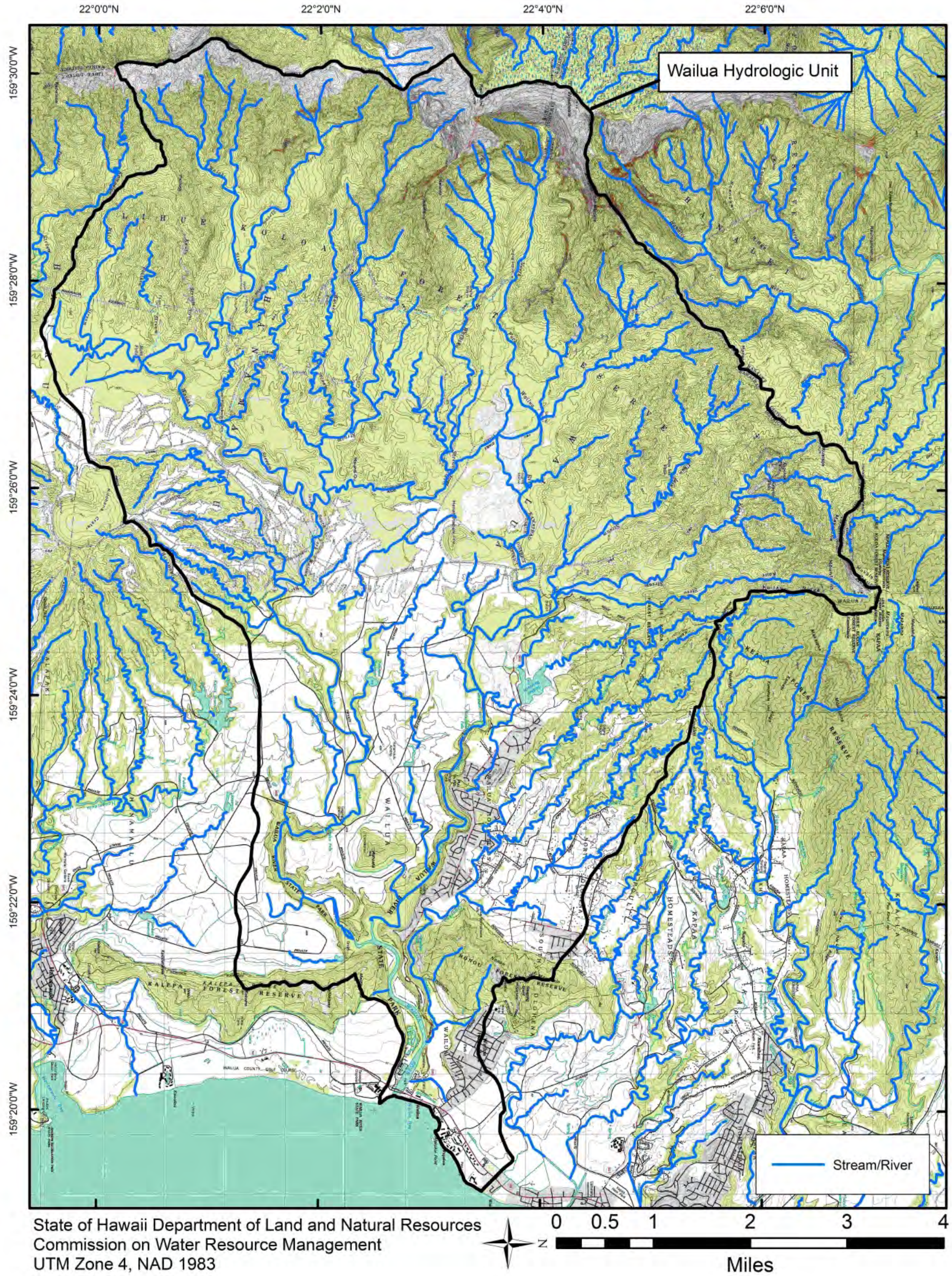
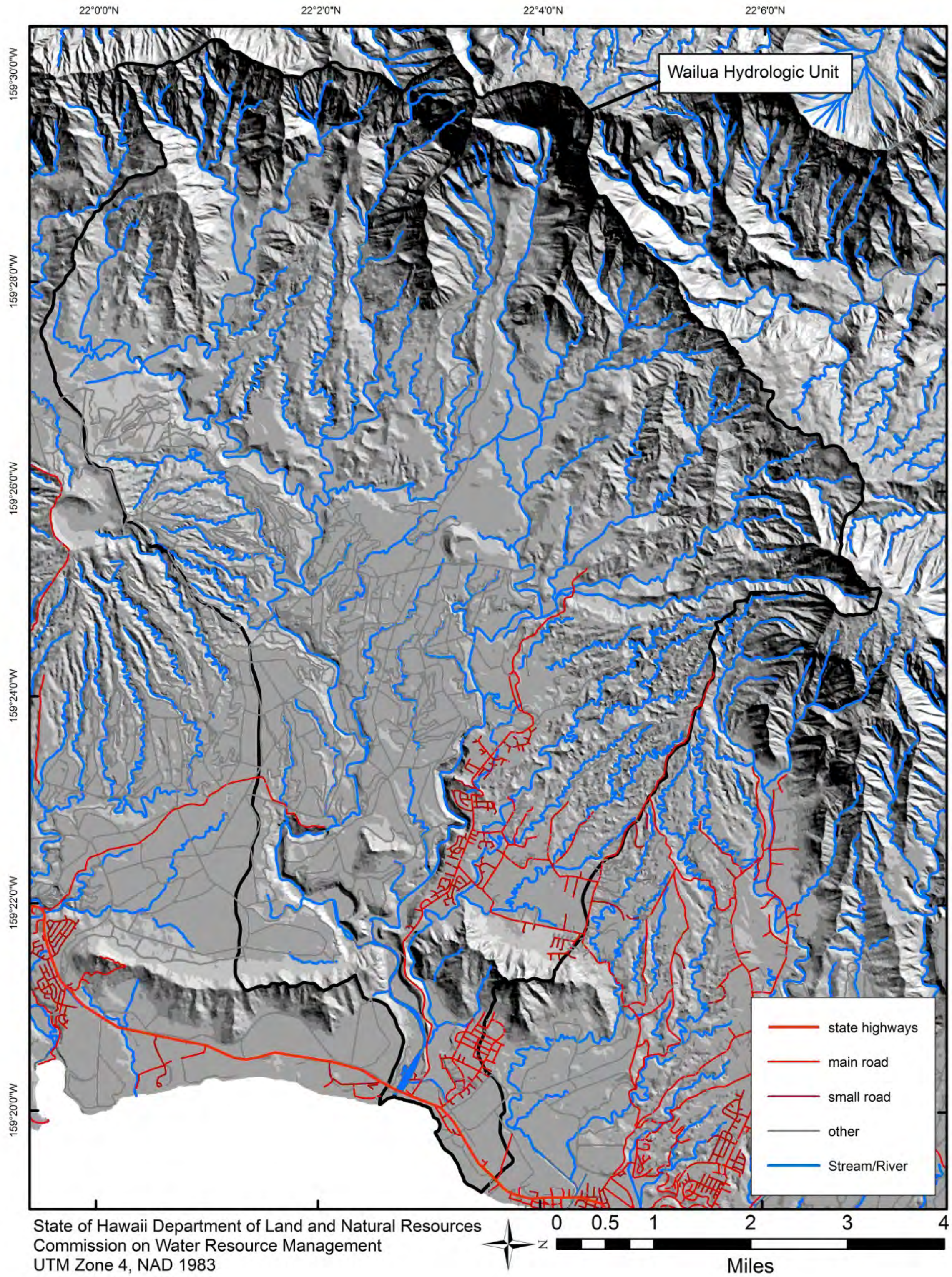


Figure 1-6. Major and minor roads (2008) for the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning 2018b; USGS 2001b)



2.0 Unit Characteristics

Geology

Wailua is on the eastern flank of the Waialeale Volcano, bordered on the north by the Makaleha Mountains and the south by the Kilohana Volcano and near the coastline by the Nonou and Kalepa ridges. It forms the northern portion of the Lihue Basin, a unique geologic depression that also includes the Huleia, Nawiliwili and Hanamaulu watersheds. There were two separate volcanic phases in Kauai that produced the geology of the region: the Waimea Canyon volcanic series (Stearns and Macdonald 1942). The two formations of the Waimea Canyon volcanic series with the most impact on southeast Kauai include the Napali formation, which is composed of thin-bedded pahoehoe and aa flows that originated at the caldera boundary, and the Haupu formation, which is composed of thick massive flows accumulated in a large pit carter in the southeast. Kauai is primarily composed of tholeiitic Waimea Canyon basalt, which was formed during the initial shield-building phase and makes up the lower layers of the Lihue Basin. Only in the ridges and central mountains is this basalt layer visible (Gingerich 1999a). Most of this basalt belongs to the Napali Member series and is considered highly permeable (Macdonald et al. 1960). Volcanic dikes in the ridges have been exposed by erosion and may also be present in the basalt beneath the Lihue Basin, although this is unconfirmed (Gingerich 1999a). In the second volcanic phase, thick aa and pahoehoe lava flows of mostly of massive alkalic olivine basalts of Koloa Volcanics dominate the Lihue Basin (Macdonald et al. 1960). This stage of rejuvenated shield building filled valleys, gorges, and depressions in the Waimea Canyon basalt with heterogeneous lava flows, ash, tuff, cinder, and sediments as much as 1,000 ft thick (Macdonald et al. 1960). While some studies have shown that the contact between Koloa Volcanics and the Waimea Basalt occurs at about 500 ft in elevation, there is evidence that the thickness of the Koloa Volcanic layer is highly variable and dependent on the shape of the eroded surface and thus the contact may occur deeper (Gingerich 1999a). Some sediments originating as Koloa Volcanics are now classified as Palikea Breccia Members. The generalized geology of the Wailua hydrologic unit is depicted in Figure 2-2.

Soils

The U.S. Department of Agriculture's Natural Resources Conservation Service (formerly known as the Soil Conservation Service) divides soils into hydrologic soil groups (A, B, C, and D) according to the rate at which infiltration (intake of water) occurs when the soil is wet. The higher the infiltration rate, the faster the water is absorbed into the ground and the less there is to flow as surface runoff. Group A soils have the highest infiltration rates; group D soils have the lowest. In the Wailua hydrologic unit, there is a large mix of soil types with 0.74% of soils in Group A, 39.0% of soils in Group B, 29.1% of soils in Group C, and 30.8% of soils in Group D (Table 2-1). The Wailua hydrologic unit consists largely of soils that are in hydrologic group C and D with generally lower permeability resulting in rapid runoff (Table 2-2). The gently sloping regions between the interior mountains and eastern ridges are dominated by soils in the hydrologic group B composed of moderately deep to deep, well drained soils supporting moderate infiltration (Figure 2-3). The numerous tributaries have carved out gulches with slopes of 40 to 70 percent, leading to high rates of runoff and geologic erosion is active, transporting alluvium to lower reaches. Soils in Group D tend to have a high clay content with the highest potential for runoff (low infiltration rate) and are often shallow soils on top of impervious lava (U.S. Department of Agriculture, Soil Conservation Service, 1972).

Table 2-1. Area and percentage of soil types for the Wailua hydrologic unit, Kauai.

Map Unit	Hydrologic Soil Group	Description	Area (mi^2)	Percent (%)
rRR	C	Rough broken land	13.194	25.08
rRT	D	Rough mountainous land	10.178	19.35
rRO	D	Rock outcrop	4.925	9.364
KkB, KkC, KkD, KkE,	B	Kapaa	4.176	7.938
HfB, HfC, HfE2, HfD2	B	Halii	3.881	7.378
PlB, PlD, PmB, PmC, PmD, PmE	B	Pooku	3.009	5.721
HsB, HsC, HsD, HsE, Hte, HuE	B	Hanamaulu	2.781	5.288
PnA, PnB, PnC, PnD, PnE	B	Puhi	2.175	4.134
KUL, Kw	B	Kolokolo	1.804	3.431
HnA, HpA, HrB	C	Hanalei	1.193	2.268
LhB, LhC, LhD,. LhE2, LlB, LlC	B	Lihue	1.0257	1.95
KdD, KdE, KdF, KEHF	B	Kalapa	1.021	1.94
HNUD, HNUF	D	Hulua	0.729	1.386
KVSB, KVSE	C	Koolau	0.727	1.382
Mr, Mta	B	Mokuleia	0.366	0.697
rRH	A	Riverwash	0.365	0.695
MZ	D	Marsh	0.274	0.521
W		water	0.191	0.363
LcB, LcC, LcD	B	Lawai	0.162	0.309
HMMF	B	Hihimanu	0.125	0.239
KvB	C	Koloa	0.091	0.172
IoB, IoC	C	Ioleau	0.091	0.172
NnC	D	Nonopahu	0.0289	0.055
BS	A	beaches	0.027	0.051
Kfa	D	Kaloko	0.0259	0.049
LuB	D	Lualualei	0.012	0.023
rAAE	C	Alakai	0.008	0.015
BL	D	Badland	0.006	0.011

Rainfall

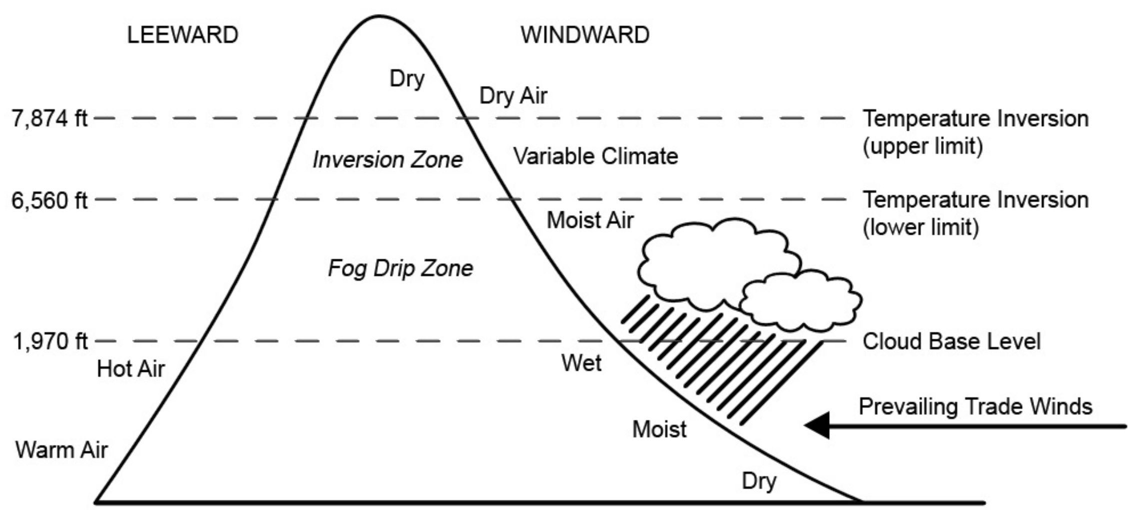
Orographic[1] rainfall is the driving force affecting the distribution of rainfall in Wailua (Figure 2-4). Near the coast, mean annual rainfall is only 50 inches but the interior-most ridges receive at least 400 inches per year. Orographic precipitation occurs when the prevailing northeasterly trade winds lift warm air up the windward side of Waialeale 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 fog drip zone occurs below the elevation where cloud height is restricted by the temperature inversion, where temperature increases with elevation, thus favoring fog drip over rain-drop formation (Sholl et al., 2002). The temperature inversion zone typically extends from 6,560 feet to 7,874 feet. This region is influenced by a layer of moist air below and dry air above, making climate extremely variable (Giambelluca and Nullet, 1992). Fog drip is a result of cloud-water droplets impacting vegetation (Scholl et al, 2002) and can contribute significantly to ground water recharge. Above the inversion zone, the air is dry and the sky is frequently clear (absence of clouds) with high solar radiation, creating an arid atmosphere with little rainfall.

[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.

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. Precipitation on Waialeale is influenced by its position relative to the trade winds. The highest position in Wailua lies in the cloudy layer below the trade wind inversion on Mt. Waialeale, resulting in peak rainfall for the region; mean annual rainfall as measured at USGS station 220427159300201 is about 430 inches. The steep gradient around the island forces moisture-laden air to rapidly rise in elevation (over 3,000 feet) in a short distance, resulting in a rapid release of rainfall. Finally, the relatively round, conical shape of the Waialaeale exposes all sides of the peak to wind and moisture.

The Wailua hydrologic unit is situated on the windward flank of the Waialeale and as such receives more orographic rainfall than leeward slopes (Figure 2-1). The high spatial variability in rainfall is evident by the 350 inch variation in mean annual rainfall across the hydrologic unit. Total monthly rainfall varies from 10.73 inches in July to 21.51 inches based on recent (2002-2017) monitoring data at 1,110 feet elevation with an annual mean of 16.60 inches per month (USGS station 220356159271401).

Figure 2-1. Orographic precipitation in the presence of mountains higher than 6,000 feet.



Fog drip is also expected to contribute substantially to the water budget of the hydrologic unit. Shade (1999) used the monthly fog drip to rainfall ratios for the windward slopes of Mauna Loa on the island of Hawaii (Table 2-2) to calculate fog drip contribution to the water budget in windward east Maui. A similar method was used to estimate the fog drip contributions in Wailua using 1) the fog drip zone boundaries (elevations greater than 2,000 ft); and 2) the same ratios between fog drip and rainfall for the windward slopes of Mauna Loa, Island of Hawaii (Juvik and Nullet, 1995). This method assumes the seasonal contributions of fog drip to total precipitation are similar between islands. By multiplying the ratios with the monthly rainfall values, the total contribution of fog drip to the water budget in the Wailua hydrologic unit can be calculated (Giambelluca et al, 2013). Calculations show that approximately 10 percent (5.805 square miles) of Wailua lies in the fog drip zone based on elevation (Figure 2-4). The total contribution from fog drip to the water budget based on percent of fog drip from monthly rainfall is about 26%, assuming the same ratios as windward Hawaii (Table 2-2).

Table 2-2. Fog drip to rainfall ratios for the windward slopes of Mauna Loa on the island of Hawaii and approximate contributions to the Wailua Hydrologic Unit based on monthly (Water Year 2002-2017) rainfall data from USGS station 220356159271401.

Month	Ratio (%)	Mean Rainfall (in)	Contribution (in)
January-March	13	16.16	2.10
April-June	27	12.45	3.36
July-September	67	11.89	7.96
October-November	40	14.51	5.80
December	27	14.12	3.81
Annual Total		161.88	55.67

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 Wailua, average annual solar radiation is 205.2 W/m^2 per day with a range of 162.1-229.5 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).

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[1], rainfall, humidity, wind speed, surface temperature, and sensible heat advection[2]. Higher evaporation rates are generally associated with greater net radiation, high wind speed and surface temperature, and lower humidity.

A common approach to estimating evaporation is to employ a relationship between potential evaporation and the available water in the watershed. Potential evaporation is the maximum rate of evaporation if water is not a limiting factor, and it is often measured with evaporation pans. In Hawaii, pan evaporation measurements were generally made in the lower elevations of the drier leeward slopes where sugarcane was grown. These data have been compiled and mapped by Ekern and Chang (1985). Most of the drainage basins in 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

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

evaporation data for Hawaii, evaporation generally decreases with increasing elevation below the temperature inversion[3] 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 at the slopes (Nullet, 1987). Shade (1999, Fig. 9) estimated pan evaporation rates of 30 inches per year below 2,000 feet elevation to 90 inches per year near the coast. Within the cloud layer, evaporation rates are particularly low due to the low radiation and high humidity caused by fog drip. Pan evaporation rates dropped below 30 inches per year in this area as reported in Shade (1999, Fig. 9). Near the average height of the temperature inversion, evaporation rates are highly variable as they are mainly influenced by the movement of dry air from above and moist air from below (Nullet and Giambelluca, 1990). Above the inversion, clear sky and high solar radiation at the summit causes increased evaporation, with pan evaporation rates of about 50 to 70 inches per year (Shade, 1999, Fig. 9). For example, Ekern and Chang (1985) reported evaporation increased to 50 percent more than surface oceanic rates near the Mauna Kea crest on the island of Hawaii. Potential annual evapotranspiration in the Wailua hydrologic unit (Figure 2-6) averages 119.5 inches and ranges from 62.8 in to 234.1 inches per year (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 ground water resources, land use classification continues to serve as a valuable tool for long-range planning purposes.

As of 2014, the LUC designated 68.6 percent of the land in Wailua as conservation and 27.9 percent as agricultural with 1.46 percent as rural and 1.97 percent as urban (State of Hawaii, Office of Planning, 2015d). The conservation district is located in the upper part of the hydrologic unit, whereas the agricultural district lies in the lower part of the hydrologic unit (Figure 2-7).

Land Cover

Land cover for the hydrologic unit of Wailua 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 Wailua, e.g. forest, grassland, shrub land, with minor developed areas, cultivated areas, and bare land (Figure 2-8). The second is developed by the Hawaii Gap Analysis Program (HI-GAP), which mapped the National Vegetation Classification System (NVCS) associations for each type of vegetation, creating a more comprehensive land cover dataset (Figure 2-9).

Based on the two land cover classification systems, the land cover of Wailua consists mainly of scrub and grassland areas in the lower elevations. Much of the middle to higher elevations of the hydrologic unit is made up of evergreen forest composed of alien species. Small areas on the steeper, higher elevation

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

slopes are composed of open ohia forest and native wet forest/shrubland. Some of the lowest elevation and lease sloped portions of the watershed are in agriculture or developed as urban or rural development. Along the stream channel and closest to the coast are forested and emergent wetland.

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 the flood happening 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.

Peak floods in Wailua have been monitored by USGS since 1914 on the South Fork (USGS station 1606000) and since 1916 on the East Branch North Fork (USGS station 16068000) and more recently (1956-present) on the North Fork near the confluence with the South Fork (USGS station 16071000). The estimated 2-, 5-, 10-, 50-, and 100-year flood magnitudes at these stations is listed in Table 2-3. 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 the lower reaches of the Wailua hydrologic unit along the stream channels as flood-risk zone A, (Figure 2-10).

Table 2-3. Estimated peak flood magnitudes (cubic feet per second) for selected recurrence intervals at USGS stations in Wailua hydrologic unit (Oki et al. 2010).

USGS station	2-year	5-year	10-year	50-year	100-year
16068000	2940	4700	6130	10100	12200
16071000	6580	11900	16800	31900	40700
16060000	13800	23800	31300	49100	57200

Drought

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

Hydrological drought refers to declining surface and ground water levels. Lastly, socioeconomic drought occurs when water shortage affects the general public.

Impacts of drought are complex and can be categorized into three sectors: water supply; agriculture and commerce; and environment, public health, and safety sectors (State of Hawaii, Commission on Water Resource Management, 2005b). The water supply sector encompasses urban and rural drinking water systems that are affected when a drought depletes ground water supplies due to reduced recharge from rainfall. 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 Kauai are summarized in Table 2-4.

Table 2-4. Drought risk areas for Kauai. (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	Hanalei to Alakai	Koloa, Kapaa, Wailua, Lihue, Poipu, Anahola	Kapaa, Wailua, Lihue, Poipu, Hanalei, Princeville, Kilauea, Anahola
Agriculture and Commerce	Waimea, Poipu, Lihue, Anahola, Kekeha/Mana	Lihue	Lihue
Environment, Public Health and Safety	Waimea	Lihue, Poipu, Wailua	Lihue, Poipu, Koloa

Based on the 12-month SPI, the Wailua, Lihue and Koloa regions have the greatest risk to drought impact on Kauai. The growing population in the already densely populated area further stresses the water supply. The Wailua region is vulnerable to severe and extreme drought in the water supply sector as well as severe drought in the environment, public health and safety sectors.

Figure 2-2. Generalized geology of the Wailua hydrologic unit, Kauai. (Source: Sherrod et al., 2007)

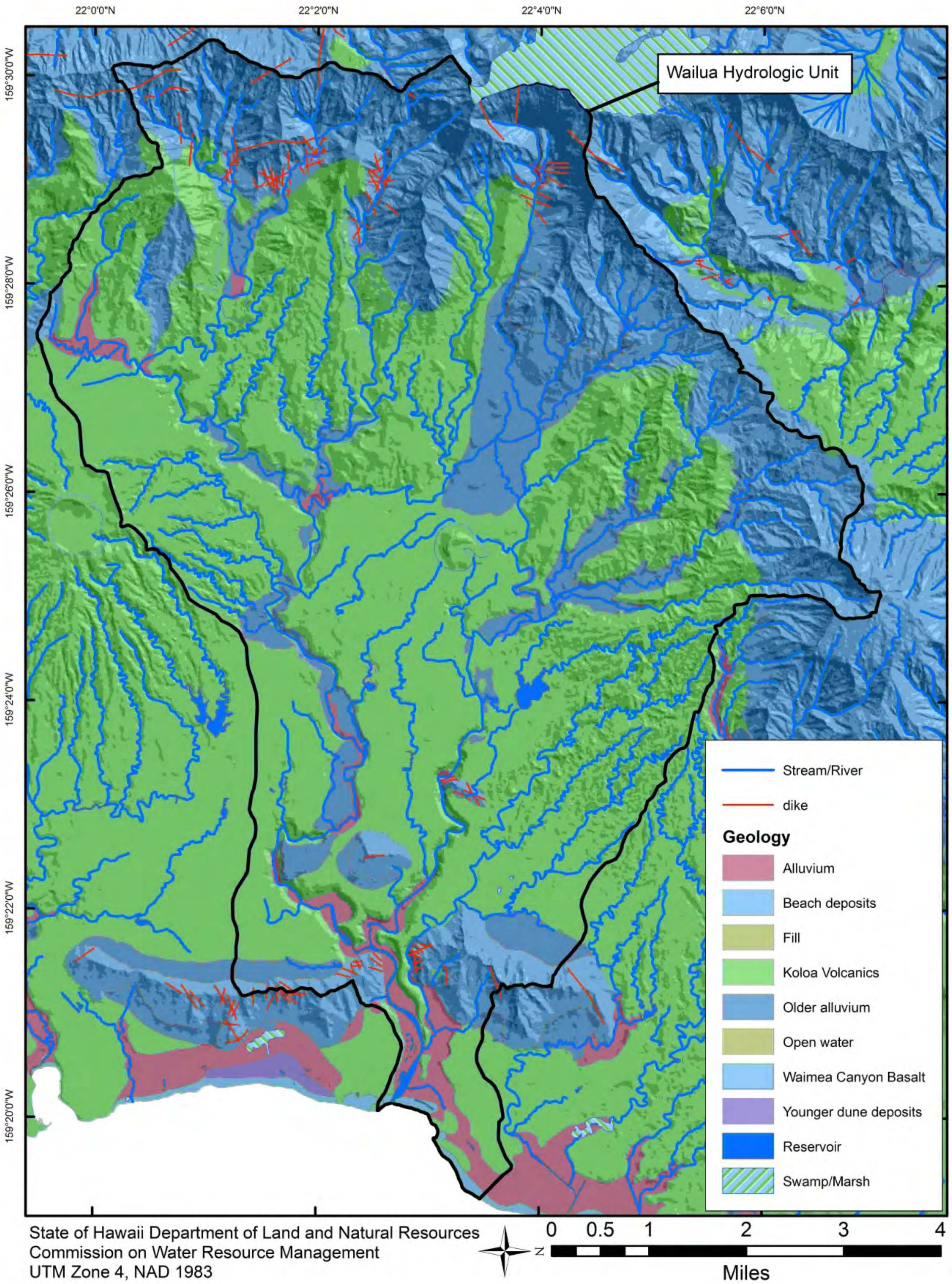


Figure 2-3. National Resource Conservation Service soil classification of the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015m)

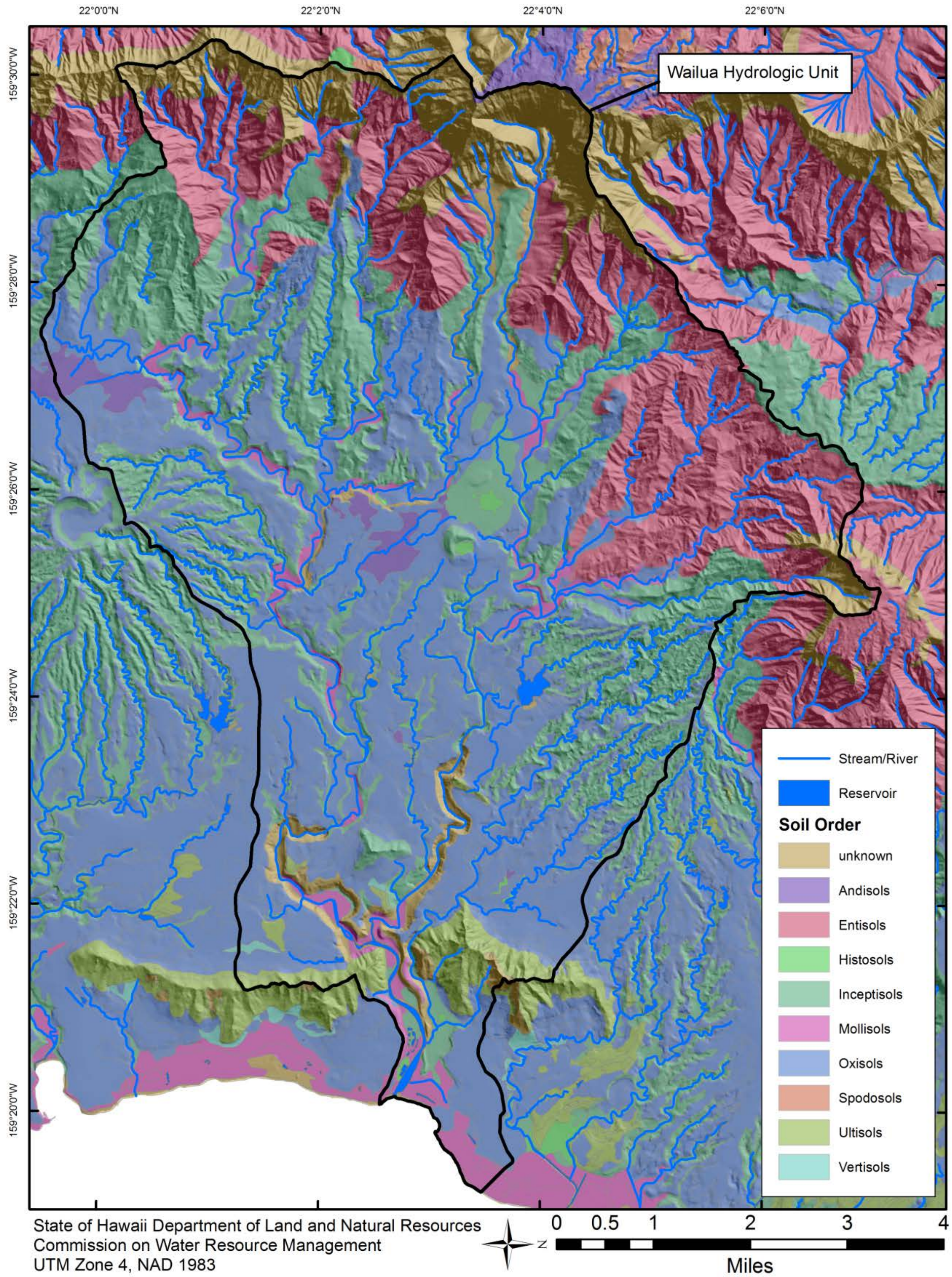


Figure 2-4. Mean annual rainfall in the Wailua hydrologic unit, Kauai. (Source: Giambelluca et al., 2013; USGS, 2001b)

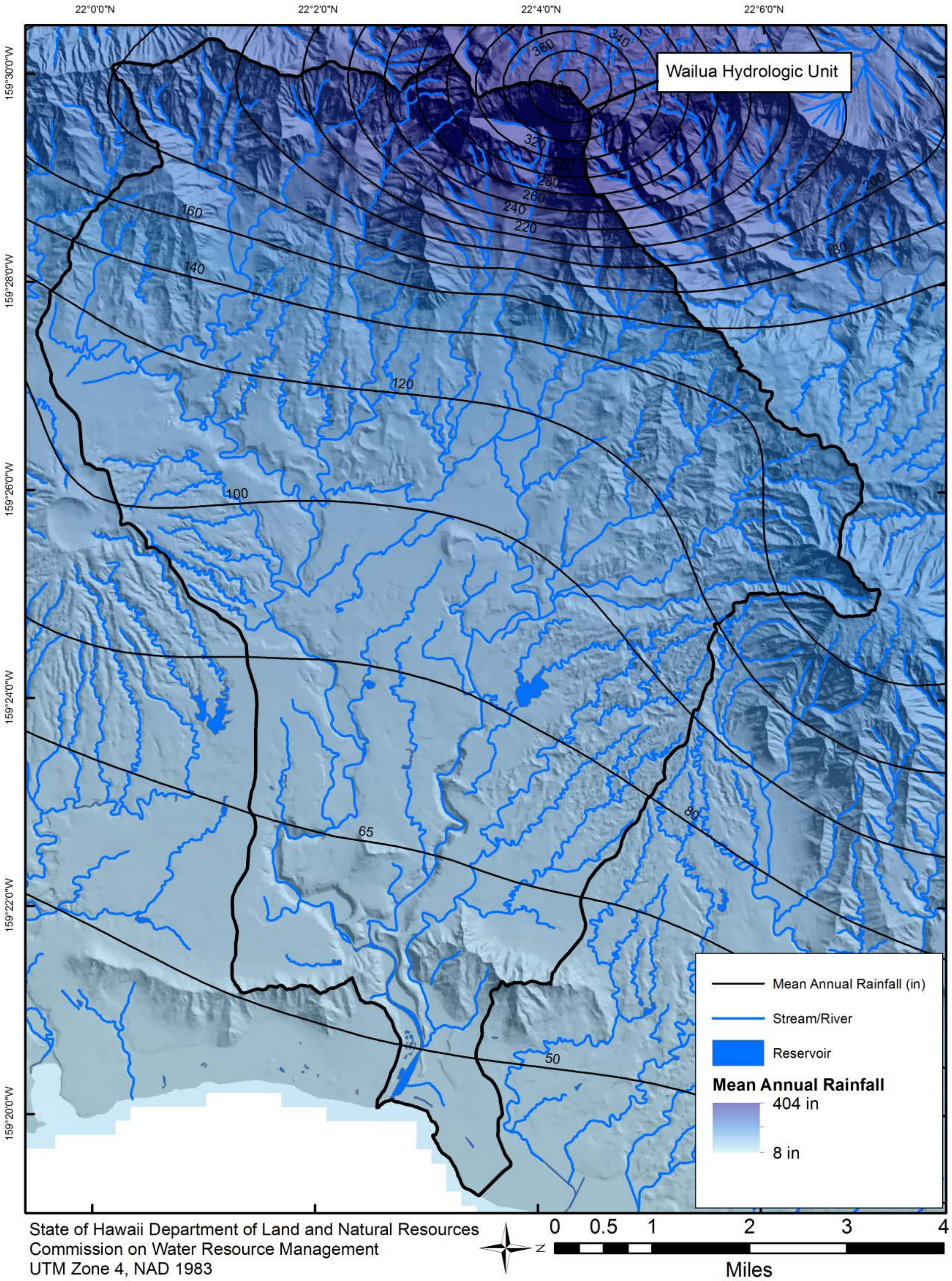


Figure 2-5. Modeled mean annual solar radiation from of the Wailua hydrologic unit, Kauai. (Source: Giambelluca et al., 2014)

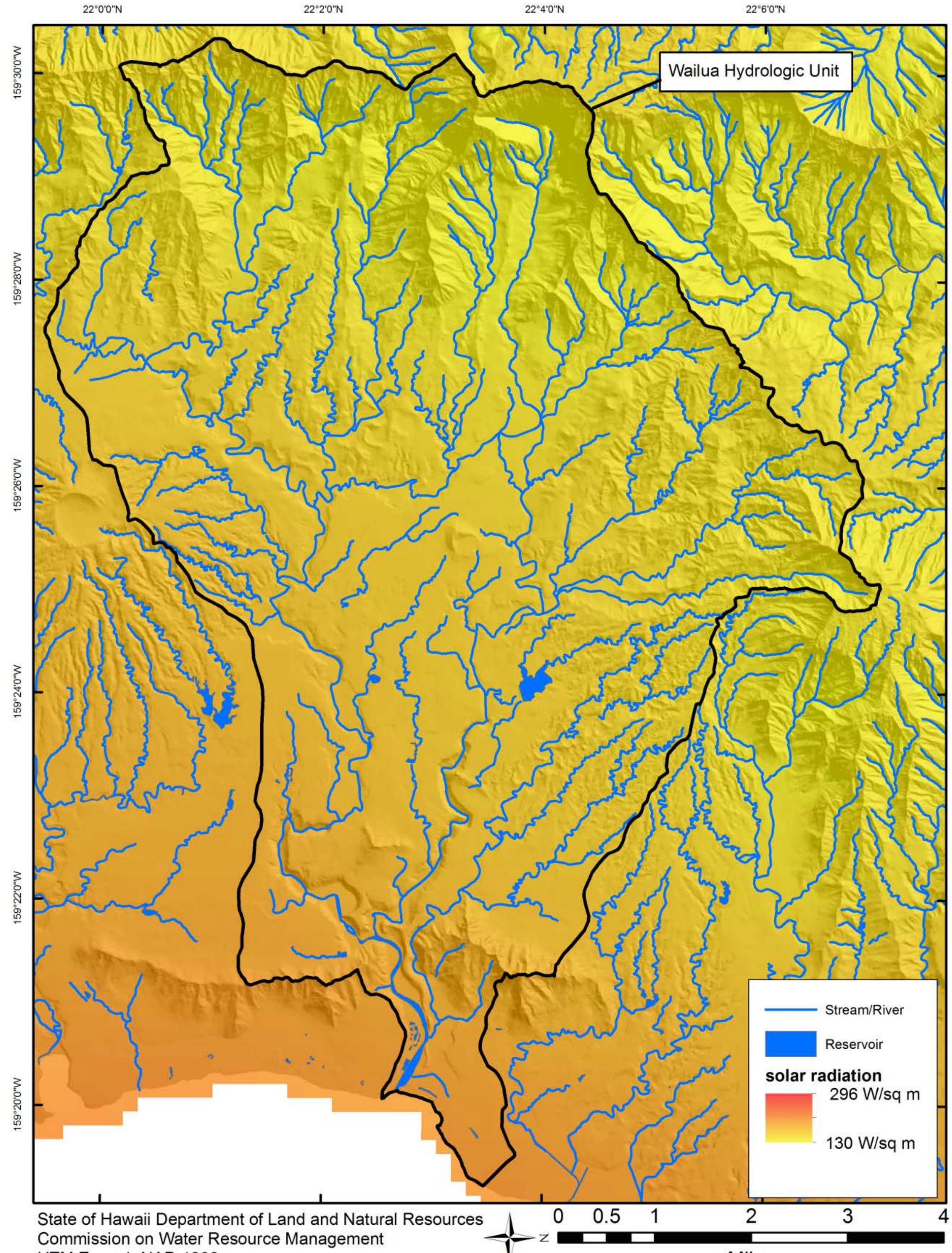


Figure 2-6. Modeled mean annual potential evapotranspiration (Penman-Monteith method) of the Wailua hydrologic unit, Kauai. (Source: Giambelluca et al., 2014)

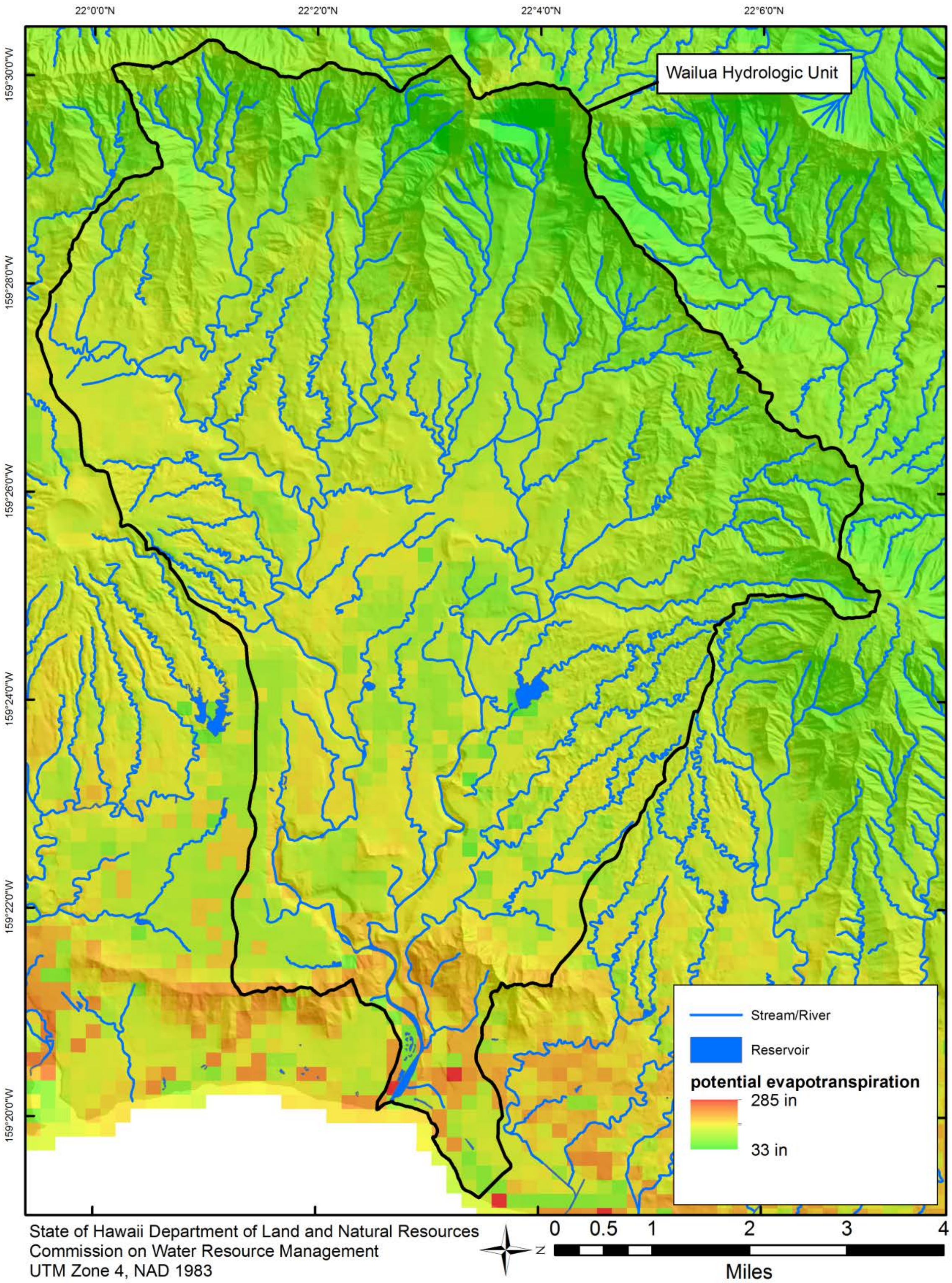


Figure 2-7. State land use district boundaries of the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015d).

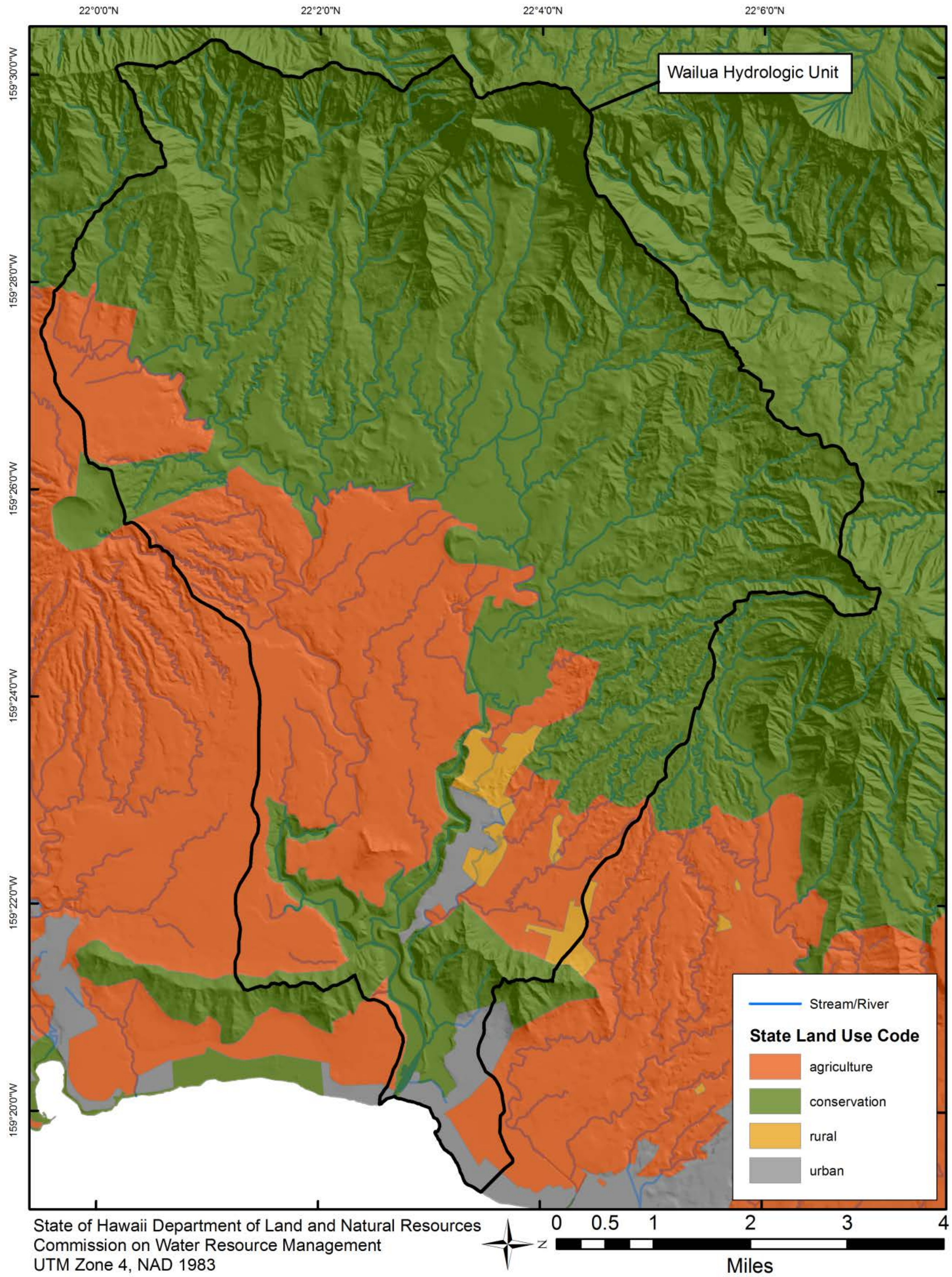


Figure 2-8. C-CAP land cover of the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015k).

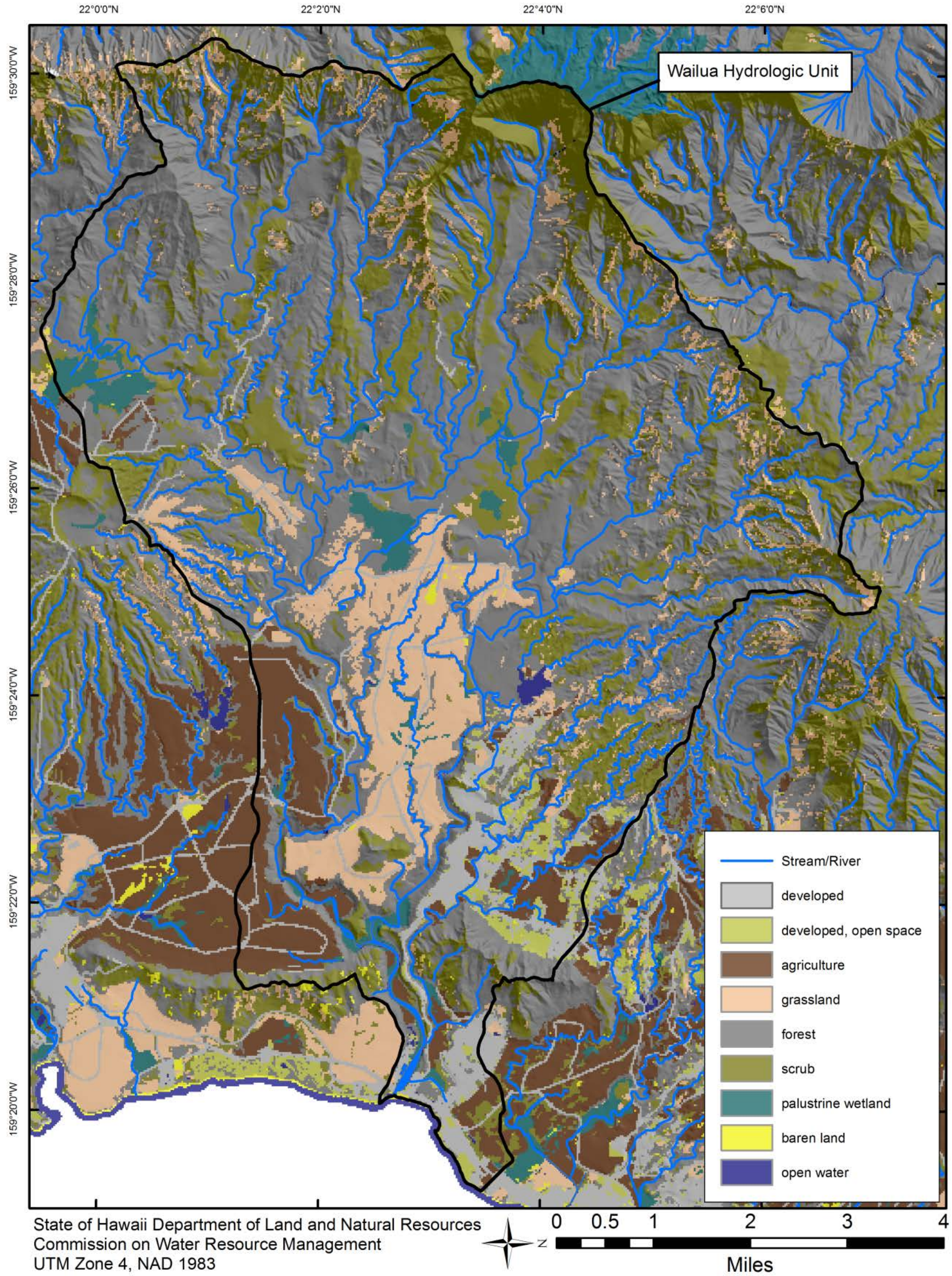


Figure 2-9. Hawaii GAP land cover classes of the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015f).

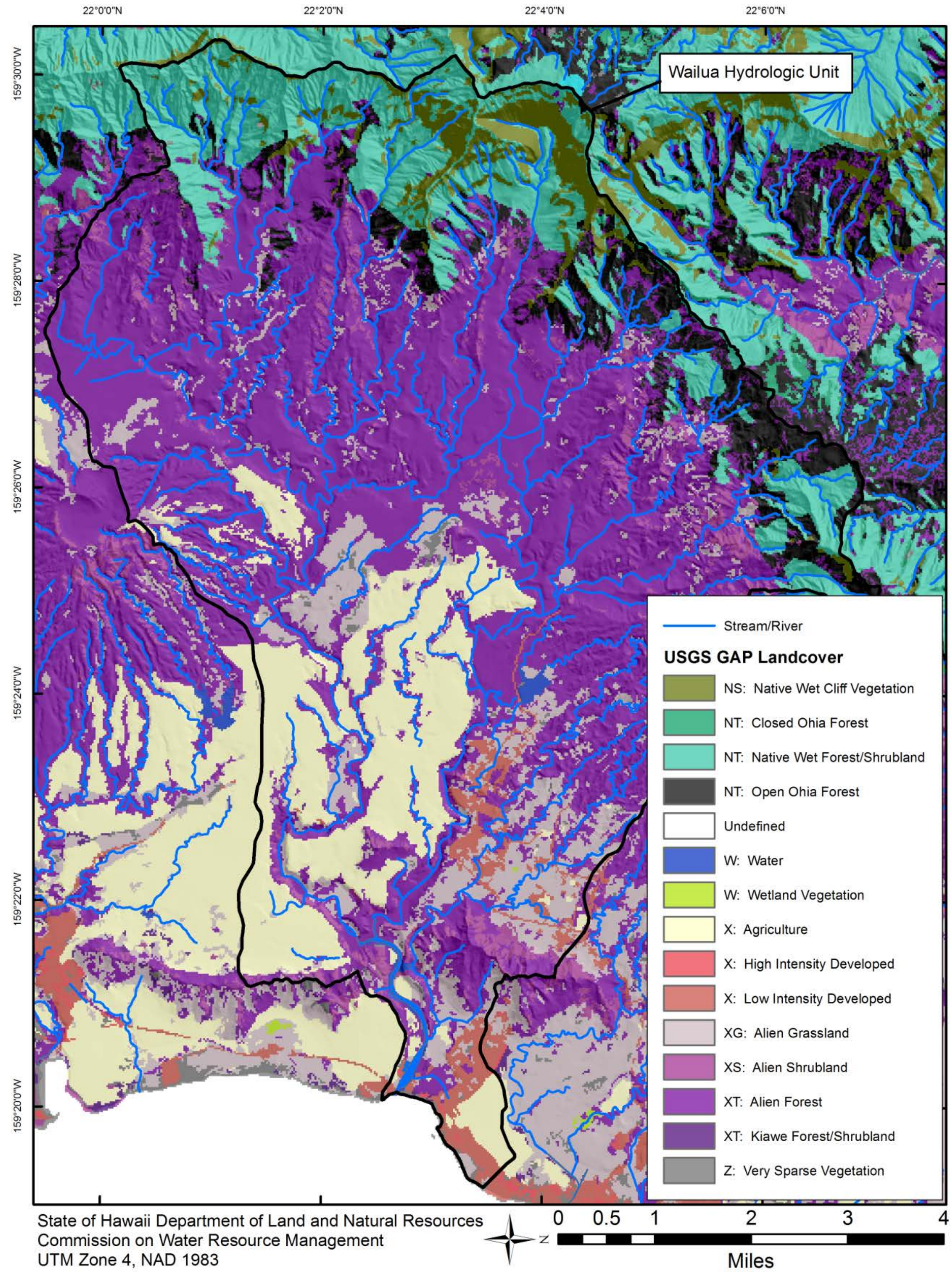
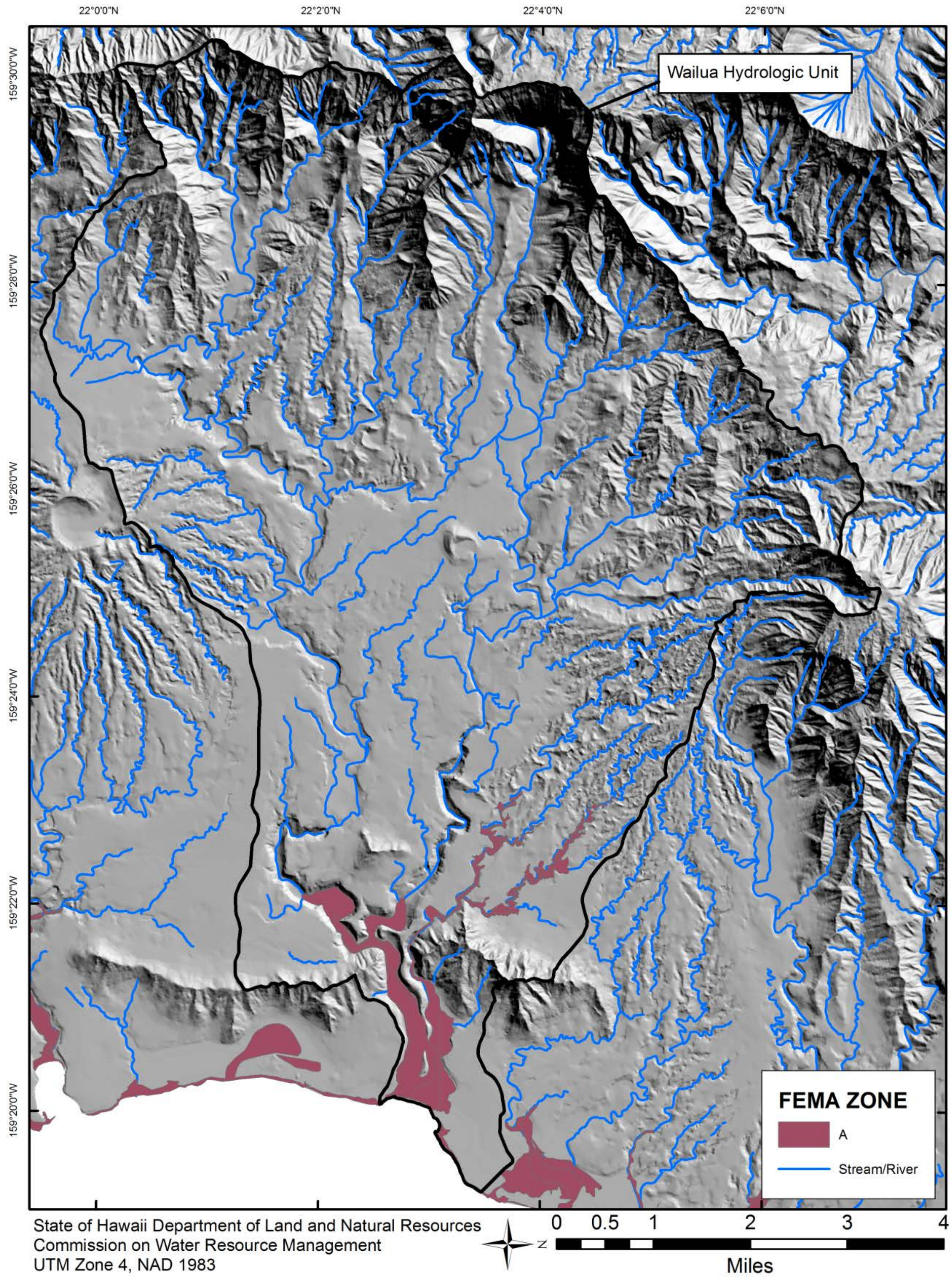


Figure 2-10. FEMA flood zone regions in Wailua hydrologic unit, Kauai. (Source: Federal Emergency Management Agency, 2014).



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 off stream 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 the Wailua Hydrologic Unit with a focus on the North Fork Wailua River (i.e., Waialeale Stream) and Waikoko Stream.

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., channelization, dam).

Streams in Hawaii can either gain or lose water at different locations depending on the hydrogeologic conditions. A stream gains water when the ground water table is above the streambed. When the water table is below the streambed, the stream can lose water. Where the streambed is lined with concrete or other low-permeability or impermeable material, interaction between surface water and ground water is unlikely. Another way that ground water influences streamflow is through springs. A spring is formed when a geologic structure (e.g., fault or fracture) or a topographic feature (e.g., side of a hill or a valley) intersects ground water either at or below the water table. It can discharge ground water onto the land surface, directly into the stream, or into the ocean. At places where erosion has removed the caprock, ground water discharges either as springs or into the ocean as seeps.

Ground Water

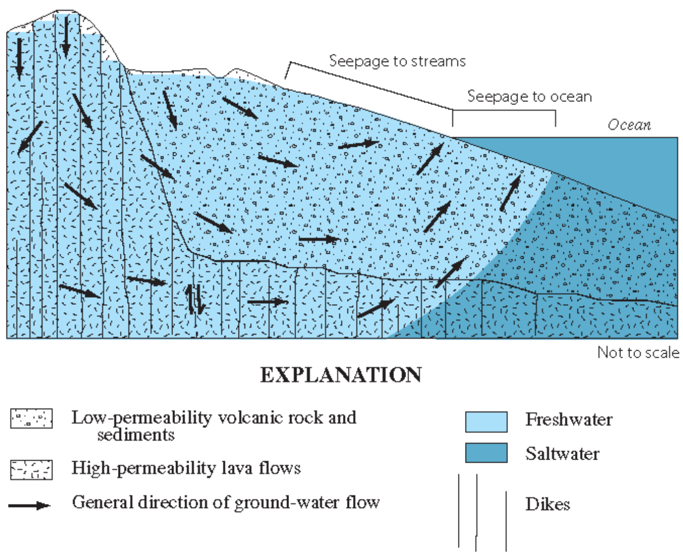
Ground water is an important component of streamflow as it constitutes the base flow[1] of Hawaiian streams. When ground water is withdrawn from a well, the water level in the surrounding area is lowered. Nearby wetlands or ponds may shrink or even dry up if the pumping rate is sufficiently high (Gingerich and Oki, 2000). The long-term effects of ground water 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 ground water warrants a close look at the ground water recharge and demand within the State as well as the individual hydrologic units.

In Hawaii, ground water 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 fresh ground water systems: 1) fresh water-lens system; 2) dike-impounded system; and 3) perched system. The fresh water-lens system provides the most important sources of ground water. It includes a

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

lens-shaped layer of fresh water, an intermediate transition zone of brackish water, and underlying salt water. A vertically extensive fresh water-lens system can extend several hundreds or even thousands of feet below mean sea level. By contrast, a dike-impounded system is found in rift zones and caldera of a volcano, where low-permeability dikes compartmentalize areas of permeable volcanic rocks, forming high-level water bodies. On Kauai, dikes impound water to as high as 3,300 feet above mean sea level. A perched system such as the Alakai Swamp 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 (Gingerich and Oki, 2000).

Figure 3-1. Diagram illustrating the ground water system of Lihue Basin, Kauai. Arrows indicate general direction of ground water flow (Source: Izuka 2006).



The hydrologic unit of Wailua almost completely occupies the Wailua aquifer system. A general overview of the ground water occurrence and movement in the Lihue Basin is described in Izuka (2006) and illustrated in Figure 3-1. Ground water is found in perched and dike-impounded structures of Koloa Volcanics as well as in the fresh water-lens system making up the basal aquifer in Waimea Volcanics. Withdrawal from wells at or below sea level should not affect the high-elevation water table because the thick unsaturated zone will prevent any significant changes in the vertical flow gradient. However, during certain hydrologic conditions, there may be surface water-groundwater interactions, especially in the gaining reaches. A summary of the wells registered in the Wailua hydrologic unit is provided by Table 3-1 with their locations identified in Figure 3-2. As of 2008, the Wailua aquifer's sustainable yield is estimated to be 43 mgd. Current reported installed pump capacity is 5.658 mgd with the calendar year 2017 12-month moving average of 0.348 mgd.

The West Branch of the North Fork Wailua (i.e., Waialeale Stream) is a gaining stream from its headwaters (Bluehole region of Waialeale) to the confluence with the East Branch of the North Fork (Figure 3-4). The Waikoko Stream is gaining above the Iliiliula-North Wailua Ditch as well as below the ditch at least to the confluence with the Iliiliula Stream (Figure 3-4).

Table 3-1. Information for wells as of January 2018 located in the Wailua hydrologic unit, Kauai (Source: State of Hawaii, Commission on Water Resource Management, 2018).
[Negative elevation values indicate feet below mean sea level; positive elevation values indicate feet above mean sea level. Pump rate measured in gallons per minute converted to million gallons per day (mgd); 12-MAV = 12 month moving average; -- indicates value is unknown.]

Well number	Well Name	Well Owner	Year drilled	Use	Ground elevation (feet)	Well depth (feet)	Pump elevation (feet)	Pump depth (feet)	Pump rate (mgd)	Current 12-MAV
0123-01	Maalo Road Mon	USGS	2002	OBS	382	910	n/a	n/a	n/a	n/a
0124-01	Ne Kilohana	USGS	1995	OBS	466	1033	n/a	n/a	n/a	n/a
0124-02	Hanamaulu 3	Kauai DWS	1998	MUN	467	560	7	460	0.230	0.000
0124-03	Hanamaulu 4	Kauai DWS	2002	MUN	467	467	239	228	0.432	0.017
0126-01	NW Kilohana Mon	USGS	1996	OBS	678	1004	n/a	n/a	n/a	n/a
0221-01	Fern Grotto 1	State Parks	1986	UNU	17	61	--	--	--	--
0221-02	Fern Grotto 2	State Parks	1991	OTH	--	36	--	--	0.040	--
0221-05	Opaekaa 2	Benjamin Garfinkle	2007	UNU	297	430	--	--	--	--
0222-01	Aahoaka Mon	USGS	2002	OBS	313	804	n/a	n/a	n/a	n/a
0222-02	Hanamaulu	ADC	2006	IRR	500	1180	--	--	--	--
0320-01	Nonou 9-1A	Kauai DWS	1960	UNU	155	240	--	--	0.650	0.000
0320-02	Wailua	SOH DOA	1952	UNU	90	230	--	--	--	--
0320-03	Nonou 9-1B	Kauai DWS	1970	MUN	157	302	--	--	1.430	0.134
0321-01	Nonou 9-1C	Kauai DWS	1971	MUN	72	275	--	--	1.440	0.203
0321-02	Allen	Greg Allen	2006	DOM	7	235	--	126	0.043	0.000
0321-03	Flow	Dwain Hill	2010	IRR	390	430	--	--	0.173	--
0323-01	Wailua-Smith	Gregory Smith	1993	UNU	462	230	n/a	n/a	n/a	--
0323-03	Kawaikini Estates	Eric Braun	2007	UNU	448	200	--	--	--	--
0323-04	Babalou	Robert Soares	2007	DOM	456	200	296	160	0.010	--
0327-01	Waikoko Monitoring	USGS	2003	OBS	1006	605	n/a	n/a	n/a	n/a
0421-01	Wailua Homesteads 1	Kauai DWS	1972	MUN	462	568	-9	471	0.720	0.062
0421-02	Wailua Homesteads B	Kauai DWS	1985	MUN	460	560	-17	477	0.720	0.066

Streamflow Characteristics

North Fork Wailua

Ditch flow (the amount of water diverted from Waialeale Stream into the Iliiliula-North Wailua Ditch) was monitored by the USGS from 1932 to 1985 (station #16061000). Ditch flow in the Iliiliula-North Wailua Ditch was also monitored by the USGS after the contribution from Waikoko Stream from 1965 to 2002 (station #16061200) as depicted in Figure 3-3. The exceedance values for these time periods are provided in Table 3-2.

During the plantation era, the Hanalei Tunnel was built to bring water from the headwaters of the Hanalei Watershed into the Wailua Watershed, and a USGS station (station #16100000) monitored that contribution from 1932-1985. Water transmitted by the Hanalei Tunnel contributed to stream flow in the Maheo Stream, a tributary of the West Branch, North Fork Wailua River, until a partial tunnel collapse and discontinuation of maintenance work by Lihue Plantation following hurricane Iniki in 1992. Below the confluence of the Maheo and Waialeale streams, a diversion (REG.687.2) diverted water into the Stable Storm Ditch, which was gaged by the USGS (station #16062000) from 1937 to 2002. This diversion is now abandoned. Below the Stable Storm Ditch intake, USGS measured streamflow at an altitude of 650ft (station #16063000) from 1914 to 1985. Ditch Flow duration exceedance values for these stations are provided in Table 3-2. Lihue Plantation monitored ditch flow at the Upper Waiahi power-house from 1936 to 1938 (3 complete years), from the tailrace (Iliiliula Cut-off Ditch) of the Upper Waiahi power-house from 1927 to 1931 (3 complete years), and ditch flow at the Lower Waiahi powerhouse from 1927 to 1938 (10 complete years). Using the equivalent overlapping natural stream flow from the USGS EB NF Wailua gaging station (#16068000), mean and median flow statistics calculated from monthly mean flow for each station were converted to the current climate period (1984-2013) based on the percent decline in natural flow (Table 3-3).

Table 3-2. Selected flow duration discharge exceedance values for continuous-record gaging stations for ditches in the Wailua hydrologic unit, Kauai. (Source: Cheng 2016; USGS 1939)
[Flows are in cubic feet per second (million gallons per day)]

Station ID	name	Period of Record	Discharge (Q) for a selected percentage ($_{xx}$) discharge was equaled or exceeded				
			Q_{50}	Q_{60}	Q_{70}	Q_{80}	Q_{90}
16100000	Hanalei Tunnel	1937-2002	28.0 (18.1)	25.0 (16.2)	20.0 (12.9)	13.0 (8.4)	3.1 (2.0)
16061000	Iliiliula-North Wailua Ditch	1932-1985	19.0 (12.3)	18.0 (11.6)	17.0 (11.0)	16.0 (10.3)	14.0 (9.0)
16061200	Iliiliula-North Wailua Ditch blw Waikoko Intake	1965-2002	21.0 (13.6)	21.0 (13.6)	20.0 (12.9)	18.0 (11.6)	16.0 (10.3)
16062000	Stable Storm Ditch	1936-2002	0.28 (0.18)	0.12 (0.08)	0.04 (0.03)	0.0 (0.0)	0.0 (0.0)
16069000	Wailua Ditch	1936-2002	15.0 (9.7)	12.0 (7.8)	8.2 (5.3)	4.3 (2.8)	1.0 (0.60)
16057000	Upper Lihue Ditch	1925-1938	30.0 (19.4)	26.5 (17.1)	23.2 (15.0)	20.1 (13.0)	13.5 (8.7)
16058000	Hanamaulu Ditch	1910-1938	33.4 (21.6)	28.6 (18.5)	21.3 (13.8)	12.5 (8.1)	4.7 (3.0)

Historic natural low-flow characteristics from USGS gaged stations are provided in Table 3-3. Dike-impounded and perched groundwater supports continuous flow throughout the Wailua Watershed with springs at the base of ridges emanating from Waialeale Mountain supporting reaches with continuous gains in surface flows (Figure 3-4). The long-term continuous natural stream flow monitoring stations maintained by the USGS are on the East Branch of the North Fork Wailua River (station 16068000) and on Opaekaa Stream (station 16071500). Natural-flow duration discharges were estimated for the current climatic period (1984-2013) at select stations as provided in Table 3-4. From 2016 to 2018, a low-flow partial record gaging station was established at station 220346159280601 on the West Branch of the North Fork Wailua (i.e., Waialeale Stream) and on the two branches of Waikoko above the Iliiliula-North Wailua Ditch (220326159275401 and 220325159275401 with an index station on the East Branch of the North Fork Wailua (station 16068000). Using flow measurements with a record extension technique, estimates of flow duration discharges were derived in Table 3-5. Selected flow duration discharges based on diverted flow data (USGS station 16061000 and 16061200) for the current climate period (1984-2013) were generated for comparison as well (Table 3-6). Waialeale Stream at the 1,100 ft elevation (at the Iliiliula-North Wailua Ditch intake) contributes about 41% of the median flow to the West Branch North Fork as measured at station 16063000 at 650 ft elevation.

Table 3-3. Mean and median ditch and stream flow discharge values at Lihue Plantation gaging stations for various periods of record in the Wailua hydrologic unit and values corrected for the current (1984-2013) climate period based on natural flows at USGS 16068000. (Source: USGS 1939) [Flows are in million gallons per day]

station name	Period of Record	Period of Record		1984-2013		USGS 16068000	
		Mean	Median	Mean	Median	Mean	Median
Upper Waiahi Powerhouse Ditch	1936-1938	18.63	18.70	16.88	14.75	32.45	22.94
Lower Waiahi Powerhouse Ditch	1932-1938	17.76	15.18	19.81	16.84	29.12	20.68
Waiahi Stream at 600 ft	1932-1938	37.25	32.55	37.61	28.48	29.12	20.68

Table 3-4. Selected natural low-flow duration discharge exceedance values for continuous-record streamflow gaging stations corrected for the current (1984-2013) climate period in the Wailua hydrologic unit, Kauai. (Source: Cheng 2016)
[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_{60}	Q_{70}	Q_{80}	Q_{90}
16068000	EB NF Wailua	27 (17.5)	24 (15.5)	21 (13.6)	18 (11.6)	15 (9.69)
16071500	LB Opaekaa Stream	1.3 (0.84)	1.1 (0.71)	0.89 (0.58)	0.74 (0.48)	0.58 (0.37)
16063000	NF Wailua nr 650 ft	43 (27.8)	38 (24.6)	34 (22.0)	29 (18.7)	25 (16.2)

Table 3-5. Selected natural low-flow duration discharge exceedance values for partial-record streamflow gaging stations for which record augmentation was used to estimate duration discharges for the Wailua hydrologic unit, Kauai. (Source: USGS 2018) [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_{60}	Q_{70}	Q_{80}	Q_{90}
220346159280601	WB NF Wailua	23.0 (14.88)	21.2 (13.69)	18.8 (12.12)	16.8 (10.87)	14.8 (9.54)
220326159275401	NF Waikoko	4.4 (2.86)	3.8 (2.45)	3.0 (1.95)	2.5 (1.59)	1.9 (1.24)
220325159275401	SF Waikoko	1.4 (0.93)	1.2 (0.78)	0.94 (0.61)	0.74 (0.48)	0.56 (0.36)
Waikoko (combined)		5.9 (3.8)	5.0 (3.2)	4.0 (2.6)	3.2 (2.1)	2.5 (1.6)

Other methods may be employed to estimate streamflow characteristics, including using basin characteristics to estimate median total discharge (Fontaine et al. 1992), ditch gaging records adjusted by the percent declines in stream flow at an index station, the mean baseflow index at nearby stations, or present day ditch monitoring (Table 3-7)

Table 3-6. Selected natural low-flow duration discharge exceedance values based on estimates from ditch flow gaging stations in the Wailua hydrologic unit converted to the current (1984-2013) climate period. (Source: USGS 2018)
[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_{60}	Q_{70}	Q_{80}	Q_{90}
16061000	WB NF Wailua	17.7 (11.5)	17.2 (11.4)	16.2 (10.5)	15.2 (9.8)	13.1 (8.5)
16061200	Waikoko	3.9 (2.5)	2.9 (1.9)	1.9 (1.3)	1.9 (1.3)	0.63 (1.0)

Differences in discharges between historic and current periods are likely due to differences in the phases of the Pacific Decadal Oscillation in which the data were collected as well as the completeness of the actual datasets.

Long-term daily flow statistics for the West Branch of the North Fork (USGS 16063000) indicate that there is a median flow of 43.0 cubic feet per second (27.8 million gallons per day) at an elevation of 640ft. Thus Wai‘ale‘ale Stream (median flow of 17.7 cubic feet per second, 11.5 million gallons per day) contributes approximately 41% of this flow, with groundwater gains and contributions from other tributaries contributing the rest. Using point measurements from a USGS seepage run in 1982 that included ditch flows on the Kanaha and Wailua Ditches, the West Branch (31.4 cubic feet per second) contributes approximately 46% and the East Branch (37.0 cubic feet per second) contributes approximately 54% of the total flow below the confluence of the East and West branches of the North Fork Wailua River (69.8 cubic feet per second). Median streamflow at USGS station 16071000 on the North Fork Wailua (elevation 33 feet) above the confluence with the South Fork from 1952 to 2003 (during the plantation era when diversions were operated) was 64 cubic feet per second (41.3 million gallons per day).

Table 3-7. Estimated flow values using various statistical methods for Wai‘ale‘ale Stream (Tributary of the North Fork Wailua River) at the Bluehole Intake on the ‘Ili‘ili‘ula-North Wailua Ditch (i.e., at 1,100 ft elevation). Total flow includes the contributions of runoff and baseflow while baseflow is the groundwater contribution alone; Q50 = median flow; Q70 = 70th percentile magnitude flow [cubic feet per second (million gallons per day)]

method	**Total Flow Q50**	**Total Flow Q70**	**Baseflow Q50**	**64% of Baseflow Q50**
USGS ditch gage record corrected for current (1984-2013) climate period based on 5.2% decline in total flow at Index[1]	18.01 (11.64)	16.11 (10.42)		
Equation from Fontaine et al. (1992) USGS Report 92-4099	14.90 (9.63)			
Statistics converted using unit discharge of USGS 16068000 and USGS 16063000 based on means of drainage area and mean annual precipitation	19.72 (12.75)	15.44 (9.98)	13.65 (8.82)	10.38 (6.71)
Statistics converted using mean baseflow index of USGS 16068000 and USGS 16063000 stations			8.72 (5.64)	5.58 (3.60)
Preliminary MOVE.1 Model results using USGS 16068000 as an Index Station (only 7 measurements available)	23.75 (15.35)	20.98 (13.56)		
KIUC/ITC Ditch monitoring from June 2017-February 2018[1]	21.55 (13.93)	19.51 (12.61)		

[1] doesn't include days when the ditch was plugged by debris due to high flow events

Long-term trends in flow

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 3-5 illustrates the results of the study for 7 long-term gaging stations around the islands. According to the analyses, low flows generally decreased from 1913 to 2002, which is consistent with the long-term downward trends in rainfall observed throughout the islands during that period. Monthly mean base flows decreased from the early 1940s to 2002, which is consistent with the measured downward trend of low flows from 1913 to 2002. This long-term downward trend in base flow may imply a reduction of ground water contribution to streams. For example, in the East Branch of the North Fork Wailua River (USGS station 16068000) mean annual streamflow has declined from 1913 to 2016 by about 9%. At this station, the 10-year moving average annual streamflow was 50.8 cfs (32.9 mgd) in 1930 and 43.1 cfs (27.8 mgd) in 2016. This mirrors the long-term decline in rainfall at higher elevations (Bassiouni & Oki, 2012). Declines in mean annual rainfall will alter natural stream flow regimes, with increases in the number of low flow days and stream flow variability (Strauch et al. 2015). Changing streamflow characteristics could pose a negative effect on the availability of drinking water for human consumption and habitat for native stream fauna (Oki, 2004).

Figure 3-2. Aquifer system area and well locations (with well numbers) of the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015d; State of Hawaii, Commission on Water Resource Management, 2015f)

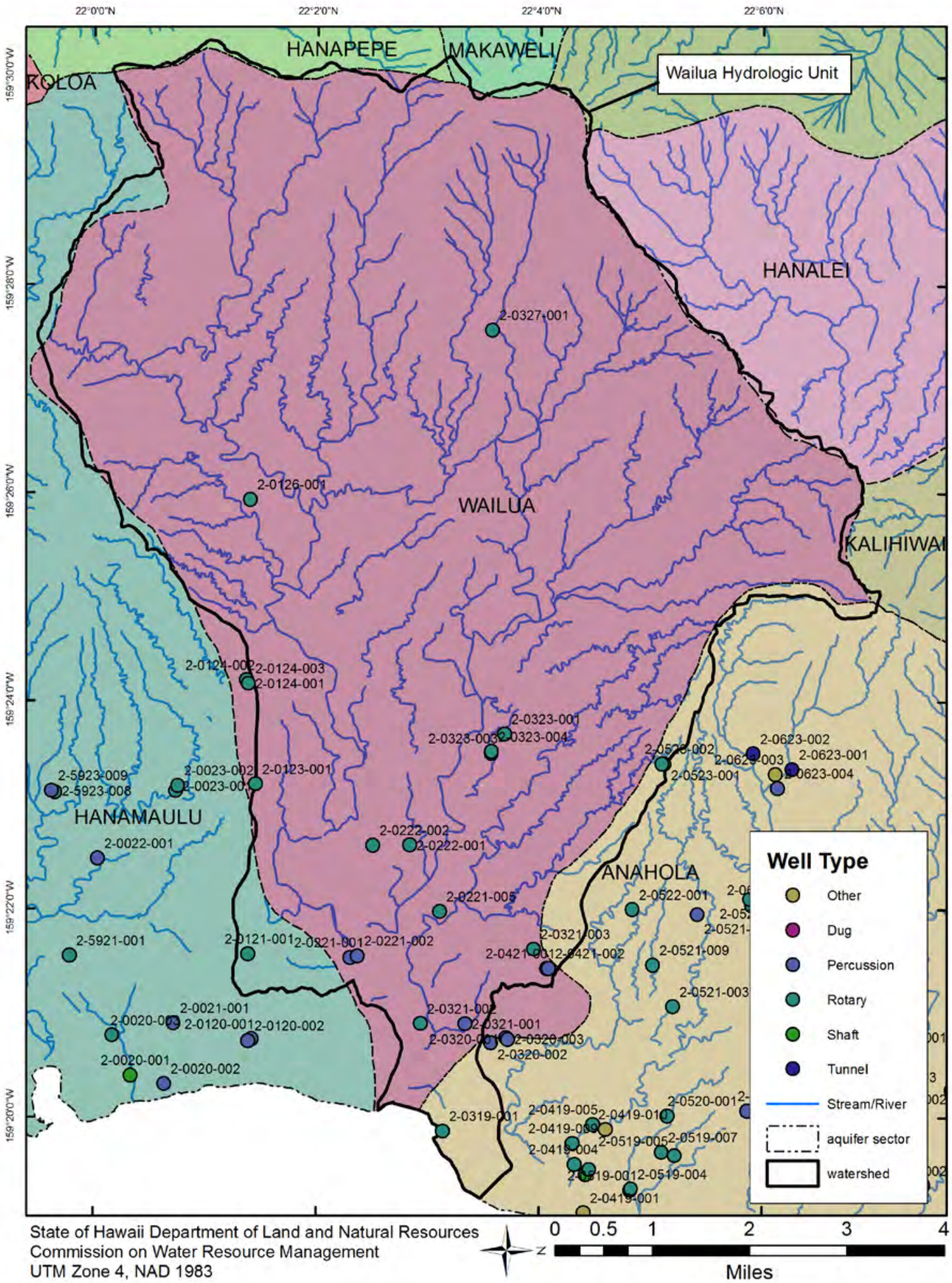


Figure 3-3. Location of all US Geological Survey surface water monitoring stations in streams and ditches for the Wailua hydrologic unit, Kauai. (Source: USGS, 2001)

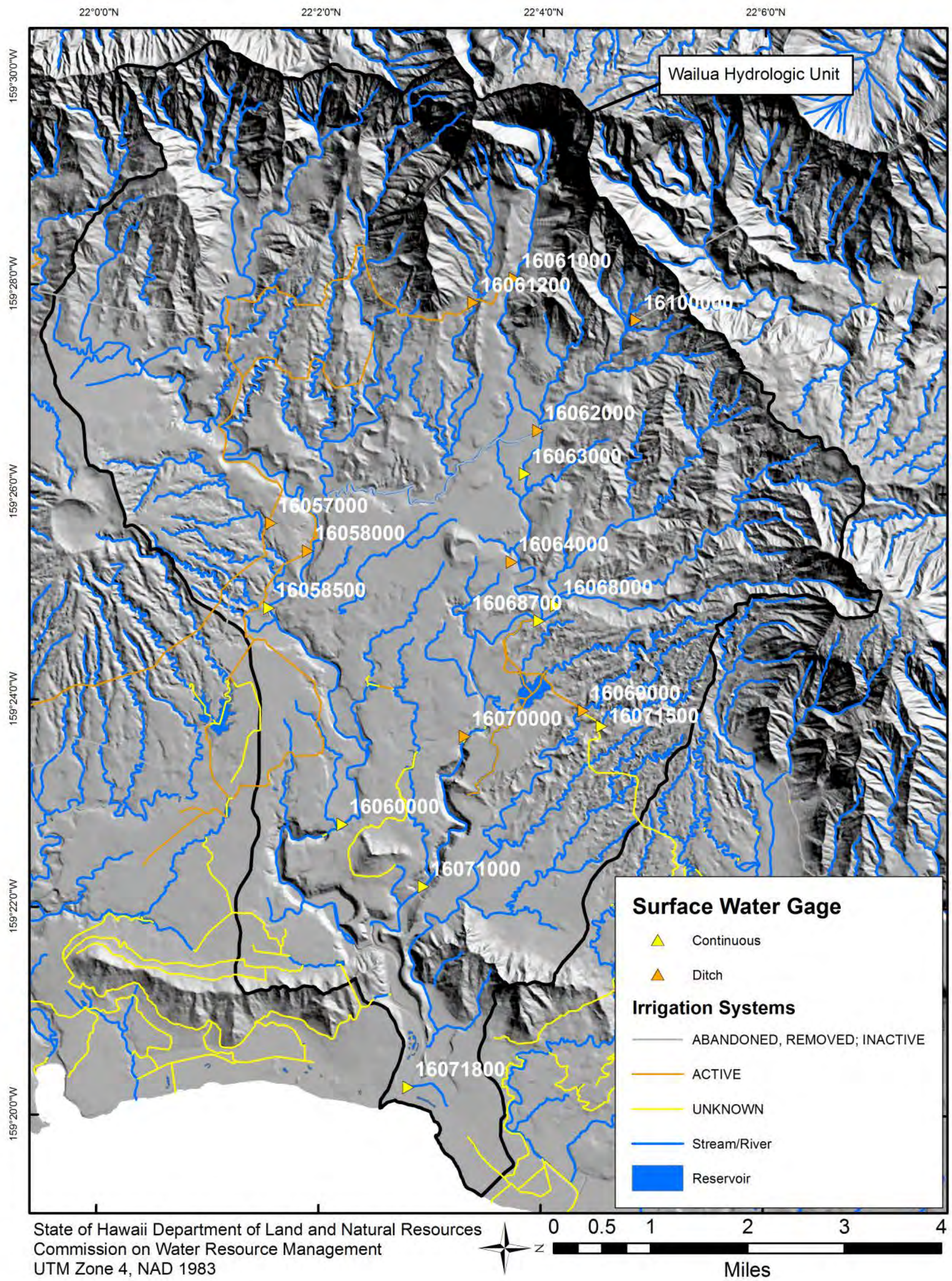


Figure 3-4. Selected natural median flow estimates at continuous-record gaging stations for Waikoko Stream and the West Branch of the North Fork Wailua River as well as seepage run results (in million gallons per day per mile) (Source: Cheng 2016, USGS 2018).

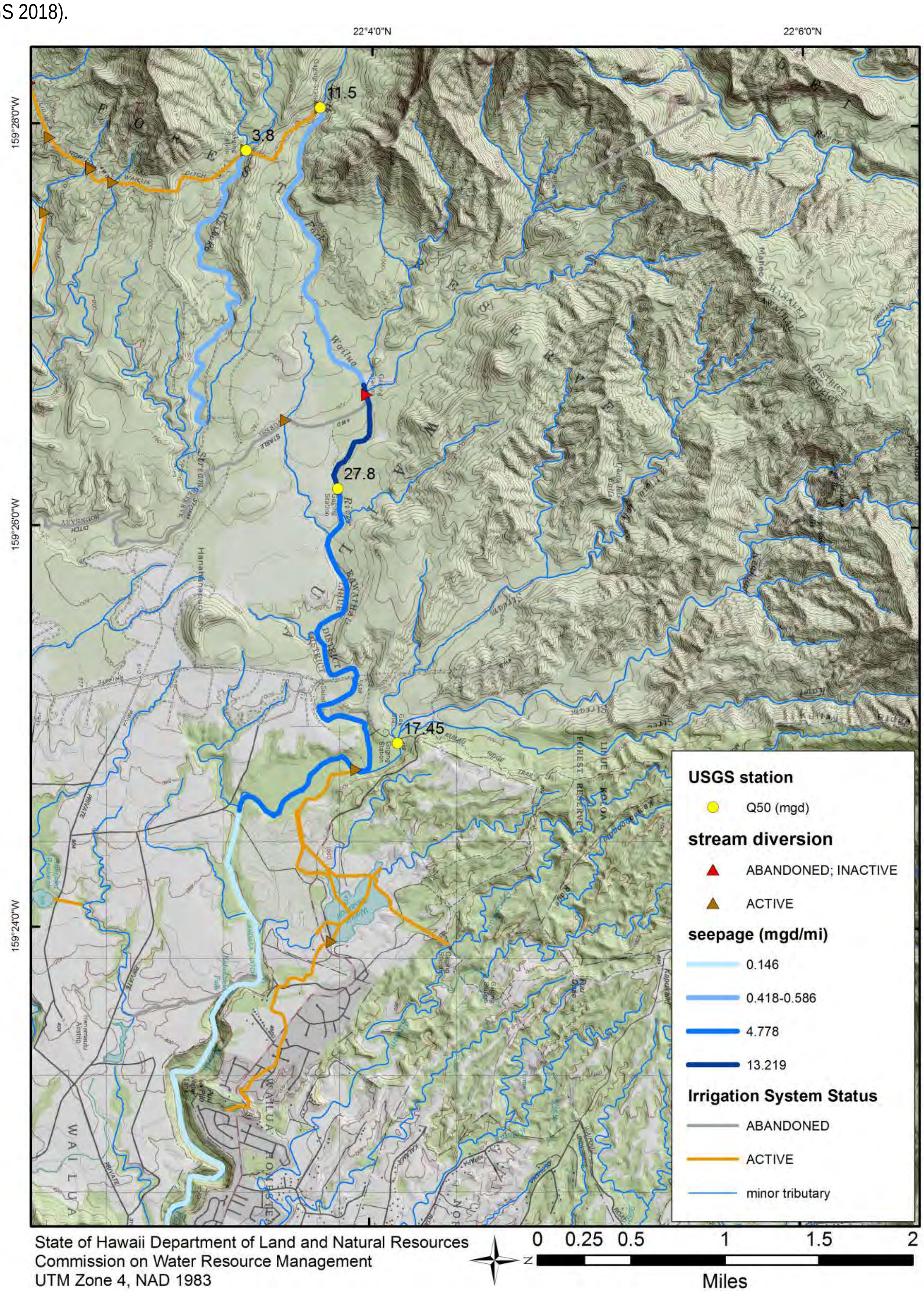
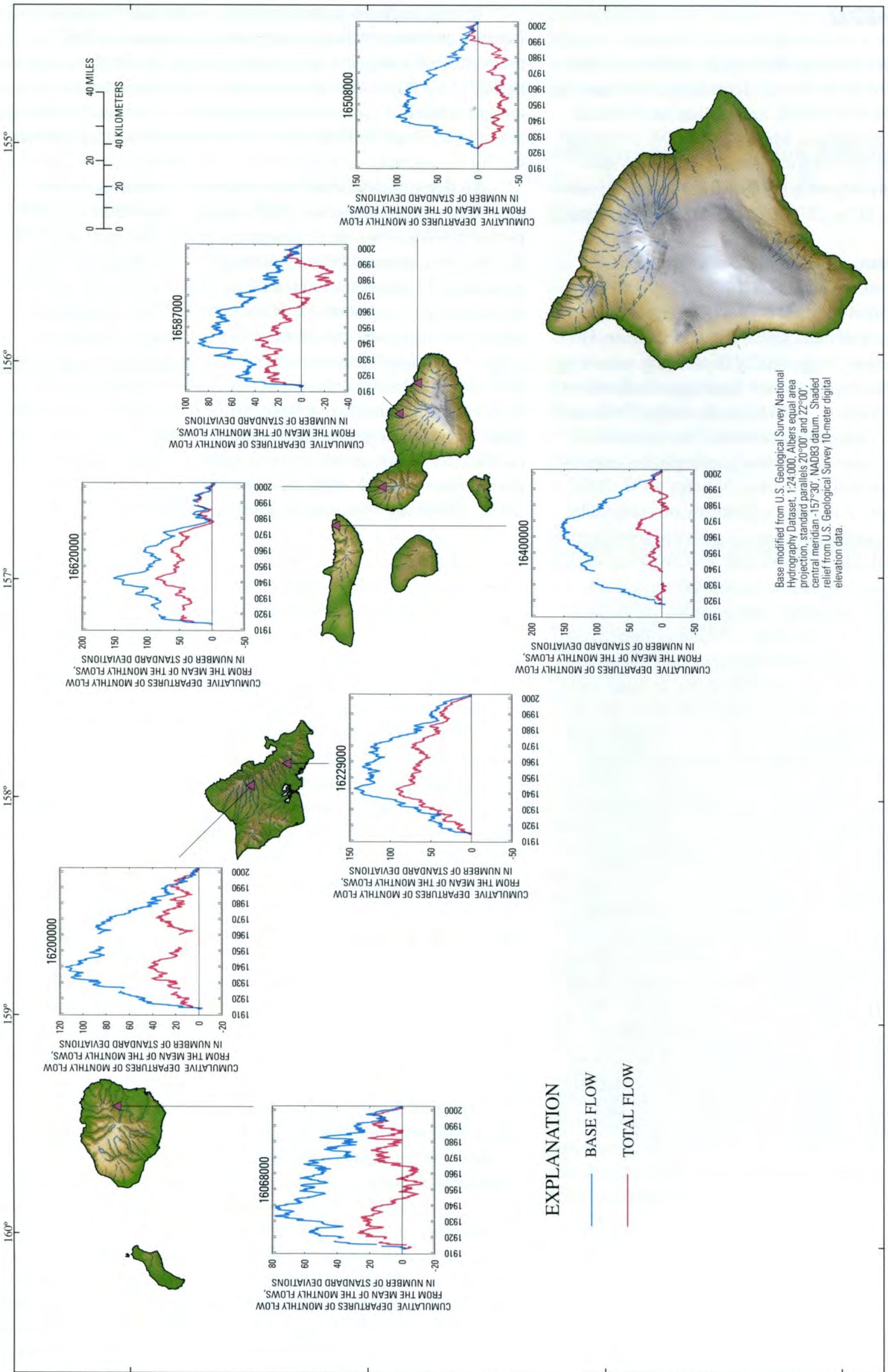


Figure 3-5. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii. This data is based on complete water years from 1913 through 2002. (Oki, 2004, Figure 4)



4.0 Maintenance of Fish and Wildlife Habitat

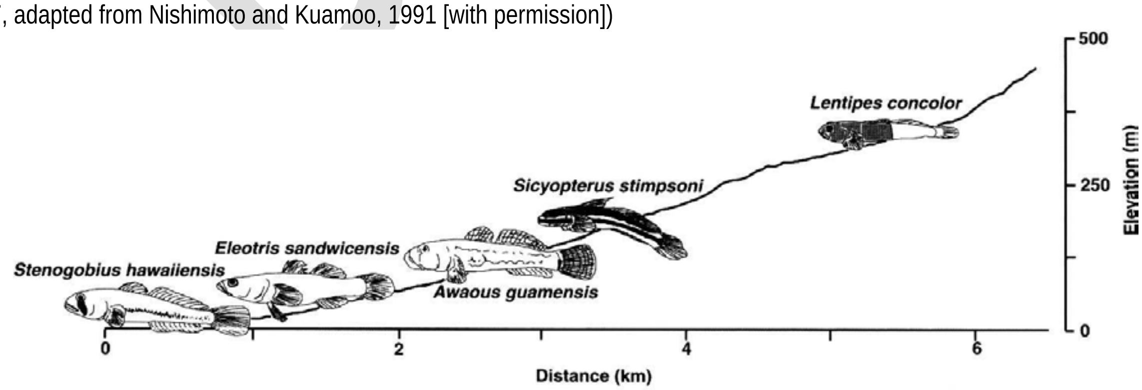
When people in Hawaii consider the protection of instream flows for the maintenance of fish habitat, their thoughts generally focus on just a handful of native species including five native fishes (four gobies and one eleotrid), two snails, one shrimp, and one prawn. Table 4-1 below identifies commonly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

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])



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.

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, channelization, 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 Wailua River System be listed as a candidate streams for protection based on its diversity and "blue ribbon" riparian, cultural and recreational resources. Furthermore, Wailua was given a moderate rank for aquatic resources with a number of group one native species including: nakea (*Awaous stamineus*), nopili (*Sicyopterus stimpsoni*), and hihiwai (*Neritina granosa*) with six group two native species.

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 atlas 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 Wailua Stream is in Appendix A. The following is a brief summary of findings.

- **Point Quadrat Survey.** In Wailua, the native freshwater shrimp *Atyoida bisulcata* was observed in the lower, middle, and upper reaches and the endemic freshwater prawn *Macrobrachium grandimanus* was observed in the estuary and lower reaches. Endemic fish observed in the estuary and lower reaches include *Eleotric sandwicensis* and *Sicyopterus stimpsoni*, and *Awaous* *guamensis*, with *A. guamensis* also found in the middle and upper reaches. No native fish were observed in the headwaters of Wailua, even in undiverted streams. Introduced Tahitian prawn (*Machrobrachium lar*), *Tilapia sp.*, smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*) are commonly found throughout the watershed.

- **Insect Survey.** Wailua does not meet the DAR qualification for streams of biotic importance based on native insect diversity (>19 spp) but did for native macrofauna diversity (>5 spp.). Wailua supports an abundance of native dragonflies (*Anax junius*) and native damselflies (*Megalagrion spp.*). No native damselfly on Kauai is currently proposed for listing as Endangered under the federal Endangered Species Act. Streamflow restoration may increase insect biota diversity.

- **Watershed and Biological Rating.** The Wailua watershed rates above average for Kauai and above average statewide for land cover and shallow waters but poorly on stewardship. The Wailua watershed rates high in size, average in wetness, and high in reach diversity, giving it a high watershed rating. The high number and diversity of native species found throughout the watershed gives it a higher than average native species rating but the abundance of introduced genera led to a relatively low total biological rating.

There are many registered diversions in the Wailua hydrologic unit altering the availability of instream habitat or the migration of native aquatic fauna during the production of sugarcane, when Lihue Plantation took as much water as possible. However, in the post-plantation era, some water has been kept in the stream. One diversion that was restricting recruitment was the Bluehole intake (REG.716.2) on Waialeale Stream (i.e., West Branch of the North Fork Wailua River). However, damage from vandalism and the current operators management has resulted in continuous flow over the dam since the fall of 2016.

Table 4-2 provides a summary of survey results for native aquatic species in the Wailua hydrologic unit conducted by DAR. While native species inhabit the lower reaches of the Wailua River, few can be found in the middle and upper reaches of its tributaries, primarily as a result of the high density of non-native species (e.g., smallmouth bass, *Micropterus dolomieu*; largemouth bass, *Micropterus salmoides*) that compete with or prey on native species. Native species that have been observed in DAR or other published reports include: *M. gradimanus*, *A. stamineus*, *S. stimpsoni*, *A. bisulcata*, *S. hawaiiensis*, *E. sandwincensis*. The distributions of observations of native species by year are presented in Figures 4-2 to 4-7. The distribution of observations of non-native species by species are presented in Figure 4-8.

Table 4-2. Number of sites (% of total surveyed) in Wailua hydrologic unit with identified species and the mean (standard deviation, s.d.) number by survey year based on 71 (2004) 11 (2013) point-quadrat survey methods. (Source: State of Hawaii Division of Aquatic Resources, 2017)

	2004		2013	
	Sites	Mean (s.d.)	Sites	Mean (s.d.)
Atyoida bisulcata	1	2 (n/a)	0	n/a
Macrobrachium grandimanus	0	n/a	0	n/a
Awaous stamineus	10	2.4 (1.26)	0	n/a
Stenogobius hawaiiensis	0	n/a	0	n/a
Eleotris sandwicensis	0	n/a	0	n/a
Sicyopterus stimpsoni	0	n/a	0	n/a
Lentipes concolor	0	n/a	0	n/a
Neritina granosa	0	n/a	0	n/a
Neritina vespertina	0	n/a	0	n/a

Figure 4-2. Location by year of *Atyoida bisulcata* as observed by DAR or other published reports in the Wailua hydrologic unit. (Source: State of Hawaii Division of Aquatic Resources, 2017)

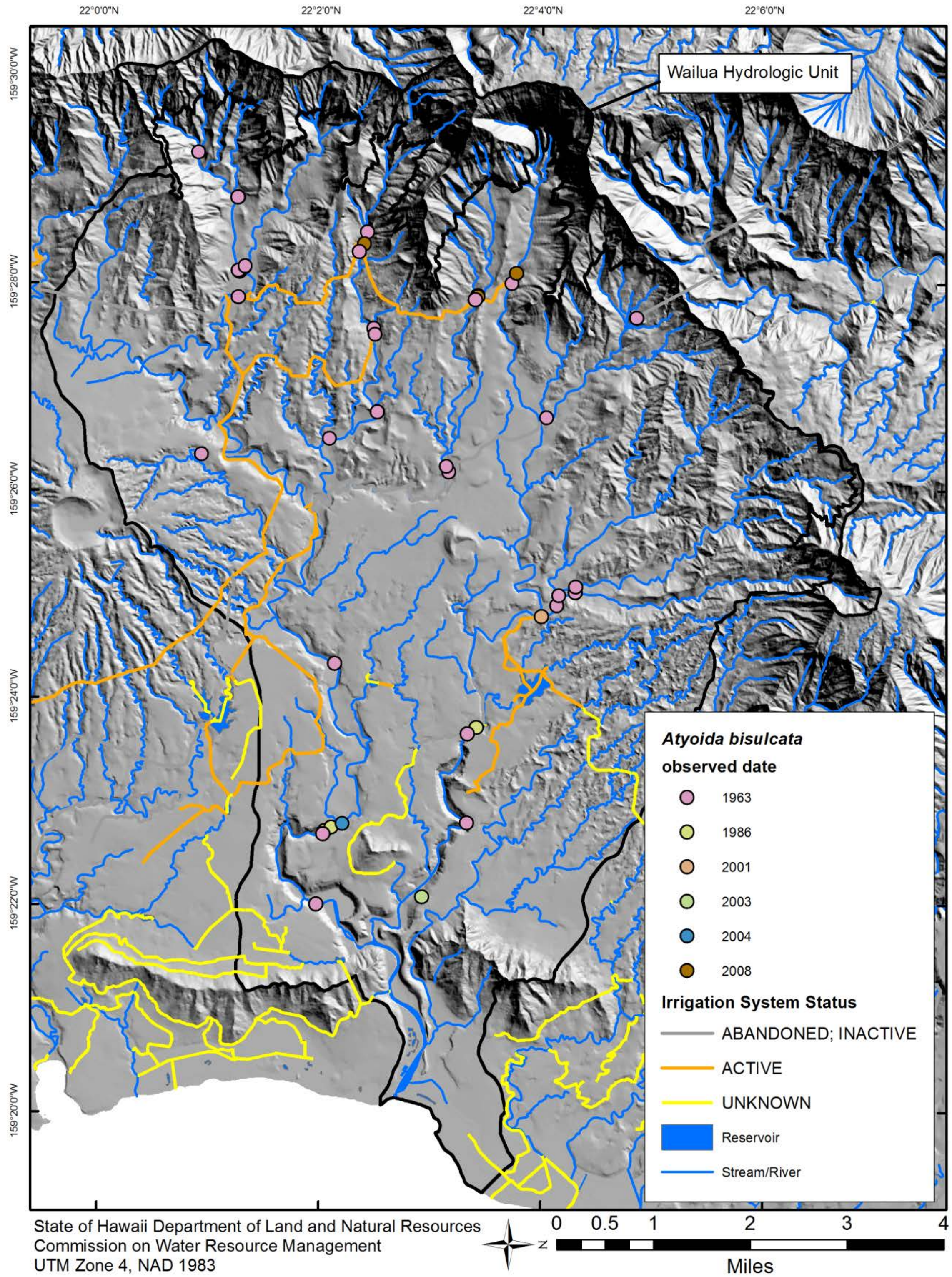


Figure 4-3. Location by year of *Macrobrachium grandimanus* as observed by DAR or other published reports in the Wailua hydrologic unit. (Source: State of Hawaii Division of Aquatic Resources, 2017)

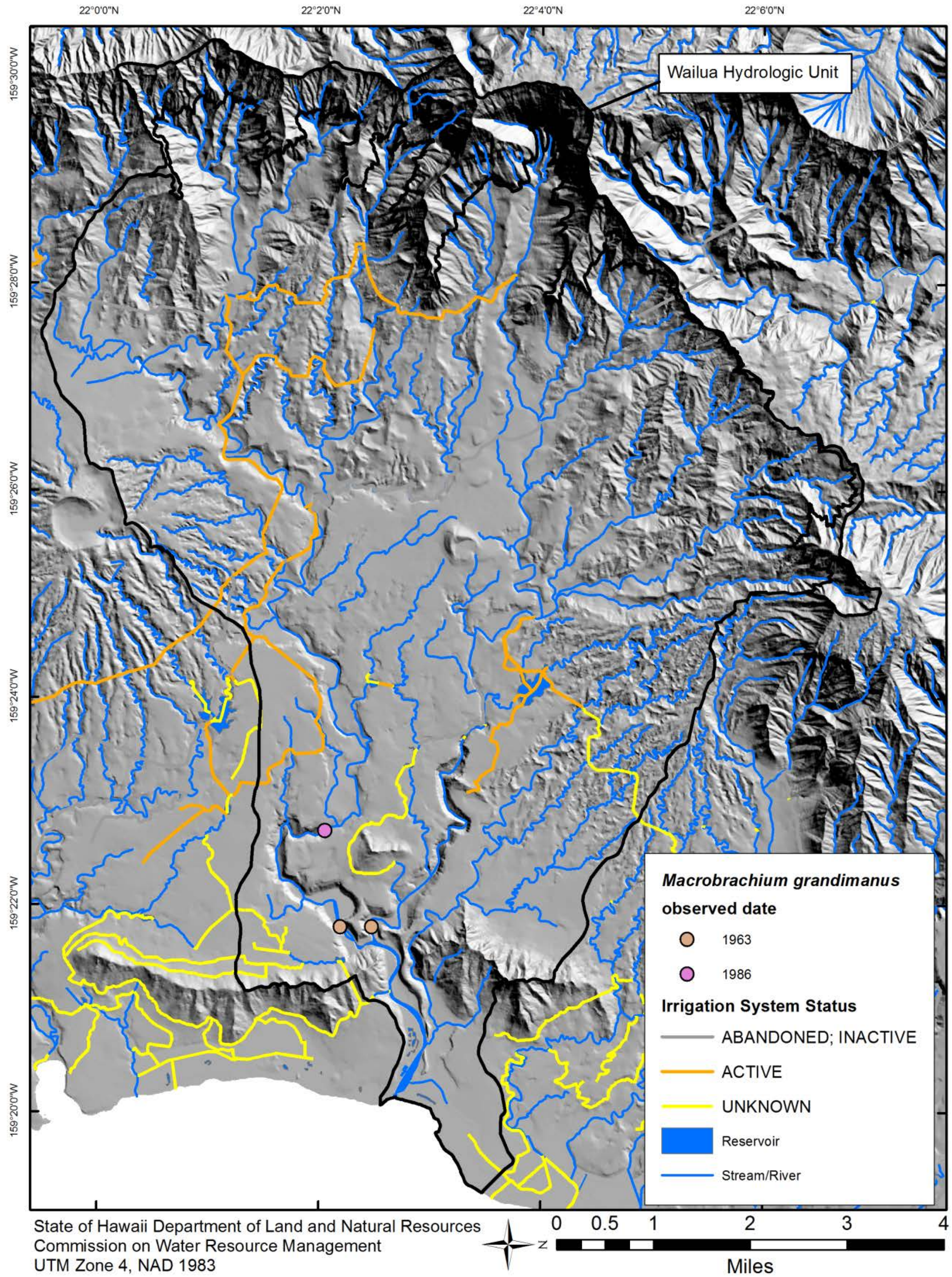


Figure 4-4. Location by year of *Awaous stamineus* as observed by DAR or other published reports in the Wailua hydrologic unit. (Source: State of Hawaii Division of Aquatic Resources, 2017)

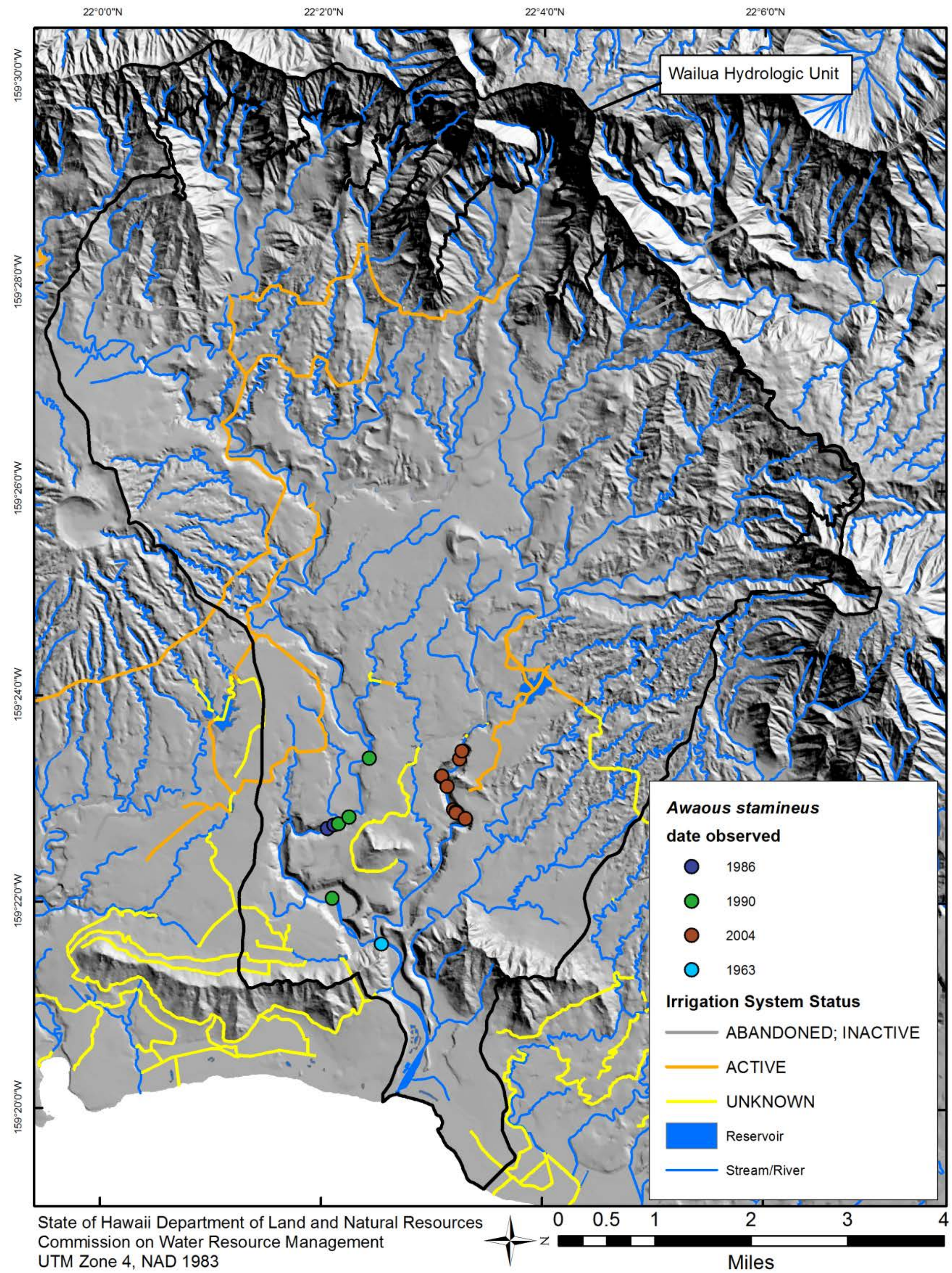


Figure 4-5. Location by year of *Stenogobius hawaiiensis* as observed by DAR or other published reports in the Wailua hydrologic unit. (Source: State of Hawaii Division of Aquatic Resources, 2017)

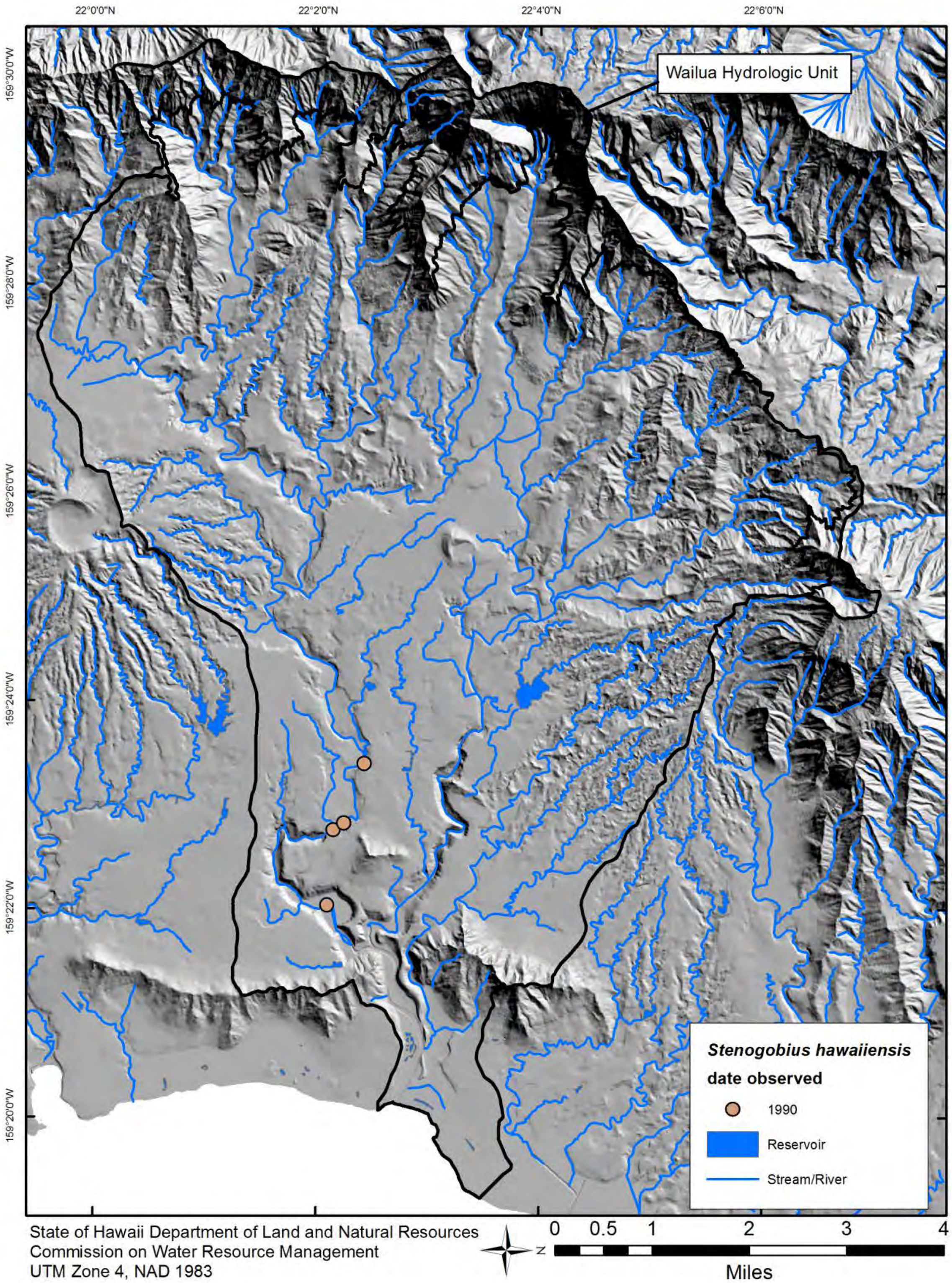


Figure 4-6. Location by year of *Eleotris sandwicensis* as observed by DAR or other published reports in the Wailua hydrologic unit. (Source: State of Hawaii Division of Aquatic Resources, 2017)

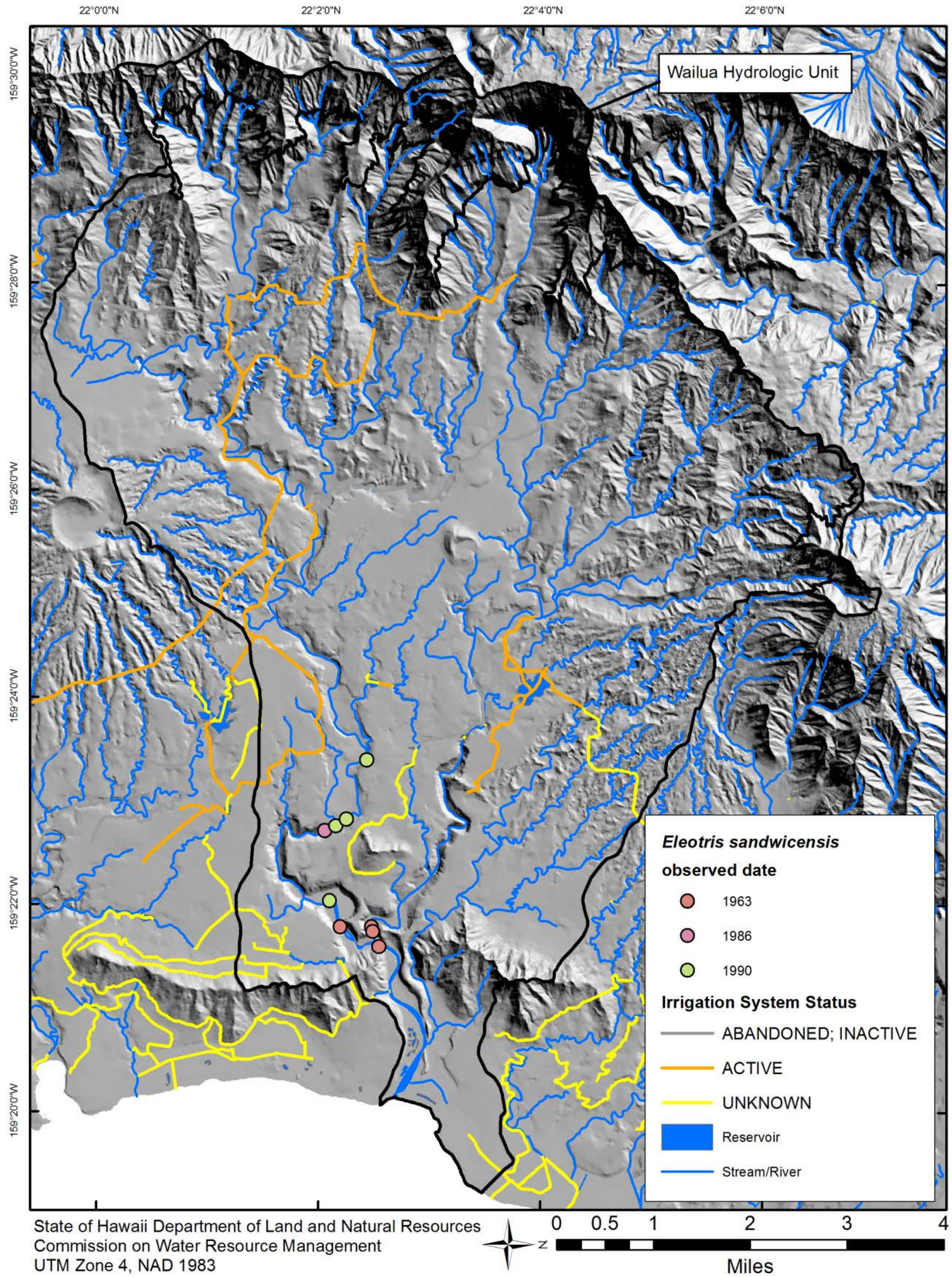


Figure 4-7. Location by year of *Sicyopterus stimpsoni* as observed by DAR or other published reports in the Wailua hydrologic unit. (Source: State of Hawaii Division of Aquatic Resources, 2017)

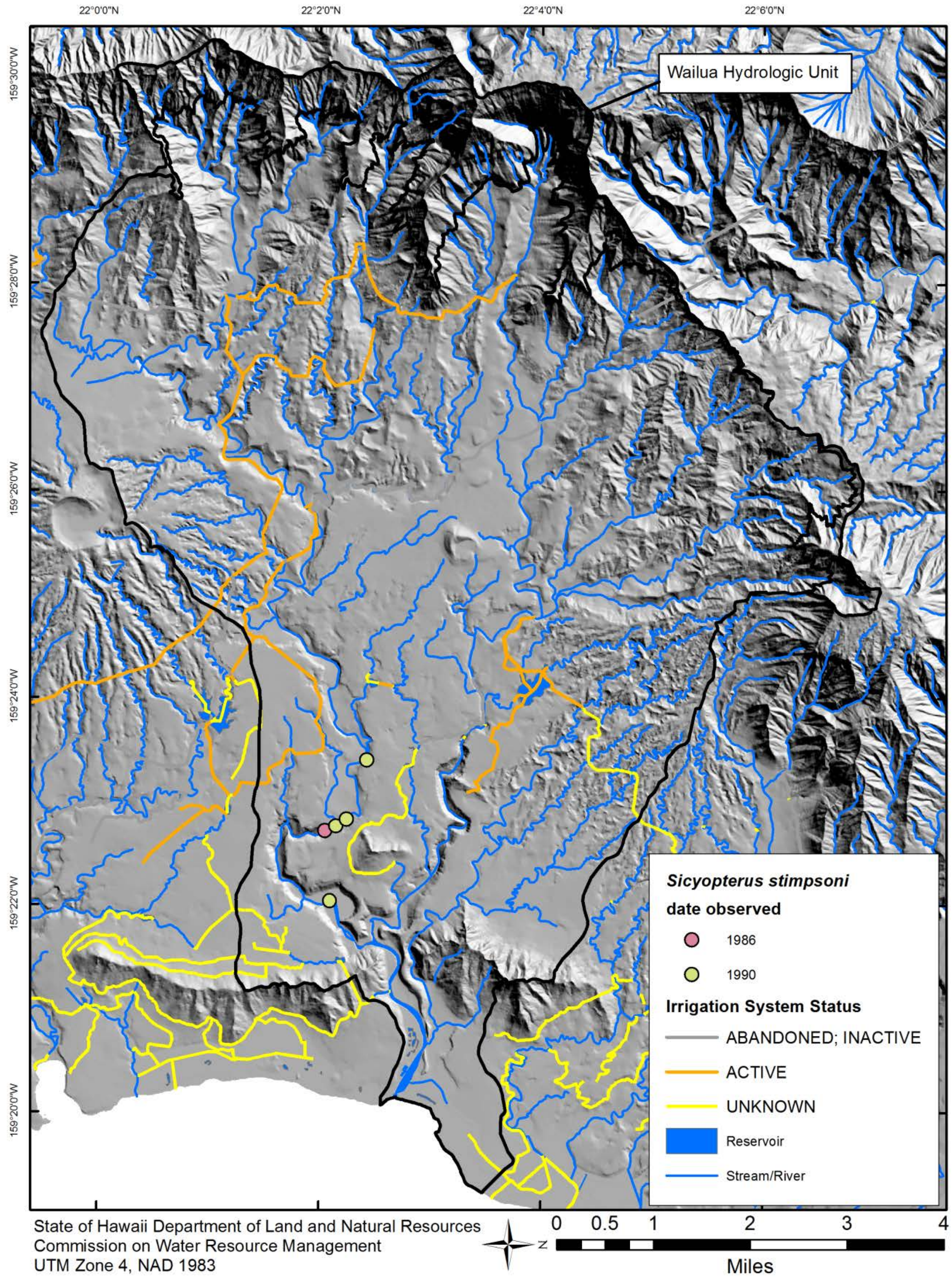
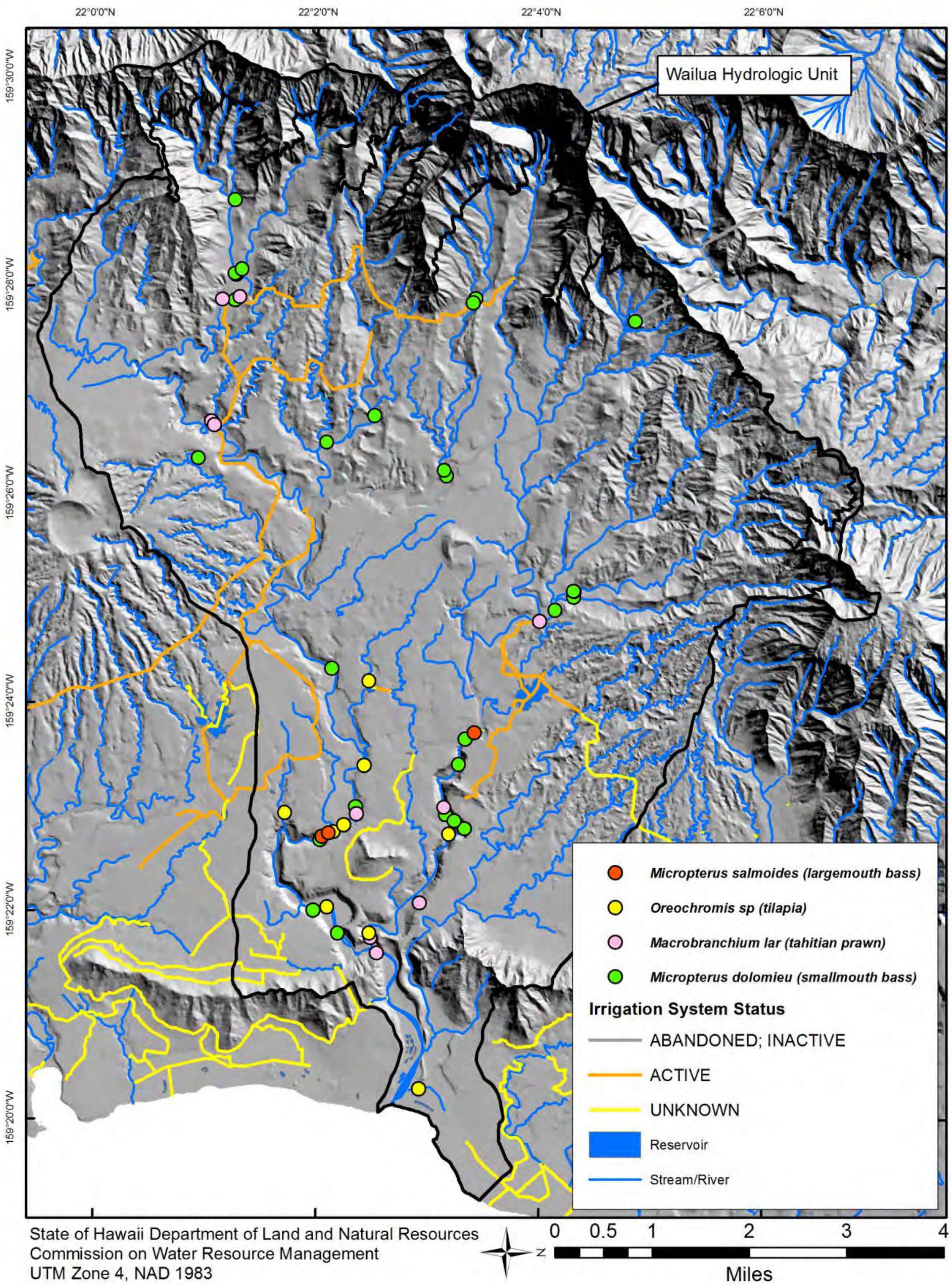


Figure 4-8. Location of aquatic invasive species as observed by DAR or other published reports in the Wailua hydrologic unit. (Source: State of Hawaii Division of Aquatic Resources, 2017)



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 recreational resources of Wailua hydrologic unit were classified as "outstanding" by the HSA's regional recreation committee and ranked as "outstanding" among all watersheds in the state, having recreational opportunities that included hiking, fishing, hunting, swimming and scenic views (National Park Service, Hawaii Cooperative Park Service Unit, 1990). Hiking is enjoyed in the protected areas of watersheds in Hawaii and streams are common features along hiking trails. There are a number of popular state-maintained hiking trails (e.g., Moalepe Trail, Powerline Trail, Wailua Forest Management Road) as well as many unofficial and illegal trails that have been popularized by social media in the headwaters. The Keahua Arboretum provides recreational opportunities and there are a variety of aesthetic points of interest from the Wailua River State Park and Opaekaa Falls State Park.

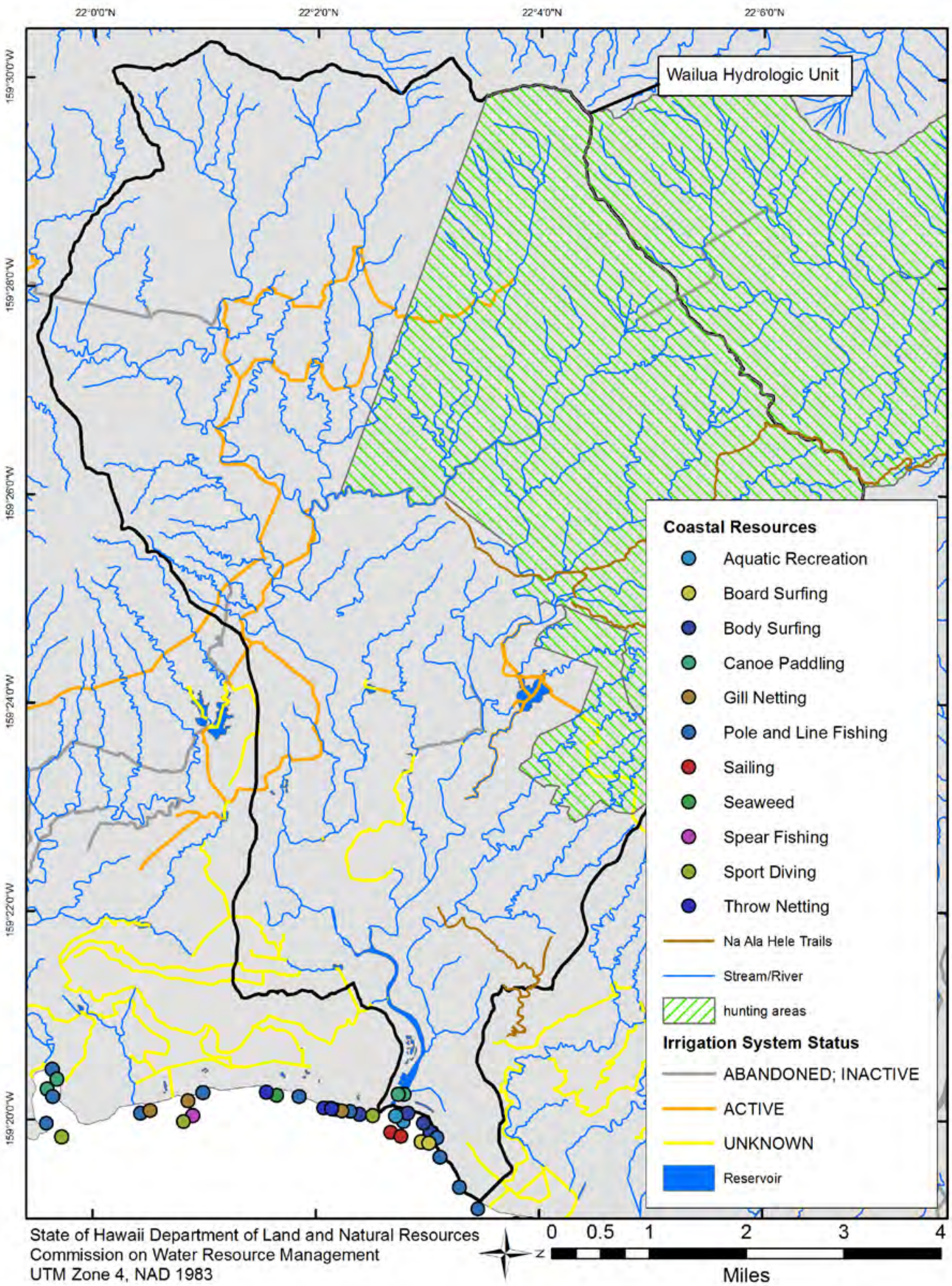
The Iliiliula-North Wailua Ditch itself offers recreational opportunities as many residents utilize the pools creaed by the stream diversions for swimming. People of all ages have floated along the ditch to the Waikoko Stream diversion. Also, there is a popular tour company that offers guided float trips down the Hanamaulu Ditch between the intake on Waiahi Stream and part way to Kapaia Reservoir.

Mammal hunting is permitted in Unit C on the island of Kauai in the state-owned portions of the Lihue-Koloa Forest Reserve that includes the Wailua hydrologic unit as well as the Wailua Game Management Area (Figure 5-1).

Smallmouth bass were introduced in Wailua River for recreational fishing many years ago. Despite the negative consequences of smallmouth bass on native aquatic species, their introduction has contributed to a small freshwater fishing industry that has been featured in national publications (Modoski 2018).

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 Wailua Stream. A 1981 Kauai Resource Atlas, prepared by the State of Hawaii Department of Transportation's Harbors Division, inventoried coral reefs and coastal recreational activities. Looking at available data, the Commission identified the following activities that were known to occur or observed at or near Wailua River: pole and line fishing, gill and throw netting, torch and spear fishing, sport diving, canoe paddling, sailing, seaweed collection, body surfing, and board surfing (Figure 5-1).

Figure 5-1. Coastal resources, official hiking trails, and public hunting areas for game mammals for Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 1999, 2002b; 2002c; 2004a)

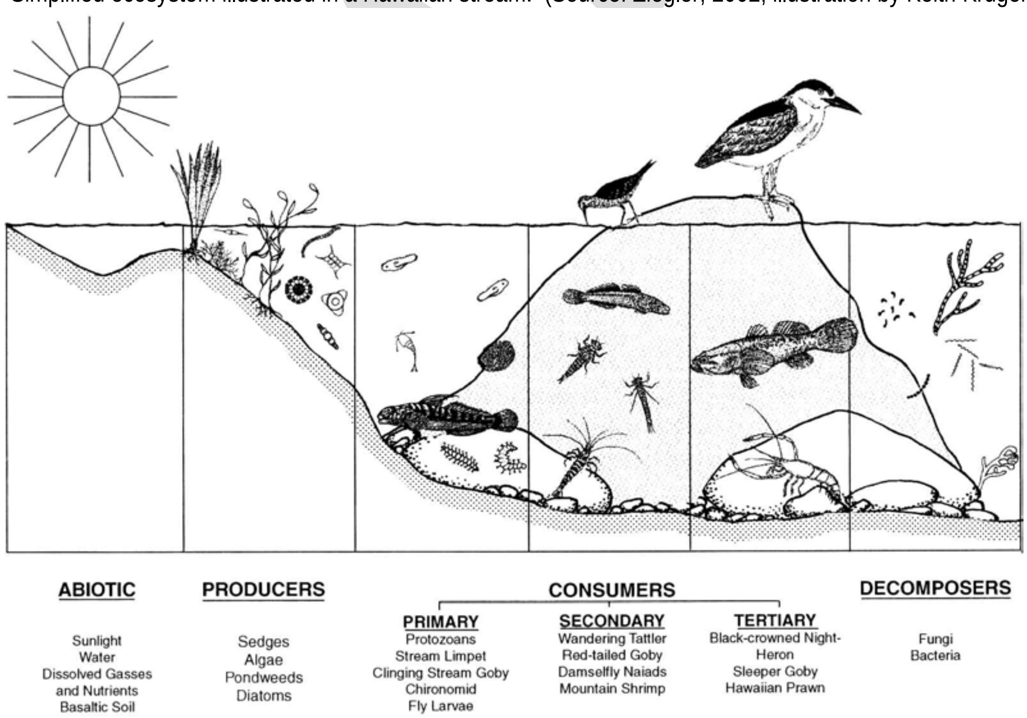


6.0 Maintenance of Ecosystems

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, riparian 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 Wailua Stream deserved to be a candidate stream for protection based on its of Diversity of Resources scoring (outstanding riparian, cultural, and recreational resources) and its Blue Ribbon Resources scoring (outstanding riparian, cultural, and recreational resources). Detrimental organisms (non-native species that have a negative effect on the ecosystem) were not considered in the final ranking; however their presence and abundance are considerable ecosystem variables. A large number of non-native aquatic species inhabit all elevations of the Wailua hydrologic unity and likely prohibit the proliferation of native aquatic fauna to a great degree through predation, competition, and disease transmittance. Further, the destruction to both vegetation and soil resources in the by detrimental organisms is considered a major factor in alterations to the hydrology and water quality of the stream.

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 Wailua Stream were classified 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 Wailua hydrologic unit.

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.	5
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.	2
Other rare organisms and communities: Many species that are candidates for endangered or threatened status have not been processed through all of the requirements of the Endangered Species Act. Also a number of plant communities associated with streams have become extremely rare. These rare organisms and communities were considered to be as indicative of natural Hawaiian biological processes as are listed threatened and endangered species.	none
Protected areas: 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.	Forest Reserve, State Park
Wetlands: Wetlands are important riparian resources. They provide habitat for many species and are often important nursery areas. Because they are often extensive areas of flat land generally with deep soil, many have been drained and converted to agricultural or urban uses. Those that remain are, therefore, invaluable as well as being indicators of lack of disturbance.	W+ (over ½ square mile of Palustrine wetland)
Native forest: The proportion of a stream course flowing through native forest provides an indication of the potential "naturalness" of the quality of a stream's watershed; the greater the percentage of a stream flowing through native forest most of which is protected in forest reserves the more significant the resource. Only the length of the main course of a stream (to the nearest 10 percent) that passes through native forest was recorded.	10%
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.	2 (Hau, Pigs)

For the purpose of this section, management areas are those locales that have been identified by federal, state, county, or private entities as having natural or cultural resources of particular value. The result of various government programs and privately-funded initiatives has been a wide assortment of management areas with often common goals. Such designated areas include forest reserves, private preserves, natural area reserves, wildlife sanctuaries, national parks, historic landmarks, and so on. In Wailua, over 35 percent of the hydrologic unit falls within the Lihue-Koloa Forest Reserve or Wailua River State Park (Table 6-2). There are also small portions of the Nounou and Kalepa Forest Reserve that fall in the Wailua hydrologic unit.

Table 6-2. Management areas located within Wailua hydrologic unit. (Source: State of Hawaii, Division of Forestry and Wildlife, 2008a).

Management Area	Managed by	Area (mi²)	Percent of Unit
Lihue-Koloa Forest Reserve	DLNR Division of Forestry and Wildlife	16.81	32.0
The Lihue-Koloa Forest Reserve was established by Governor's Proclamation in 1909 for protecting watershed ares vital to the agricultural economy. The Wailua section has over 10,750 acres and is managed by the State Department of Land and Natural Resources (DLNR)'s Division of Forestry and Wildlife as a multi-use area that incorporates various, and often competing, public uses and benefits. The management goals of the Forest Reserve System include: 1) Watershed protection; 2) recreation, including hiking, horseback riding, hunting, fishing, four-wheel driving, and commercial ecotourism; 3) maintenance of the Keahua Arboretum; 4) timber and/or biomass plant production			
Nounou-Kalepa Forest Reserve	DLNR Division of Forestry and Wildlife	1.05	1.9
The Nounou and Kalepa Forest Reserve was established in 1944 by Governor's Proclamation for the purpose of reforestation to prevent continued soil erosion occurring on the windward side of the ridge. The reserve is managed by the State Department of Land and Natural Resources (DLNR)'s Division of Forestry and Wildlife. The Kalepa portion occupies 670 acres of land in the ahupuaa of Waipouli and Wailua, only part (0.23 mi^2) of which is in the hydrologic unit of Wailua. The Nounou portion is 723 acres in the ahupuaa of Wailua. The management priorities include: watershed values (reduction and prevention of erosion), resource protection (reduced fire, insect and disease on forest resources), public activity (access), improve protection and recovery of rare and endangered plants and animals; invasive species control, native ecosystem restoration, promote public hunting of game animals; and to generate income from commercial activities in the reserves.			
Wailua Game Management Area	DLNR Division of Forestry and Wildlife	1.83	3.5
The Wailua Game Management Area administered by the State Department of Land and Natural Resources Division of Forestry and Wildlife encompasses hunting unit I on the Island of Kauai.			
Wailua River State Park	DLNR Division of State Parks	1.64	3.1
The Wailua River State Park, administered by the State Division of State Parks, includes the lowest reaches of both the North and South Forks of the Wailua River to the Ocean. The park includes many important cultural and archeological sites, an unusual fern-covered cave, scenic vistas of two large waterfalls (Opaekaa Falls and Wailua Falls), and the Wailua River Valley.			

In addition to the individual management areas outlined above, Watershed Partnerships are another valuable component of ecosystem maintenance. Watershed Partnerships are voluntary alliances between public and private landowners who are committed to responsible management, protection, and enhancement of their forested watershed lands. There are currently nine partnerships established statewide, one of which is on Kauai. Table 6-3 provides a summary of the partnership area, partners, and management goals of the Kauai Watershed Alliance.

Table 6-3. Watershed partnerships associated with the Wailua hydrologic unit. (Source: State of Hawaii, Division of Forestry and Wildlife, 2008b)

Management Area	Year Established	Total Area (mi²)	Area (ac)	Percent of Unit
Kauai Watershed Alliance	20003	78.125	50,000	64.1
The Kauai Watershed Alliance (KWA) is comprised of the County of Kauai Department of Water Supply, Hawaii State Department of Land and Natural Resources (Division of Forestry and Wildlife, Division of State Parks, Land Division), Kamehameha Schools; McBryde Sugar Company, Ltd; Grove Farm Company, Inc; Lihue Land Company; Kealia Ranch, LLC; B.A.Dyer; Princeville Development, LLC. The KWA is delineated into three primary management designations: with three Core 1 (highest priority) areas, seven Core 2 (second priority) areas, and various buffer areas (third priority). The management priorities of the KWA include: 1) ungulate management; 2) weed management; 3) KWA infrastructure ; 4) Staff control to remove pest animals from upper watershed; and 5) Pest plant control, particularly of priority weed species such as *Psidium cattleianum*. As of 2013, 19.44 miles of fencing have been built, of which 4.43 miles are pig and deer fencing (8-foot) and 14.91 miles are pig (4-foot) fencing resulting in 21,084 acres of protected lands. Approximately 33.7 mi^2 of the Wailua hydrologic unit falls into the Kauai Watershed Alliance.				

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. Nearly half of the unit is dominated by introduced species, while almost 40 percent of the unit is dominated by native species.

Another important consideration of fish and wildlife habitat is the presence of critical habitat. Under the Endangered Species Act, the U.S. Fish and Wildlife Service is responsible for designating critical habitat for threatened and endangered species. Critical habitat for endangered or threatened birds, snails and plants that may occur in the Wailua hydrologic unit are identified in Figure 6-3. Though there are very few threatened or endangered Hawaiian species that are directly impacted by streamflow, the availability of surface water may still have indirect consequences for other species. For example, increasing streamflow reduces breeding habitat for introduced mosquitoes that transmit diseases to threatened and endangered native birds. The density of threatened and endangered plant species is high at elevations above 1,200 feet and low to none at lower elevations (Figure 6-4).

Damselfly Habitat

Damselflies, in the insect order Odonata, resemble miniature dragonflies, but are smaller is size, more slender in stature, and have rectangular rather than round heads. While capable fliers, damselflies are slower and less animated than dragonflies and spend more time perched on vegetation. Most damselflies have an aquatic immature life stage. Females lay small cigar-shaped eggs on emergent aquatic vegetation or mats of moss and algae on submerged rocks. Once the eggs hatch (10-20 days), immatures crawl or swim through the aquatic substrate, eating smaller animals with their extendable labium. After three to four months (equating to 10-15 instars), immatures crawl out of the water and molt one last time into a fully-mature winged adult. On Kauai, there are a variety of native species that occur along upland streams or adjacent to waterfalls, but no species of damselfly on Kauai is listed threatened or endangered (Polhemus and Asquith 1996).

Newcomb's Snail

The critical habitat designation for Newcomb's Snail (*Erinna newcombi*), as determined by the U.S. Fish and Wildlife Service (USFWS), includes a small region in the headwaters of the Waialeale Stream on the West Branch of the North Fork Wailua, starting above the stream diversion. The original extent of critical habitat was determined based on reports provided by scientists with the University of Hawaii to the USFWS. The lack of designated critical habitat at lower elevations was possibly due to the lack of streamflow past the diversion during the time of designation. Recent surveys by USFWS found no evidence that this species exists either upstream or downstream 500 meters of the diversion structure. Restoration of flows will not impact springs which feed the stream and originate as high elevation rainfall (Appendix B). However, the current absence of the species in these areas does not diminish the conservation value of restored flow.

Wetland Habitat

In 1974, the 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). Only 5.7 percent of the Wailua Hydrologic Unit is classified as wetlands (Figure 6-5). Palustrine wetlands are nontidal wetlands dominated by trees, shrubs, persistent emergent species, emergent mosses or lichens, or wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5 percent. A total of 1.435 mi^2 (2.7 percent) of the hydrologic unit is classified as palustrine freshwater forested/shrub wetland and 0.643 mi^2 (1.2 percent) is composed of other non-riverine wetlands.

Economic Value of Ecosystem Services

A working paper is being developed by the University of Hawaii's Economic Research Organization (UHERO), entitled *Environmental Valuation and the Hawaiian Economy*, which discusses the use of existing measures of economic performance and alternative statistical devices to provide an economic valuation of threatened environmental resources. The paper focuses on the Koolau, Oahu watershed and illustrates three categories of positive natural capital (forest resources, shoreline resources, and water resources) against a fourth category (alien species) that degrades natural capital. In the case of the Oahu Koolau forests, a benchmark level of degradation is first defined for comparison against the current value of the Oahu Koolau system. The Oahu Koolau case study considers a hypothetical major disturbance caused by a substantial increased population of pigs with a major forest conversion from native trees to the non-indigenous Miconia (*Miconia calvescens*), along with the continued "creep" of urban areas into the upper watershed (Kaiser, B. et al., n.d.).

Recognizing that in the United States, the incorporation of environmental and natural resource considerations into economic measures is still very limited, the paper provides the estimated Net Present Value (NPV) for "Koolau [Oahu] Forest Amenities." These values are presented in Table 6-5.

Following upon 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. Certain areas of Wailua provide critical habitat for native forest birds, endangered plants and invertebrates in Kauai.

Table 6-4. Estimated Net Present Value (NPV) for Koolau [Oahu] Forest Amenities. (Source: Kaiser, B. et al., n.d.)

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

Figure 6-2. Reserve areas for the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2007b; 2015n)

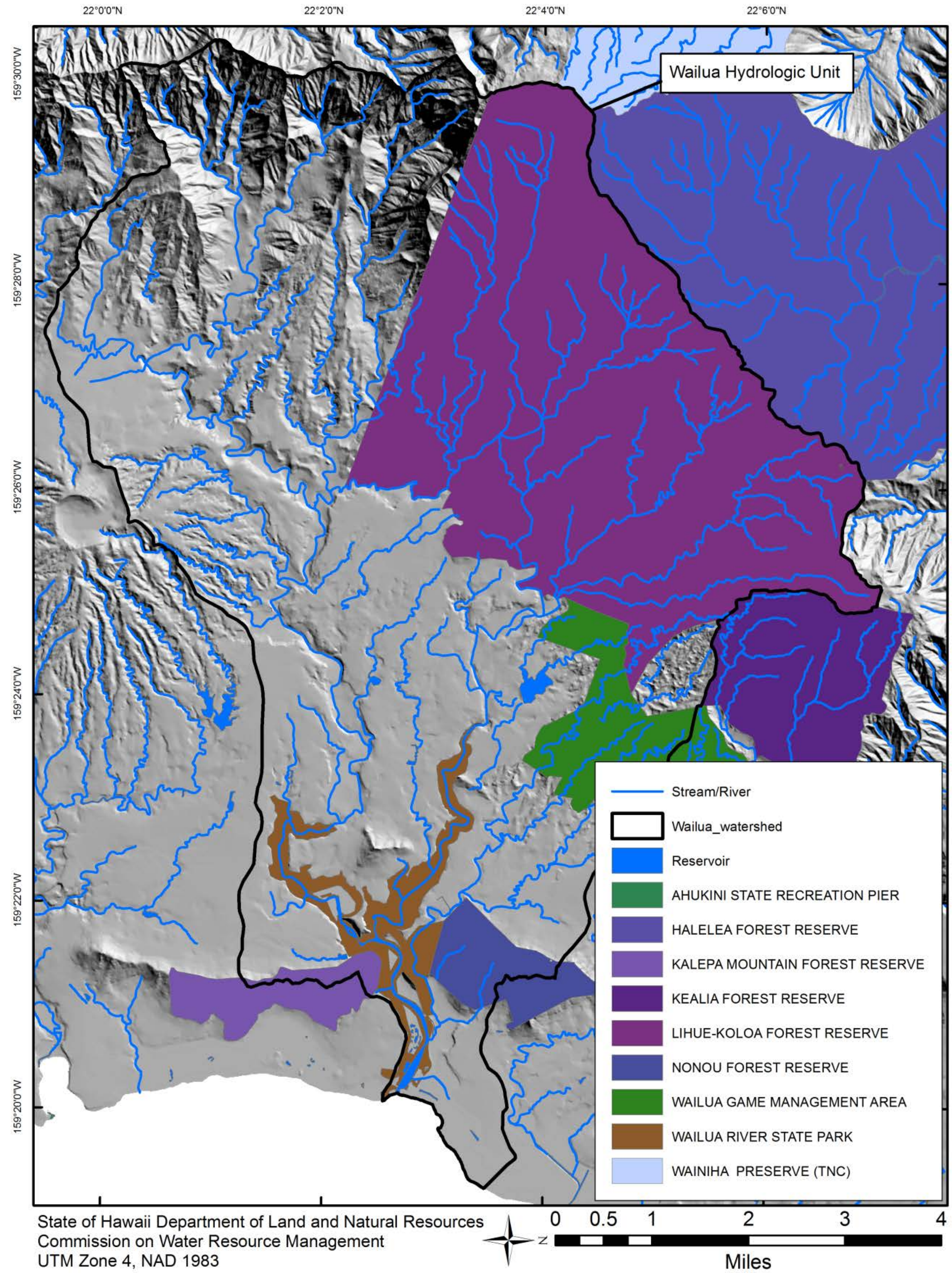


Figure 6-3. Distribution of critical habitat for particular endangered species including plants and snails in the Wailua hydrologic unit. (Source: Scott et al., 1986; State of Hawaii, Office of Planning, 1996; 2004b)

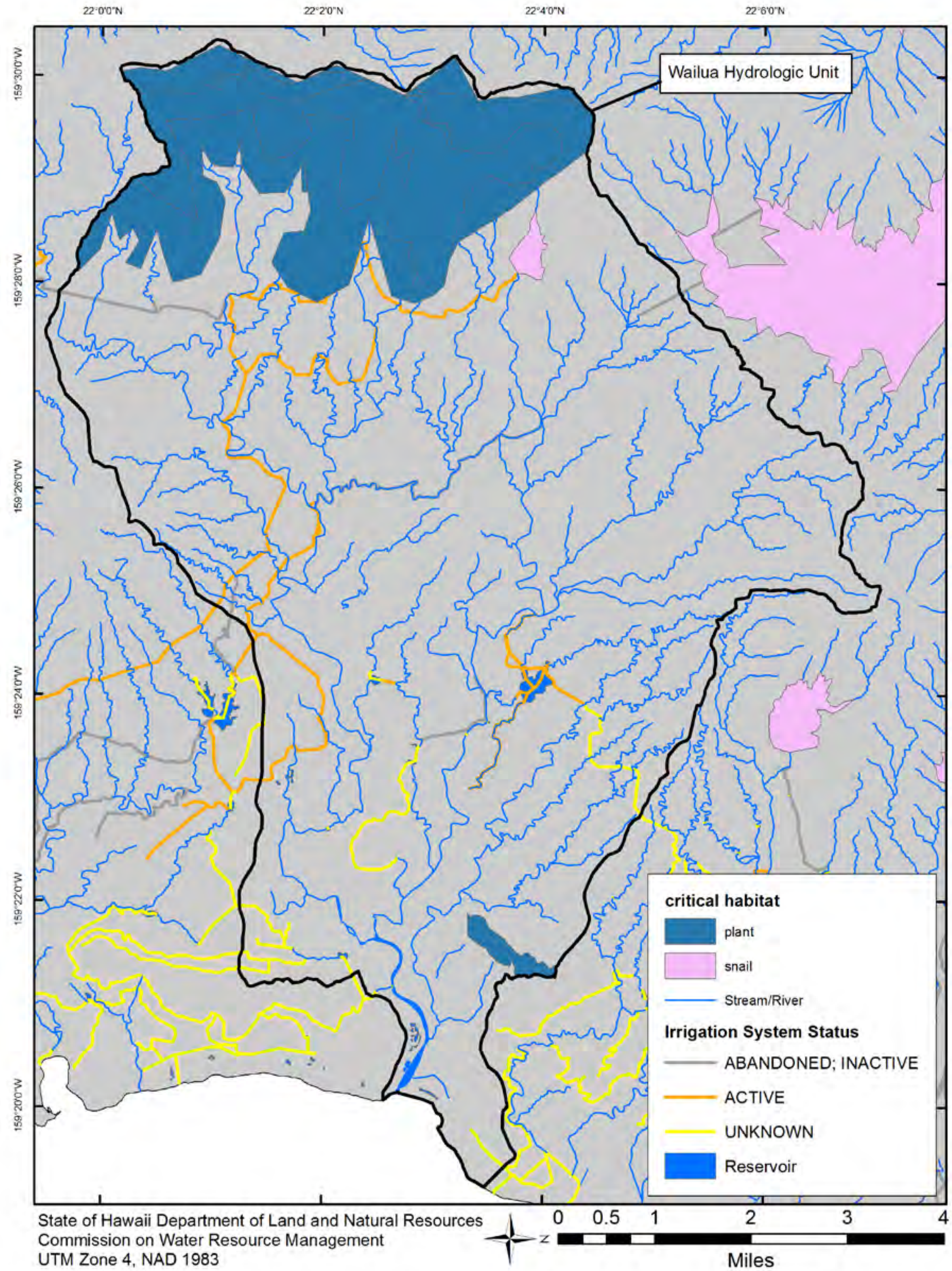


Figure 6-4. Density of threatened and endangered plants species in the Wailua hydrologic unit. (Source: State of Hawaii, Office of Planning, 2015h)

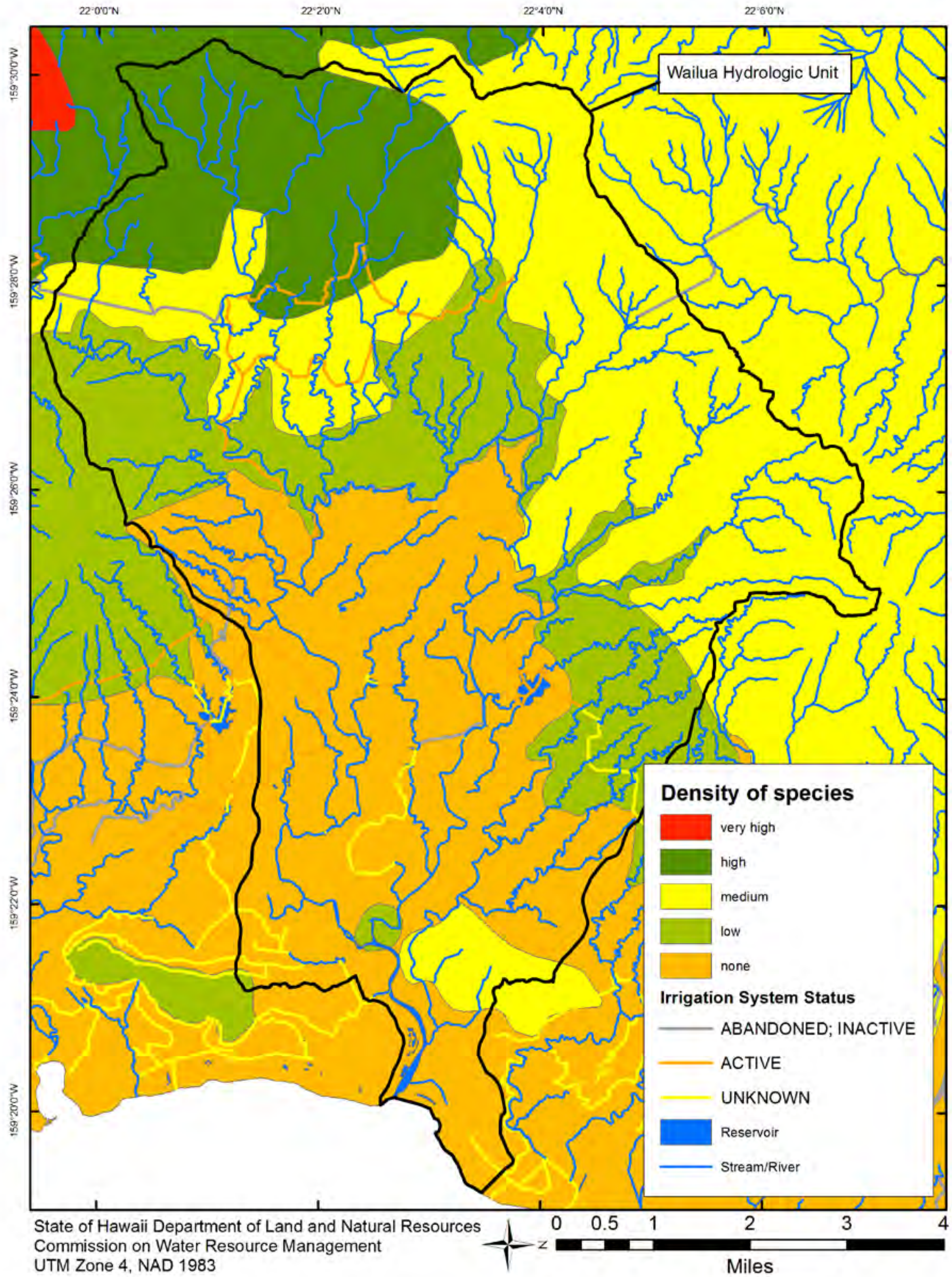
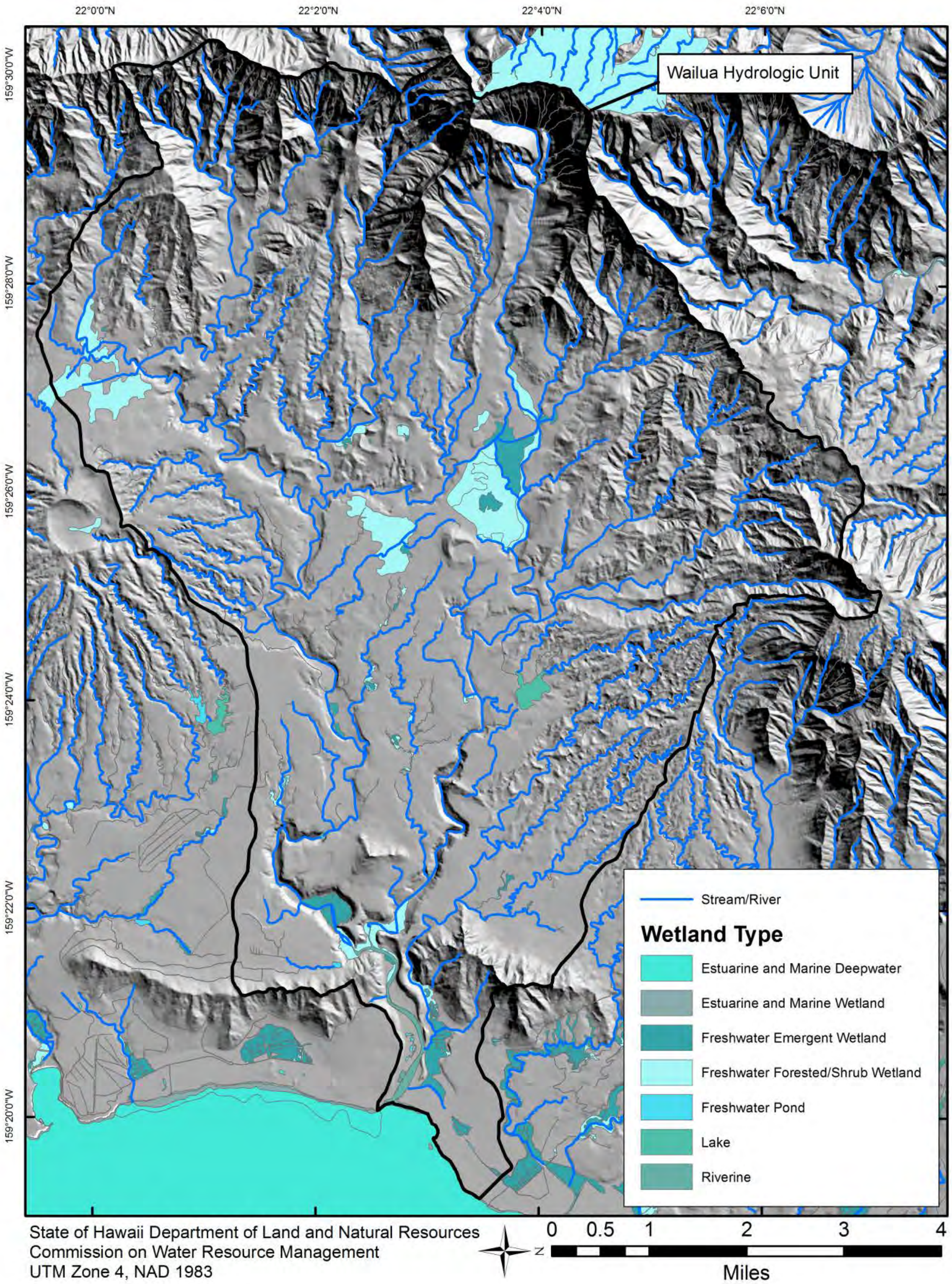


Figure 6-5. Designated wetlands by type in the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015n)



7.0 Aesthetic Values

Aesthetics is a multi-sensory experience related to an individual's perception of beauty. Since aesthetics by definition is a subjective observation, a stream's aesthetic value cannot be determined quantitatively (Wilson Okamoto & Associates, Inc., 1983). However, there are certain elements, either within or surrounding a stream, which appeal to an observer's visual and auditory senses, such as waterfalls and cascading plunge pools. Visitors and residents can identify a point that has aesthetic value and continue to return to such a point to gain that value. Such points can potentially be identified, as maped in Figure 5-2. However, the points listed are not exhaustive and it is beyond the scope of this report to list all potential aesthetic values.

The headwaters of Waialeale Stream (West Branch of the North Fork Wailua River) and Waikoko Stream (tributary to South Fork Wailua River) originate on the eastern flank of Mt. Waialeale, in a location called Bluehole. The cliffs are dominated by native wet forest and it is considered a unique ecological region home to endemic threatened and endangered birds, plants, and insects (State of Hawaii Division of Foresty and Wildlife, 2010). The continual flow of water through the natural watercourse improves the aesthetic value of the stream.

In a 2007 Hawaii State Parks Survey, released by the Hawaii Tourism Authority (OmniTrak Group Inc., 2007), scenic views accounted for 21 percent of park visits statewide, though that was a decrease from 25 percent in a 2003 survey. Other aesthetic-related motivations include viewing famous landmarks (9 percent), hiking trails and walks (7 percent), guided tour stops (6 percent), and viewing of flora and fauna (2 percent). On the island of Kauai, out-of-state visitors' most common reasons to visit state parks for scenic views (28 percent) were tied with outings with family and friends (28 percent). Similarly, residents primarily used state parks in Kauai for outings with family and friends (42 percent) followed by scenic views (16 percent). Overall, Kauai residents were very satisfied with scenic views giving a score of 8.9 (on a scale of 1 to 10, with 10 being outstanding), with out-of-state visitors giving a score of 9.2. Wailua State Park (including Opaekaa Falls, Wailua Falls, and Wailua Marina) is one of the most popular parks in the state with 888,100 visitors in 2007, 91 percent of which were out-of-state. The primary reason behind tourist visits to Kauai are for nature and scenery (71 percent) and relaxation (67 percent).

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. As streams in the Wailua watershed gain streamflow downstream and little out of watershed transfer of water occurs relative to the total streamflow at the mouth of the river, management of stream diversions is not expected to affect the navigational potential of Wailua River, which is restricted to the lowest reaches.

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 off stream power generators. In these "run-of-river" (i.e., utilizes water flow without reservoir) designs, water is diverted through a series of ditches, pipes, and penstocks to the power plant, and then returned to the stream. There is some debate as to what actually constitutes "instream" hydropower. In the Wailua watershed, water from the North Fork Wailua is transferred to a tributary of the South Fork Wailua, although all water exits at the same river mouth. Further, many systems were designed for the power plant to be situated such that the drop of water level (head) exiting the plant can be sent to fields for crop irrigation. So a diversion that supplies water for hydropower may also supply water for off stream uses, such as agriculture.

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. Areas with more exposed soil, tend to generate higher quantities of sediment.

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

The DOH, Environmental Health Administration maintains the State of Hawaii Water Quality Standards (WQS), a requirement under the Federal Clean Water Act (CWA) regulated by the EPA. The CWA aims to keep waters safe for plants and animals to live and people to wade, swim, and fish. Water Quality Standards are the measures that states use to ensure protection of the physical, chemical, and biological health of their waters. “A water quality standard defines the water quality goals of a water body, or portion thereof, by designating the use or uses to be made of the water and by setting criteria necessary to protect the uses (CWA §131.2).” Each state specifies its own water uses to be achieved and protected (“designated uses”), but CWA §131.10 specifically protects “existing uses”, which it defines as “…those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards (CWA §131.3).”[1] Although the State WQS do not specify any designated uses in terms of traditional and customary Hawaiian rights, the “protection of native breeding stock,”

[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.

“aesthetic enjoyment,” and “compatible recreation” are among the designated uses of Class 1 inland waters, and “recreational purposes, the support and propagation of aquatic life, and agricultural and industrial water supplies” are among the designated uses of Class 2 inland waters. This means that uses tied to the exercise of traditional and customary Hawaiian rights that are protected by the State Constitution and the State Water Code (Section 12.0, Protection of Traditional and Customary Hawaiian Rights), including but not limited to gathering, recreation, healing, and religious practices are also protected under the CWA and the WQS as designated and/or existing uses. Therefore, the Commission’s interim IFS recommendation may impact the attainment of designated and existing uses, water quality criteria, and the DOH antidegradation policy, which together define the WQS and are part of the joint Commission and DOH obligation to assure sufficient water quality for instream and noninstream uses.

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

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

The sources for the 2014 Integrated Report are Hawaii’s 2012 §303(d) list, plus readily-available data collected from any State water bodies over the preceding 6 years (State of Hawaii, Department of Health, 2014). Per §303(d), impaired waters are listed after review of “‘all existing and readily available water quality-related data and information’ from a broad set of data sources” (State of Hawaii, Department of Health, 2004, p.57). However, available data are not comprehensive of all the streams in the State. According to the Hawaii Administrative Rules Title 11 Chapter 54 (HAR 11-54) all State waters are subject to monitoring; however, in the most recent list published (from the 2010 list that was published in 2012), only 88 streams statewide had sufficient data for evaluation of whether exceedance of WQS occurred. Wailua Stream did not appear on the 2012 List of Impaired Waters in Hawaii, Clean Water Act §303(d). The 2006 Integrated Report indicates that the current WQS require the use of *Enterococci* as the indicator bacteria for evaluating public health risks in the waters of the State; however, no new data were available for this parameter in inland waters. As mentioned in Section 5.0, Outdoor Recreational Activities, DOH maintains WQS for inland recreational waters based on the geo-mean statistic of *Enterococci*: 33 colony-forming units per 100 mL of water or a single-sample maximum of 89 colonies per 100 mL. This is for full-body contact (swimming, jumping off cliffs into waterfall pools, etc.). If *Enterococci* count exceeds those values, the water body is considered to be impaired. DOH Clean Water Branch efforts have been focused on coastal areas (State of Hawaii, Department of Health, 2006, Chapter II, p.20). The marine recreational zone, which extends from the shoreline seaward to 1,000 feet from shore, requires an *Enterococci* geo-mean of less than 7 colony-forming units per 100 mL of water to protect human health (HAR 11-54-8.). The 2012 Integrated Report also states: "Public health concerns may be underreported. *Leptospirosis* is not included as a specific water quality standard parameter. However, all fresh waters within the state are considered potential sources of *Leptospirosis* infection by the epidemiology section of the Hawaii State Department of Health. No direct tests have been approved or utilized to ascertain the extent of the public health threat through water sampling. Epidemiologic evidence has linked several illness outbreaks to contact with fresh water, leading authorities to issue blanket advisories for all fresh waters of the state (State of Hawaii, Department of Health, 2007, Chapter II, p.3)."

The tributaries of the Wailua River are classified as Class 1a inland waters from its headwaters to the boundary of the forest reserve as the surrounding land is in the conservation subzone "protective", while the middle reaches are not classified since they run through agriculture and rural zoned districts. The lowest reaches of the Wailua River are located in Wailua River State Park, and therefore classified as a Class 1A inland water again. A few sections of low elevation tributary drainages are classified as Class 1B inland waters. It should be noted that there is no direct relationship between elevation and attainment of water quality standards. The proliferation of fecal bacteria in warm, moist soils inoculated by mammals and the high density of cesspools in developed areas contribute to high bacteria levels in the river. Restoration of flows in already gaining stream reaches do not impact the frequency of runoff events, which is the primary driver of pathogen loading in surface waters (Strauch et al., 2014).

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. The marine waters at the mouth of the Wailua hydrologic unit are Class A waters.   Figure 10-1 shows the Wailua hydrologic unit, including inland and marine (coastal) water classifications.

The State of Hawaii Department of Health (DOH) maintains water quality standards (HAR 11-54) for recreational areas in inland recreational waters based on the geo-mean of *Enterococcus*, a fecal indicator: 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, etc.). If *Enterococcus* exceeds those values, the water body is considered to be impaired. DOH also has a standing advisory for *Leptospirosis* in all freshwater streams. 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. Land-based sources of fecal pollution are common in the tropics, where high densities of animals and a warm, moist environment provide ideal conditions for the proliferation of bacteria (Strauch et al., 2014). Data available through the US Environmental Protection Agency's online database (STORET) is available in Table 10-1. Water quality is especially dependent on streamflow conditions, as runoff transports particulates into the stream channel and higher flows keep particles in suspension for longer periods of time (Strauch 2017). Bacterial water quality has been monitored monthly approximately at the mouth of Wailua River since 2016 by the Surfrider Foundation, BlueWater Task Force. The frequency of various levels of contamination are graphed in Figure 10-2.

Figure 10-1. Water quality standards for the Wailua hydrologic unit. (Source: State of Hawaii, Office of Planning, 2015e; 2008). The classifications are general in nature and should be used in conjunction with Hawaii Administrative Rules, Chapter 11-54, Water Quality Standards.

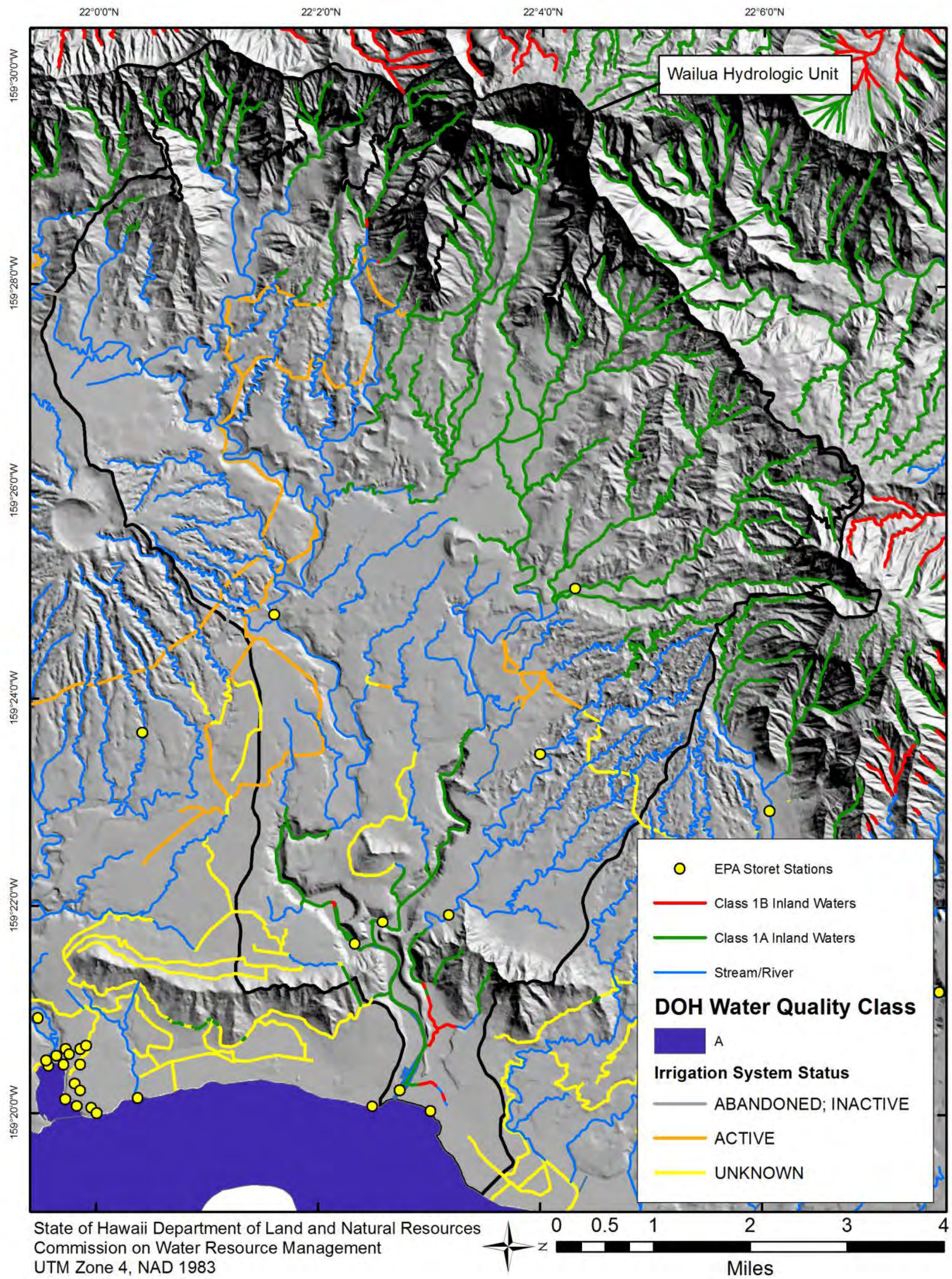
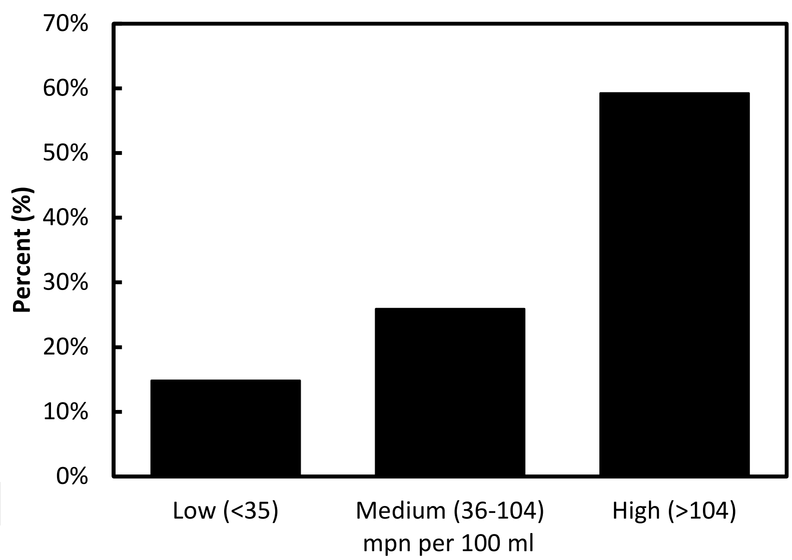


Table 10-1. Mean (standard error) for water quality data available from the US Environmental Protection Agency online database (STORET) at various elevations in the Wailua Hydrologic Unit. (Source: www.waterqualitydata.us, accessed March 2018)

	North Fork Wailua River		South Fork Wailua River		Opaekaa Stream	
parameter	at 33 ft a.s.l.	at 500 ft a.s.l.	At 8 ft a.s.l.	At 430 ft a.s.l.	At 270 ft a.s.l.	At 400 ft a.s.l.
Dissolved Oxygen (mg L^{-1})	8.39 (0.20)	9.21 (0.54)	8.81 (1.45)	9.37 (0.26)	6.68 (0.57)	8.47 (0.25)
pH	7.59 (0.10)	7.58 (0.08)	7.46 (0.08)	7.62 (0.09)	6.90 (0.08)	7.32 (0.13)
Salinity (mg L^{-1})	0.04 (0.007)	0.03 (0.003)	0.04 (0.008)	0.03 (0.002)	0.04 (0.001)	0.03 (0.00)
Specific Conductance (umho cm^{-1})	0.10 (0.005)	0.09 (0.004)	0.09 (0.004)	0.08 (0.004)	0.11 (0.002)	0.08 (0.002)
Temperature (°C)	21.01 (0.35)	20.50 (0.60)	20.83 (0.38)	20.66 (0.48)	21.93 (0.79)	23.00 (0.64)
Turbidity (mg L^{-1})	5.25 (1.17)	3.46 (0.66)	6.53 (1.02)	9.55 (3.45)	8.16 (1.03)	19.10 (7.02)

Figure 10-2. Percent of monthly water samples (n = 16) that exceeded particular water quality standards (most probable number, mpn) at the mouth of Wailua River. (Source: Surfrider Foundation, accessed: July 2018).



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 County of Kauai Department of Water 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. There is a single surface water treatment plant associated with the Wailua hydrologic unit regulated by the DOH, Safe Drinking Water branch located at Kapaia Reservoir: Waiahi Surface Water Treatment Plant. This facility is the result of a private-public partnership between Waiahi Water Company and the County of Kauai Department of Water. The facility receives water diverted at the confluence of the Waiahi and Waikoko/Iliiliula streams by the Hanamaulu Ditch. The Waiahi Stream at the Hanamaulu Ditch intake receives water from tributaries of the Waiahi as well as water from the Lower Waiahi Hydropower Plant tailrace, which itself receives water diverted by the North Intake Ditch and South Intake Ditch. The South Intake Ditch receives water from Waiahi tributaries and the Upper Waiahi Hydropower Plant tailrace which is from the Iliiliula-North Wailua Ditch. Kauai County also operates a number of drinking water wells in the Wailua hydrologic unit. The Waiahi Surface Water Treatment Facility generates about 2.3 mgd potable water, with a designed capacity of 3.0 mgd, for the Lihue-Hanamaulu Water District, representing about 25% of their total current (2018) water demand. It should be noted that while domestic water supply is an identified public trust priority use by the Hawaii State Constitution, not all municipal water is domestic water and that other water users served by the county's municipal water supply are protected (e.g., industrial, landscaping, commercial, resort).

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)."

Ahupuaa and Aha Moku Systems

In ancient Hawaii, the island regions (*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 ahupuaa, and so the Commission's surface water hydrologic units often coincide with or overlap ahupuaa boundaries. The hydrologic unit of Wailua is fully within the ahupuaa of Wailua as shown in Figure 12-2. 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.

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 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 12-1].

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

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

§174C-5(15)). 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).

Land Court Awards

Land Court Awards (LCA) occurred during the Great Māhele (1848), when land was redistributed from being the sole property of the King to a division of three categorical types: land belonging to the mōʻī (monarch) as Hawaiian Crown Lands (one-third); land belonging to the aliʻi and konohiki (chiefs and managers of the ahupuaʻa) (one-third); and land belonging to the people (kuleana). During the Māhele, a total of approximately 75 acres of Wailua was awarded to 25 individuals, the most prominent being D. Kapule and Iosia Kauniua-lii, the wife and son of Kaumualaii, the last chief of Kauai (Folk 1990). These awards were all in the lowest reaches of the Wailua Ahupuaa. The large track of forest was kept as Crown Lands or private lands of Kamehameha III (Kauikeaouli). A description of each LCA is provided in Table 12-1.

Figure 12-1. 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.

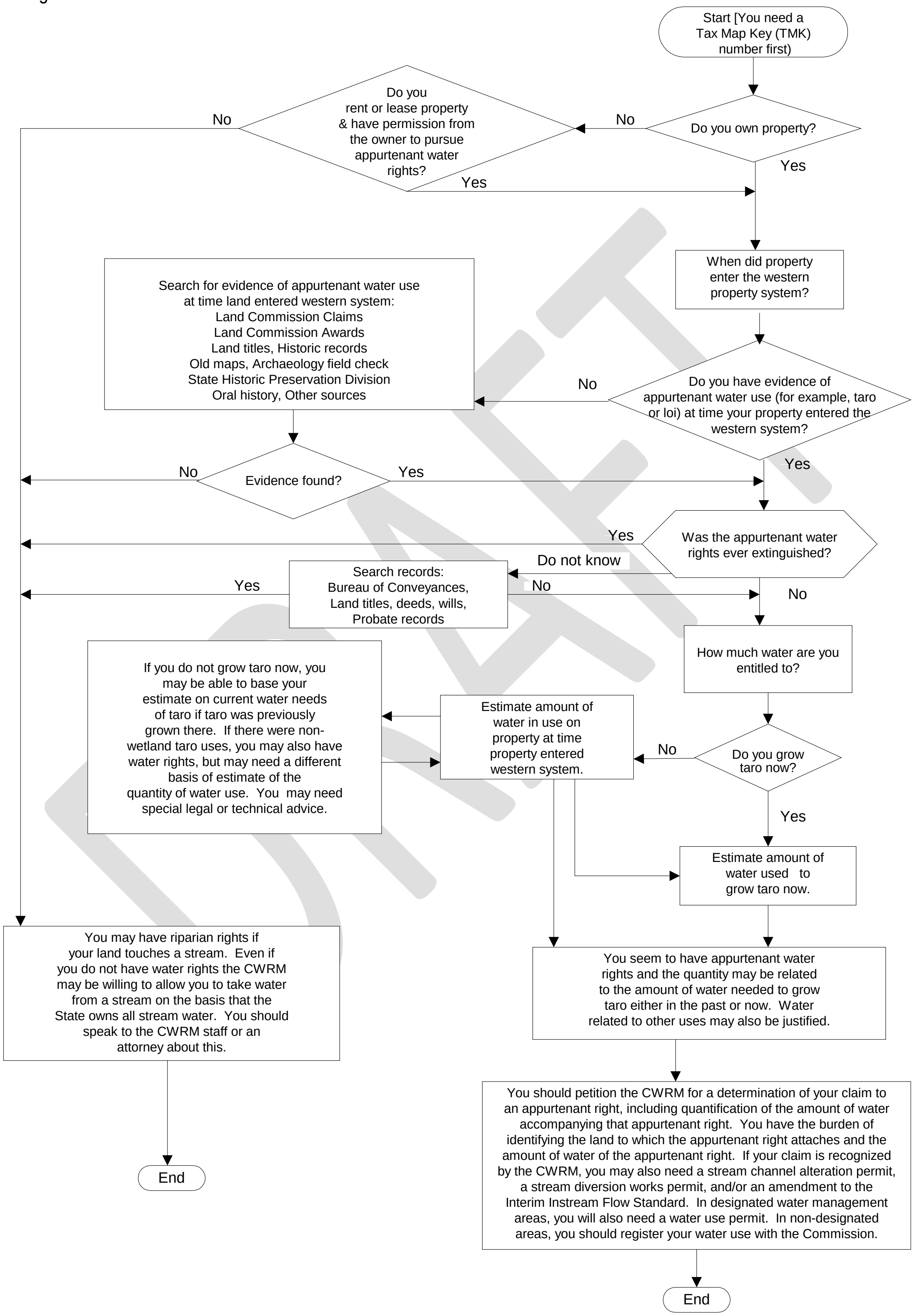


Table 12-1. Summary of Land Commission Awards (LCA) for the Wailua Hydrologic Unit. (Source: Kipuka Database, Office of Hawaiian Affairs, accessed July 2018) [RP = Royal Patent]

LCA number	TMK	Award Year	Claimant	Notes
7713:2	438002002	1860	Kamamalu, Victoria	RP:4481
452:1	439003006	1850	Brown, Thomas	
452:2	439003007	1850	Brown, Thomas	Makea Loi Complex
452:3	439003008	1850	Brown, Thomas	
452:4	439003009	1850	Brown, Thomas	
3551:1	441001005	1861	Kaihenui	RP: 4891
3551:2	442003008	1861	Kaihenui	
3909:1	441001006	1877	Nahinu	RP: 6978
3567:1	441001007	1859	Kaiapa	RP: 4705
3557:2	441001007	1860	Kaniwi	RP: 4782
3555:1	441001002	1877	Kiaipali	RP: 6945
3264:1	441001016	1861	Lanikaula	RP: 4892
3264:2	441002999	1861	Lanikaula	RP: 4892
3406:1	441001011		Pula	
3568:1	441001015	1860	Kelani	RP: 4826
3568:2	441003005	1860	Kelani	RP: 4826
3368:1	441001017	1860	Naakaakai	RP: 4828
3368:2	441004024	1860	Naakaakai	RP: 4828
3403:1	441002008	1918	Pahio	RP: 8202
3282:1	441002008	1920	Wahapuu, Sera	RP: 8325
4146	441002009	1861	Kaliu	RP: 4894
3346:1	441003007	1880	Nawai	RP: 7474
3346:2	441002007	1880	Nawai	RP: 7474
3556	441002014	1861	Kekua	RP: 4895
3345:2	441002013		Nakai	
3281:1	441002016	1861	Whineai	RP: 4857
3303:1	441002015	1881	Makaiki	RP: 7527
3302:1	441002017	1885	Maawe	RP: 7787
3226:2	441002004	1867	Chapin, O	RP: 6021
3111; 3559:3	441002004	1864	Kapule, Deborah	RP: 5489; two helu
3111; 3559:4	441003007	1864	Kapule, Deborah	RP: 5489; two helu
3569:1	441002020	1861	Kupalu	RP: 4853
3367:1	441004014	1860	Noi	RP: 4827
3367:2	441002020	1860	Noi	RP: 4827
3238:1	441002004		Hawea	
3561	441003004	1867	Kaumaulii, Iosia	RP: 6020
38:5	441003005	1882	Board of Education	BOE Grant; Wailua kai school lot
3405	441004009		Poka	RP: 8555
3557:1	441004009	1860	Kaniwi	RP: 4782

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 12-2 below. The study indicated that the "values are consistent with previously reported inflow and are significantly higher than values generally estimated for consumption during kalo cultivation." It should also be noted that farmers were interviewed during field visits; most "believed that their supply of irrigation water was insufficient for proper kalo cultivation."

The study results are presented in Table 12-2 (discharge measurements) and Table 12-3 (water-temperature statistics).

Table 12-2. Summary of water use calculated from loi and loi complexes by island, and the entire state. (Source: Gingerich et al., 2007, Table 10)

[gad = gallons per acre per day; na = not available]

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

Table 12-3. Water-temperature statistics based on measurements collected at 15-minute intervals for loi complexes on the island of Maui. (Source: Gingerich et al., 2007, Table 7)

[ºC = degrees Celsius; na = not applicable]

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

Historic Cultural Descriptions

Historical uses can also provide some insight into the protection of traditional and customary Hawaiian rights. Without delving into the extensive archive of literature (refer to Kumu Pono Associates, 2001a), Handy et al., in *Native Planters of Old Hawaii* (1972), provide a limited description as follows:

"Wailua, like Waimea, was one of the two most important areas on Kauai. It was the seat of the ruling *ali'i* of the island when Captain Cook discovered it. At one time and another it shared this distinction with Waimea. Its importance is attested to by the fact that there were six *heiau* of prime importance…"

"Wailua has the largest river on Kauai and in the Hawaiian Islands, formed by the joining of two large streams. There is ample evidence of an abundance of coconut and breadfruit trees in former times…"

Handy (1940) also provided the following description:

"Along the lower 2 miles of Wailua River, above the sandy coastal plain, are many broad, open, level areas, formerly in terraces, now mostly in sugar…The large area of terraces below the falls is now planted mostly in rice, a few of the upper terraces being used for sweet potatoes, while the uppermost are pasture. There are terraces in the canyon of the north fork of the Wailua River; presumably there are terraces also in the flatlands along Kawi, Keahua, and Iole Streams, which form the headwaters of this fork of the river. There were sizable terrace areas on both sides of the south fork of the river above the junction with the north fork.

There were sizable terrace areas on both sides of the south fork of the river above the junction wit the north fork. Extensive areas of terraces fill the valley immediately above Wailua Falls and along the river for 3 miles above Waikoko. Iliiliula, Waiaka, Waiahi, Kaulu, Palikea, and Kalii Streams, which for the headwaters of the south fork of the Wailua River, undoubtedly all had small terraces along their lower courses."

In Ching's (1981) cultural survey of the North Fork Wailua near Stable Storm Ditch, "no evidence of cultural remains" were found, with the closest archaeological sites to the project area located along the South Fork Wailua below the Hanamaulu Ditch. In the Monsarrat map (REG. No. 2141) of Lihue Plantation dating to 1900, 6 acres of rice were identified just mauka of the confluence between the East and North branches of the North Fork Wailua.

The Wailua Hydrologic Unit was identified by the State Historic Preservation Division as one of five valleys that have significant archaeological evidence indicating prehistoric settlements of some magnitude, all of which occurred in the lowest one-third of the watershed. The Hawaii Stream Assessment (HSA), states that, "Wailua's renown is as the major royal center of Kauai in late prehistory." It later describes that, "agricultural fields which supported the elite and the commoners were scattered along the valley floor, and remnants of the irrigated taro fields and canals are present here and there as well as stone field terraces along the slopes of the valley. Historical places associated with oral histories of people and underwater caves exist above Wailua Falls." The HSA collected data in three general areas of: 1) archaeological; 2) historical; and 3) modern practices. Archaeological data were originally compiled by the State Historic Preservation Division and are only current to 1990, the date of the HSA (Table 12-4). However, there is no evidence of taro production in the higher (>700 ft amsl) elevation reaches (Folk 1990) and historic maps show no settlements in this region despite the occupation of similar lands in Hanalei. This is likely due to the region being designated as Crown Lands without any Land Court Awards given.

Cultural Practices in the Wailua Hydrologic Unit

The Wailua ahupua'a was one of the original locations for ruler of Kauai. As such there are a number of historically and culturally important heiau in the lower reaches, where royalty lived and worshipped. Commoners lived throughout the flat region between the middle reaches of the two forks of Wailua River, with plentiful water supplying loi kalo. A variety of Native Hawaiian cultural and spiritual practices continue to take place in the ahupuaʻa. Waiʻaleʻale is a hugely important place to Native Hawaiians, featuring in many chants, stories and traditions across the Island of Kauai and the State of Hawaii. An extensive ʻaha moku system of land and water stewardship existed throughout the Wailua watershed, where care of the land and water supported the perpetuation of native plants, animals, soil and water resources for generations. The piko (or navel) of the island (i.e., the caldera) both literally serves as the source of nourishment and energy for the island and figuratively, as the umbilical cord connecting Hawaiian communities with their sacred mountain.

Sacred sites exist throughout the watershed, with major heiau (temples), wahi pana (celebrated places), burial grounds, and resource collecting areas are still evidenced today. Historically, the Aliʻi Nui (high chief) of Kauai would travel on annual pilgrimages as well as the royal court to Kaʻawako heiau located at Kawaikini at Waiʻaleʻale's summit to pay homage to the cyclical patterns of the atmosphere, earth, and rainfall. The waters that flow from mauka to makai are the lifeblood of this cultural landscape with importance as a religious center to all of Hawaiʻi nei. The classic admission chant to enter a place of reverence (e.g., a sacred forest, performance stage, classroom) in hula tradition specifically identifies the Waiʻaleʻale region and the importance of mauka to makai flow. The Kūnihi chant continues to be cherished by Kapuna and Kānaka Maoli alike and is often the first ʻoli hālau hula learn in Hawaiʻi and throughout the world:

Kūnihi ka mauna i ka laʻi ē,	Steep stands the mountain in the calm
ʻO Waiʻaleʻale lā i Wailua,	Waiʻaleʻale there at Wailua
Huki aʻe la i ka lani	Tossed into the heaves
Ka papa ʻauwai o Kawaikini;	Was the bridge of Kawaikini
Ālai ʻia aʻela e Nou-nou,	Obstructed by Nounou
Nalo Kaipuhaʻa,	Kaipuhaʻa Hill is hidden
Ka laulā mauka o Kapaʻa, ē!	Into the broad plans above Kapaʻa!
Mai paʻa i ka leo!	If the voice is withheld, no greeting will come!
He ʻle kāhea mai, ē!	The voice calls!

The fundamental importance of freshwater in its natural state is embodied in the names of these places: Waiʻaleʻale (rippling water), Wailua (two waters, and Kawaikini (numerous waters). Kaipuhaʻa (low gourd), is the name of the caldera at the base of Waiʻaleʻale, evoking the shape of Kāne's ipu, the water gourd that provides everlasting life (Kekua and Alapai 2010). It is sacrilege to Hawaiian culture that streamflow has been impaired for so long.

The gathering of native plant species of important cultural, spiritual, and medicinal uses takes place along and between streams at high elevations (Figure 12-3). Plants gathered for cultural purposed identified by cultural practitioners include Ohia lehua (*Meterosideros polymorpha*), kukui (*Aleurites moluccana*), makai (*Pipturus spp*.), Ohelo (*Vaccinium reticulatum*), and papala (*Charpentiera obovata*). Further, pohaku, or sacred stones) are gathered from particular places of importance in the higher elevations. Traditional and cultural practices continue to take place in the Wailua watershed, although they are impaired by the diversion of streamflow. Additional cultural information related to the Wailua ahupuaʻa can be found in Kekua and Alapai (2010).

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 were three historic fishponds present in the Wailua hydrologic unit (DHM, Inc., 1990) in TMK: 4-4-03 (class IIA type III) and 4-1-03:16 (2x class IIA type II).

Pre-European Contact Agriculture

Prior to European contact, Hawaiian irrigated wetland and dryland (rainfed) agriculture dominated river valleys and flood plains. Large systems of intensively cultivated taro required consistent and plentiful surface water diverted through an auwai (furrow or ditch) from a stream or spring with sufficient volume. Agriculture is an integral part of traditional Hawaiian culture and has also seen a resurgence of interest in recent years. Recently published datasets (see Ladefoged et al. 2009), have provided new insights in understanding the extent of both wetland and dryland agriculture pre-European contact (Figure 12-4). Due to the abundance of surface water supply and the archeological evidence of terracing in the valleys, the Wailua Hydrologic Unit probably supported wetland taro, with the greatest concentrations in the lower reaches along the stream channels in the valleys and the upper headwater streams between the North and South Fork tributaries. This is consistent with conversations staff have had with current cultural practitioners in the area.

Hawaiian Home Lands

Another component in the assessment of traditional and customary Hawaiian rights is the presence of Department of Hawaiian Home Lands (DHHL) parcels within 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). In May 2004, the Hawaiian Homes Commission approved the Kauai Island Plan which identified the individual needs and land uses for the Wailua Hawaiian Homelands. In December 2009, DHHL published the Wailua Regional Plan which served to examine infrastructure needs, provide development cost estimates, and identify priority areas for homestead development between Wailua and Anahola. DHHL owns a total of 526 acres in the Wailua area, including 52 acres makai of Kuhio Highway and 474 acres on the mauka side. As part of the plan, 99 acres divided into 25 agricultural homestead lots at 2 acres each were proposed as well as 52 acres of general agricultural land that was prone to flooding and not suitable for housing. Although DHHL land does not currently receive surface water from the Wailua River, during the plantation era, a tunnel was dug through Kalepa Ridge that supplied surface water from the Hanamaulu Ditch via the Aii Reservoir, the Okinawa Reservoir, and Reservoir 21. The Kalepa Ridge tunnel needs substantial repair and maintenance of existing ditches is needed to provide a reliable supply of surface water. In the 2017 State Water Projects Plan which focused on DHHL's needs, DHHL identified a non-potable reservation of 7.564 mgd with a projected demand of 0.337 mgd by 2031.

Table 12-4. Cultural resource elements evaluated as part of the Hawaii Stream Assessment for Wailua Hydrologic Unit (Source: Hawaii Stream Assessment, 1991)

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.	Complete
Predictability: The ability to predict what historic sites might be in unsurveyed areas was scored as high, medium, or low predictability or unable to predict. A high score was assigned if archaeologists were able to predict likely site patterns in a valley given historic documents, extensive archaeological surveys in nearby or similar valleys, and/or partial survey coverage. A low score was assigned if archaeologists were unable to predict site patterns in a valley because of a lack of historical or archaeological information. A medium score was assigned to all other cases.	High
Number of Sites: The actual number of historic sites known in each valley is straightforward yet very time consuming to count. Instead, archaeologists used survey information to estimate the number of sites in each valley. These figures, adequate for this broad-based assessment, are only rough estimates.	6
Valley significance as a Whole District: The overall evaluation of each valley's significance was made considering each valley a district. The significance criteria of the National and Hawaii Registers of Historic Places were used. Criterion A applies if the district is significant in addressing broad patterns of prehistory or early history. Criterion B applies if the district is associated with important people (rulers) or deities. Criterion C applies if the district contains excellent examples of site types. Criterion D applies if the district is significant for information contained in its sites. Finally, Criterion E applies if the district is culturally significant for traditionally known places or events or for sites such as burials, religious structures, trails, and other culturally noteworthy sites.	ABCDE
Site Density: The density patterns of historic sites make up a variable extremely important to planners. Three ranks were assigned: low for very few sites due either to normal site patterning or extensive land alteration, moderate for scattered clusters of sites, and high for continuous sites. Valleys with moderate or high density patterns are generally considered moderate or high sensitivity areas.	High
Site Specific Significance: The site specific significance variable was developed for valleys that had low densities of sites (very few sites) due either to normal site patterning or to extensive land alteration. An example of the first type might be a valley with housing sites on the side but too narrow for taro or housing sites on the valley floor. The second type might be a valley in which there had been sugar cane cultivation but a large heiau was left. The site specific significance of these valleys was categorized as either: 1) sites significant solely for information content which can undergo archaeological data recovery; or 2) sites significant for multiple criteria and merit preservation consideration. Those categorized as meriting preservation consideration would likely include large heiau, burial sites, and excellent examples of site types.	
Overall Sensitivity: The overall sensitivity of a valley was ranked very high, high, moderate, low, or unknown. Very high sensitivity areas have moderate or high densities of sites with little or no land alteration. They are extremely important archaeological and/or cultural areas. High sensitivity areas have moderate or high densities of sites with little or no land alteration. Moderate sensitivity areas have very few sites with the sites meriting preservation consideration due to multiple criteria or moderate densities of sites with moderate land alteration. Low sensitivity areas have very few sites due to normal site patterning or due to extensive land alteration. The sites present are significant solely for their informational content, which enable mitigation through data recovery. Those valleys where no surveying had been undertaken and the ability to predict what might be found was low were ranked unknown.	High

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

Figure 12-2. Traditional ahupuaa boundaries in the vicinity of Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015j)

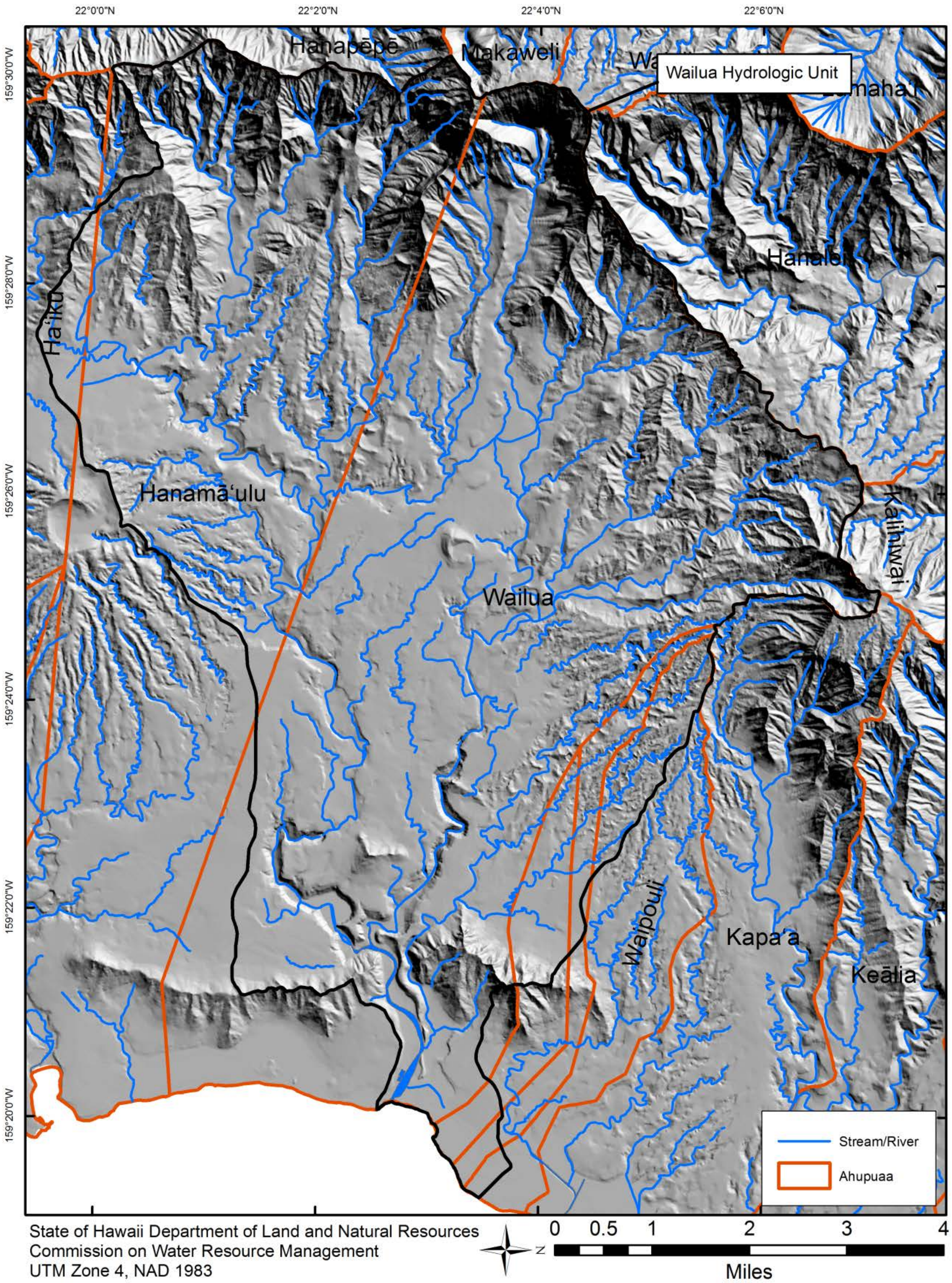


Figure 12-3 Traditional and customary or cultural practices that used to or continue to take place in the vicinity of Wailua hydrologic unit, Kauai.

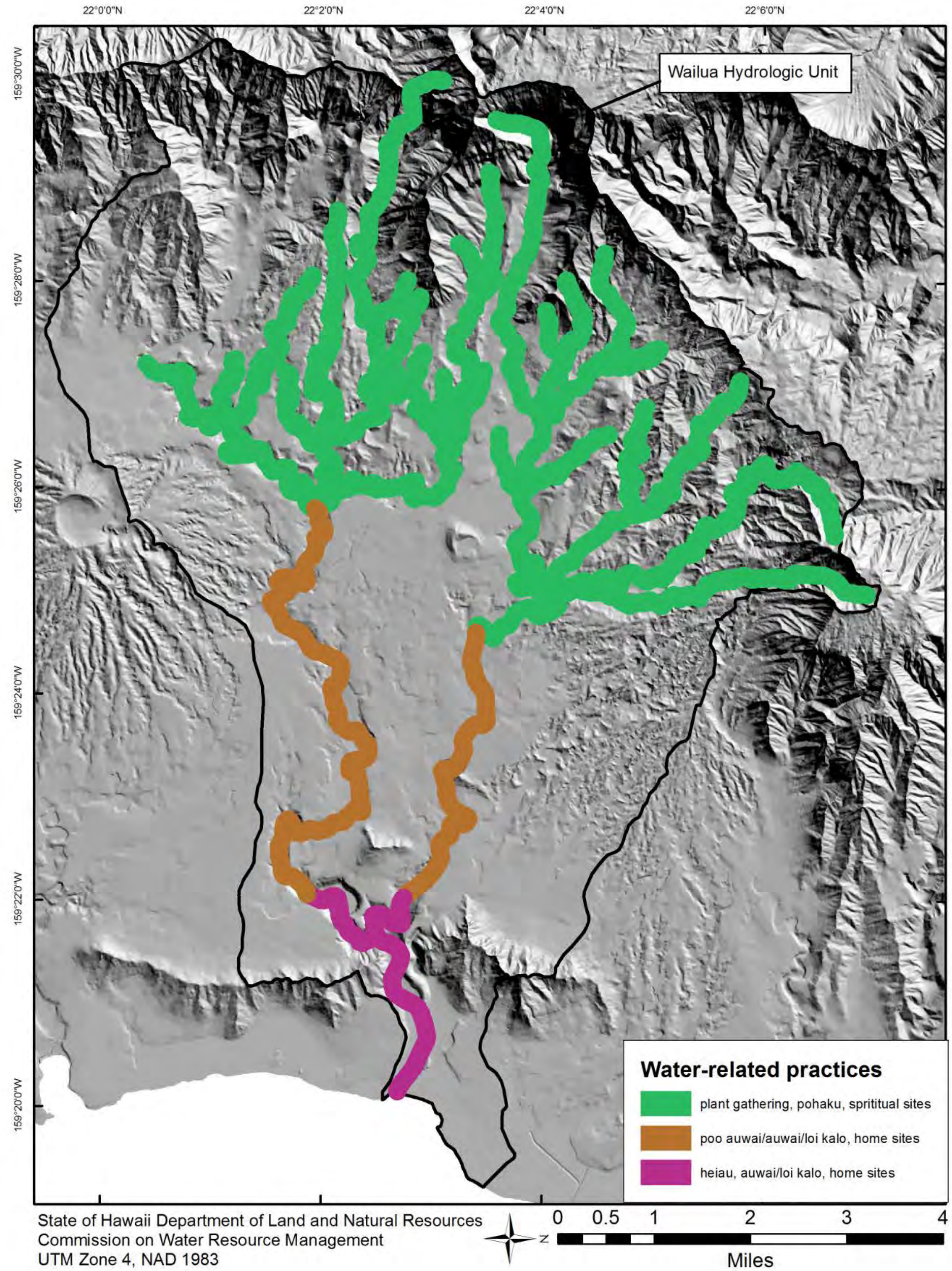
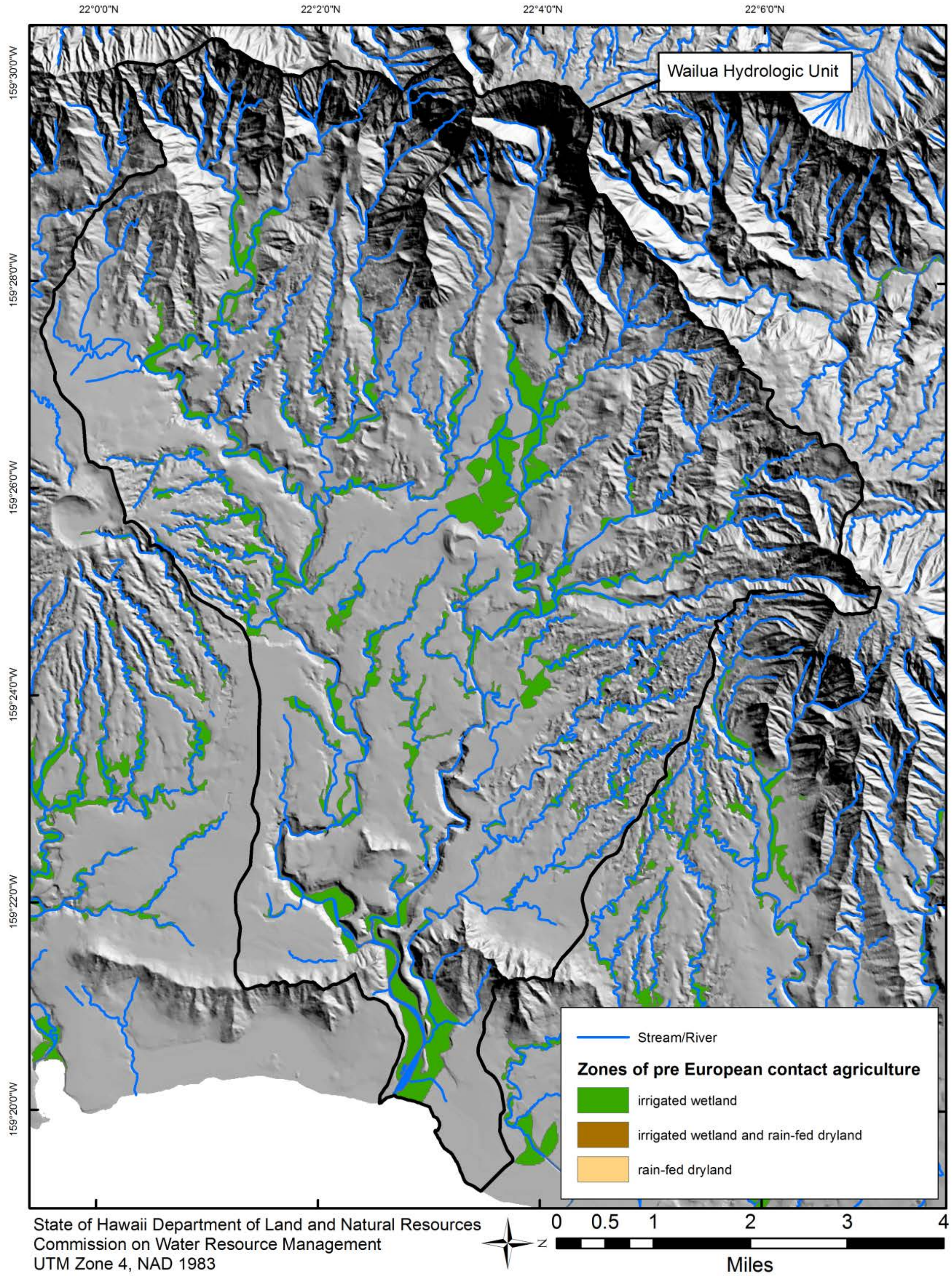


Figure 12-4. Zones of intensive agriculture in the Wailua hydrologic unit pre-European contact. (Source: Ladefoged, 2009)



13.0 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 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 poo auwai (rock dam), and concrete dams that remove relatively larger amounts of water.

Water Leaving Wailua Streams

Water for commercial purposes is most often used away from the stream channel and is not returned; however, as in the case of taro fields, water may be returned to the stream at some point downstream of its use. While the return of surface water to the stream would generally be considered a positive value, this introduces the need to consider water quality variables such as increased temperature, nutrients, and dissolved oxygen, which may impact other instream uses. There are a number of plantation era irrigation systems that transport water within and away from the Wailua hydrologic unit (Table 13-1). At the moment, there is limited demand for irrigation water from the North Fork Wailua via the Wailua Ditch (<1.0 mgd is diverted).

Table 13-1. Current surface active surface water irrigation systems in the Wailua hydrologic unit, Kauai (Source: State of Hawaii, Commission on Water Resource Management, 2015)

Name	Operator	History	Use	Estimated Flow
Iliiliula-North Wailua Ditch	Kauai Island Utility Cooperative	Lihue Plantation for hydropower and irrigation in the Wailua, Hanamaulu, Lihue area	hydropower	~ 20 mgd
North Intake Ditch	Kauai Island Utility Cooperative	Lihue Plantation for hydropower and irrigation in the Wailua, Hanamaulu, Lihue area	hydropower	n/a
South Intake Ditch	Kauai Island Utility Cooperative	Lihue Plantation for hydropower and irrigation in the Wailua, Hanamaulu, Lihue area	hydropower	n/a
Wailua Ditch	East Kauai Water Users Cooperative	Lihue Plantation for irrigation in the Wailua, Kapaa, and Kapahi area	agriculture irrigation	< 1.0 mgd
Upper Lihue Ditch	Grove Farm	Lihue Plantation for hydropower and irrigation in the Wailua, Hanamaulu, Lihue area	agriculture irrigation	~ 10 mgd
Hanamaulu Ditch	Grove Farm	Lihue Plantation for hydropower and irrigation in the Wailua, Hanamaulu, Lihue area	agriculture irrigation, municipal water supply	~25 mgd

The Upper Lihue Ditch diverts water at the 650 ft elevation from the Waiahi Tributary of the South Fork Wailua River, providing irrigation water for diversified agricultural needs in the Lihue Basin as well as to meet non-potable landscaping demands. The Hanamaulu Ditch diverts water at the 450 ft elevation from the Waiahi Tributary. Water in the Hanamaulu Ditch is transported to the Kapaia Reservoir, where some of it is treated by the Waiahi Surface Water Treatment Facility and some continues in the Alii Reservoir Ditch to provide irrigation water for diversified agriculture on Grove Farm and State of Hawaii-owned land. The Hanamaulu Ditch also provides water to the Agribusiness Development Corporation (~6 mgd) and is used by Kauai Backcountry Adventures for recreational use. A portion of water in the Hanamaulu Ditch is returned to the South Fork Wailua River. Water is transported within the Wailua hydrologic unit by the Iliiliula-North Wailua Ditch, the Stable Storm Ditch, the North Intake Ditch, the South Intake Ditch, and the Aahoaka Ditch. A few ditches that were active during the plantation era have now been discontinued. These include the Stable Storm Ditch, the Kaneha Ditch.

Diversion Structures

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

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. The Commission’s records for the hydrologic unit of Wailua indicate that there are 24 registered diversions. 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 (Table 13-3) with locations are depicted in Figure 13-1. Since the enactment of HAR Title 13 Chapter 168, stream diversion works permits are required for the construction of new diversions or alteration of existing diversions, with the exception of routine maintenance. There are six active irrigation ditches in the Wailua hydrologic unit as listed in Table 13-1.

Data from staff site visits to each of the irrigation systems may be found in Table 13-2.

Figure 13-1. Location of registered diversions and irrigation systems in the Wailua hydrologic unit, Kauai.

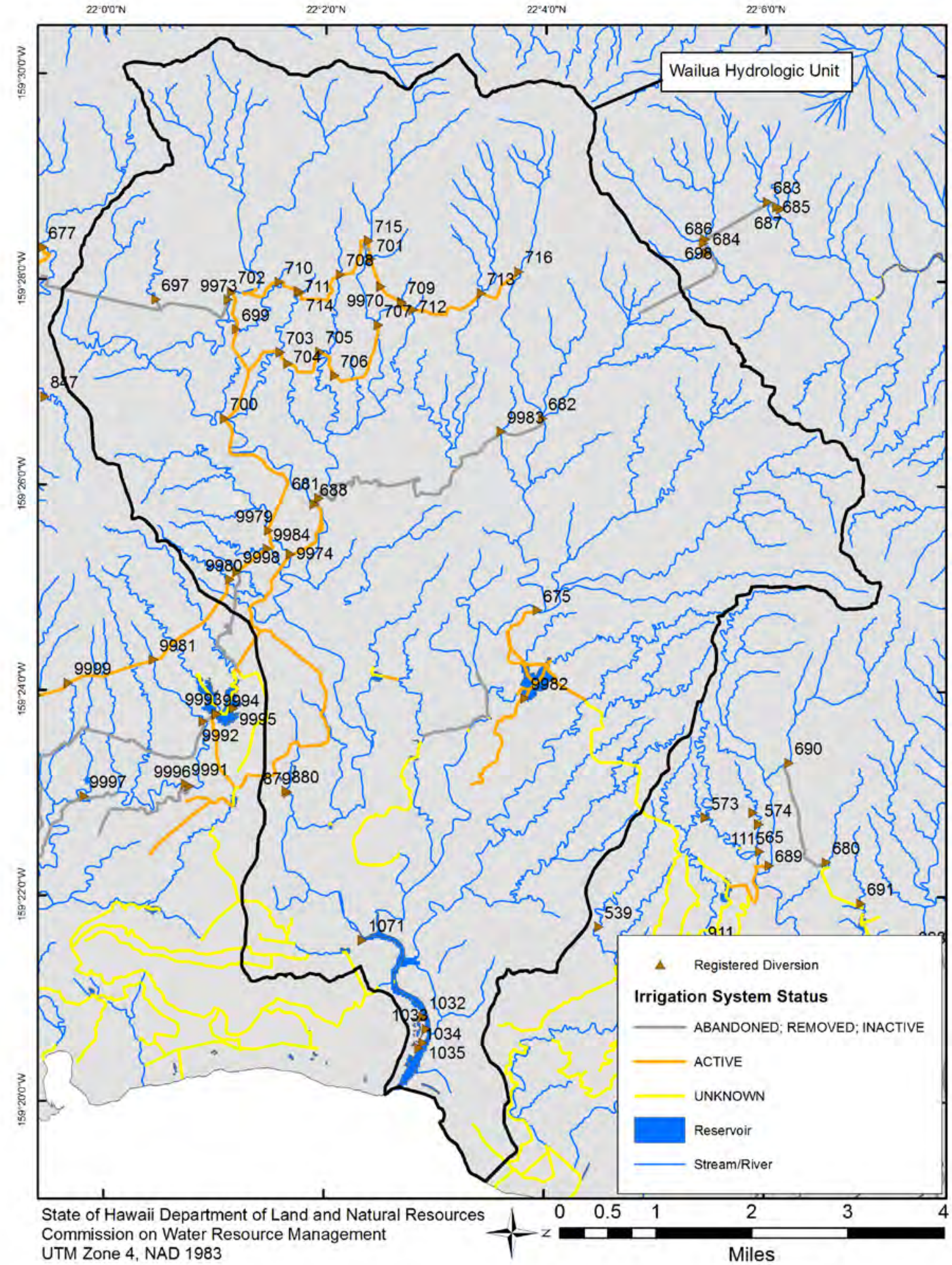


Table 13-2. Registered diversions in the Wailua hydrologic unit, Kauai.
[Source of photos are denoted at the end of each description; CWRM, Commission on Water Resource Management; Arrows (⇨)indicate general direction of natural water flow to and out of diversions; Chevrons (⋙) indicate direction of 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.716	LIHUE PLANTATION	2442001002	17.8	Yes	Yes	No	No

The Iliiliula-North Wailua Ditch begins at the West Branch of the North Fork Wailua River (Waialeale Stream). This diversion is called the Bluehole Intake as it captures water from the "bluehole" area of Mt. Waialeale. Water is transmitted along the right bank and away from the stream.

Photos. (a) Diversion structure across channel from right bank (CWRM, 01/2016); (b) Upstream view of water flowing into diversion structure (CWRM, 01/2016); (c) Downstream view of dry streambed below diversion structure (CWRM, 01/2016); (d) Diverted flow traveling along the right bank (CWRM, 01/2016); (e) Close-up of diverted flow on right bank (CWRM, 01/2016)

a)

b)

c)

d)

e)

Table 13-2. Continued. Registered diversions in the Wailua hydrologic unit.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.713	LIHUE PLANTATION	2439001001	6.0	Yes	Yes	Yes	Yes

The two tributaries of the Waikoko Stream merge just upstream of the where the Iliiliula-North Wailua Ditch crosses the channel. Ditch water enters from a tunnel on the left bank into an artificially created pool and merges with the stream. The diversion structure forces water along the right bank. There is leakage through the dam.

Photos. (a) Diversion structure across the channel (CWRM, 01/2016); (b) Upstream view of Waikoko Stream from diversion structure (CWRM, 01/2016); (c) Downstream view of Waikoko Stream from diversion structure (CWRM, 01/2016); (d) Diversion structure from right bank with ditch tunnel entering stream channel on left bank (CWRM, 01/2016); (e) Iliiliula-North Wailua Ditch on continuing on right bank past diversion on Waikoko Stream (CWRM, 01/2016)

a)

b)

c)

d)

e)

Table 13-2. Continued. Registered diversions in the Wailua hydrologic unit.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.712	LIHUE PLANTATION	2438001001	n/a	No	Yes	No	No

One of many tributaries of the Iliiliula Stream is an ephemeral stream that was diverted where the Iliiliula-North Wailua Ditch crosses underneath the channel. Stream water enters from a grate across the stream when there is flow, however, the diversion is not maintained and the grate is clogged with silt, rock and debris.

Photos. (a) Downstream view of diversion grate and concrete structure (ditch is in tunnel beneath) across the channel (CWRM, 01/2016); (b) Upstream view of ephemeral stream with diversion grate (CWRM, 01/2016); (c) Diversion grate from right bank (CWRM, 01/2016); (d) Diversion structure from left bank across ephemeral stream (CWRM, 01/2016).

a)

b)

c)

c)

Table 13-2. Continued. Registered diversions in the Wailua hydrologic unit.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.709	LIHUE PLANTATION	2438001001	n/a	Yes	Yes	No	No

Ephemeral tributary of the Iliiliula Stream diverted where the Iliiliula-North Wailua Ditch crosses the channel. Stream water flows directly into the ditch, which can be flushed out at the sluice gate before tunnel.

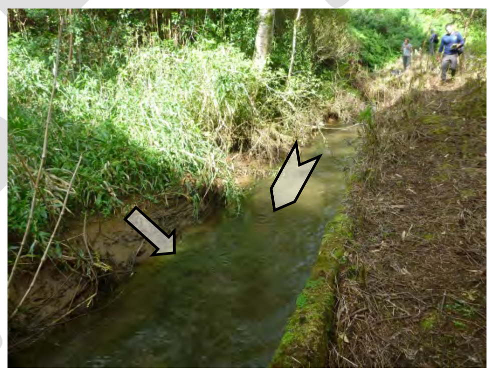
Photos. (a) Diversion from left bank across channel (CWRM, 01/2016); (b) Ditch crossing stream channel (CWRM, 01/2016); (c) Sluice grate on right bank before tunnel (CWRM, 01/2016); (d) Diversion structure from right bank across channel (CWRM, 01/2016); (e) Ditch and sluice gate before tunnel (CWRM, 01/2016); (f) Ditch from right bank (CWRM)

a)

b)

c)

d)



e)

f)

Table 13-2. Continued. Registered diversions in the Wailua hydrologic unit.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.701	LIHUE PLANTATION	2438001001	n/a	Yes	Yes	No	No

Ephemeral tributary of the Iliiliula Stream diverted where the Iliiliula-North Wailua Ditch crosses the channel. Stream water flows directly into the ditch. Ditch flows into tunnel beneath stream towards Iliiliula Stream.

Photos. (a) Upstream view from diversion (CWRM, 01/2016); (b) Downstream view from diversion (CWRM, 01/2016); (c) Sluice grate on ditch (CWRM, 01/2016); (d) Diversion structure from right bank across channel (CWRM, 01/2016); (e) Ditch and sluice gate before tunnel (CWRM, 01/2016); (f) Ditch from right bank (CWRM)

a)

b)

c)

d)

e)

f)

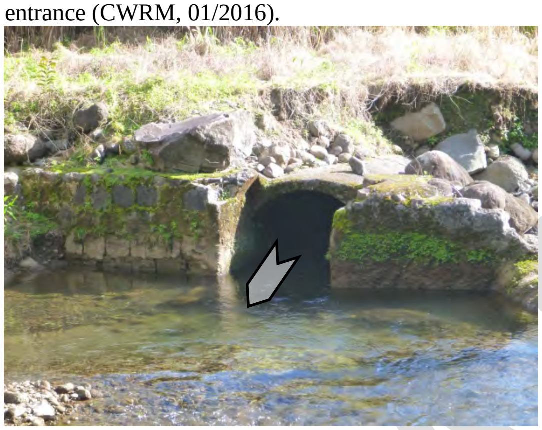
Table 13-2. Continued. Registered diversions in the Wailua hydrologic unit.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.715	LIHUE PLANTATION	2438001001	n/a	Yes	Yes	No	No

Iliiliula Stream diverted where the Iliiliula-North Wailua Ditch crosses the channel. The ditch exits a tunnel on the left bank and flows into a pool created by a concrete dam across the channel. Stream water flows directly into the same pool and a tunnel on the right bank takes water further down the ditch.

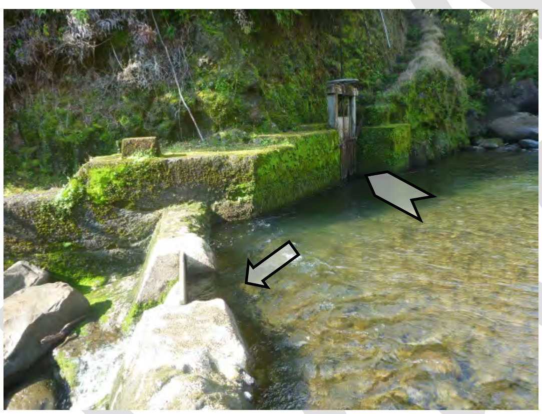
Photos. (a) Ditch exit from tunnel on left bank (CWRM, 01/2016); (b) Leakage from sluice gate on diversion (CWRM, 01/2016); (c) Diversion and ditch tunnel entrance from left bank (CWRM, 01/2016); (d) Upstream view of stream from diversion (CWRM, 01/2016); (e) Downstream view from diversion (CWRM, 01/2016); (f) Diversion, pool, stream, and ditch entrance (CWRM, 01/2016).

a)



b)

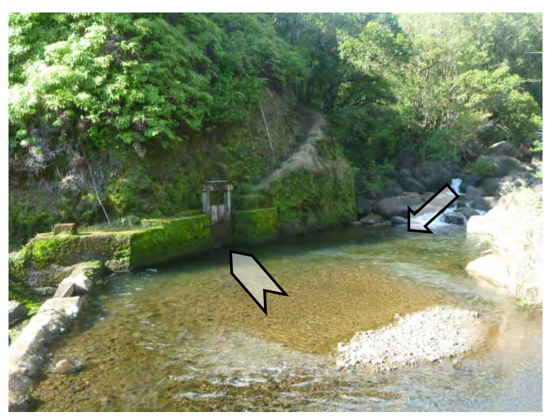
c)



d)

e)

f)



Hydropower Production

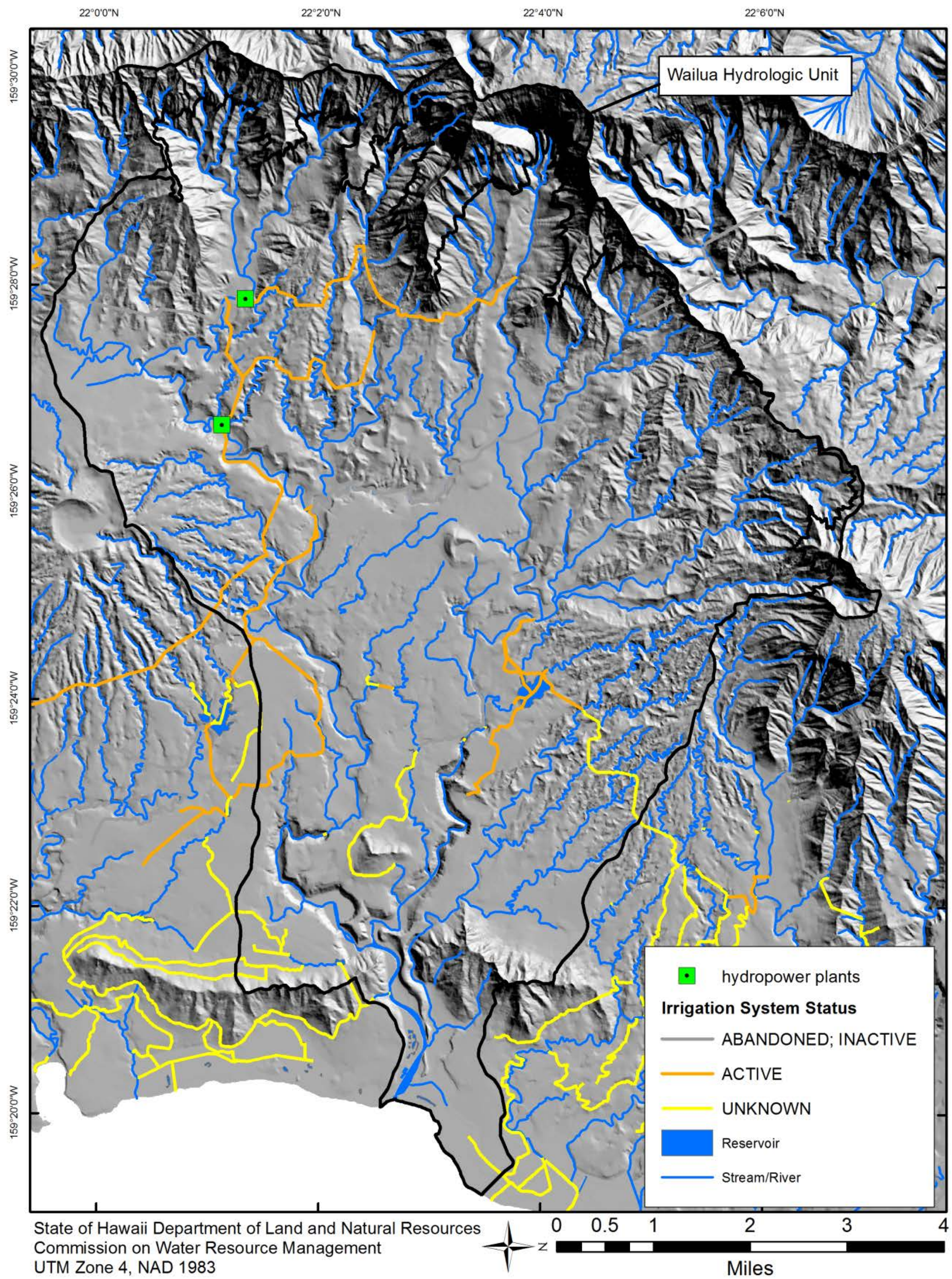
In 1914, Lihue Plantation constructed the Lower Waiahi hydropower plant with two Westinghouse generators using Pelton waterwheels with the capability of generating 600 kilowatts. These were replaced in 1931 with a Francis turbine, increasing the capacity to 800 kilowatts. In 1931, the Upper Waiahi hydropower plant was added at the 1050 ft elevation, adding 500 kilowatts of generating capacity (Figure 13-2). Power was originally sold by Lihue Plantation to Kauai Electric, a subsidiary of Mcbryde Sugar, until 1969 when Kauai Electric was sold to Citizens Utilities Company as part of an investor-owned company providing a variety of utility services. In 1999, the Kauai Island Utility Cooperative (KIUC) was formed as a non-profit entity by a group of Kauai business leaders and shortly thereafter acquired Kauai Electric Company from Citizens Utilities. While the hydropower plants provided enough energy to supply four towns on Kauai during the 1930s, in the present day, they provide approximately 1% of Kauai Island's current power needs, offsetting approximately 674,000 gallons of oil use. As a cooperative, KIUC operates as a not-for-profit organization that is owned and controlled by the people of Kauai. There are currently (2018) 22,562 electric meters and 24,745 active member-owners served by KIUC.

In the Wailua hydrologic unit, there are two hydroelectric power plants with ditches taking water from various streams to supply the penstock that ultimately generates power. While the power plants are located on the Waiahi Tributary of the South Fork Wailua, water is diverted at the Bluehole Intake from Waiʻaleʻale Stream on the North Fork and transferred (with other diverted tributary waters) along the ʻIliʻiliʻula-North Wailua Ditch to the penstock of the Upper Waiahi Hydropower plant. The tailrace water comingles with the Waiahi Stream before being diverted into the South Intake Ditch, contributing to the penstock of the Lower Waiahi Hydropower plant. Tailrace flow data is available for about one year of operation from March 2017 to March 2018 for each hydropower plant (Figure 13-3). The mean and median daily Upper Waiahi tailrace flow for this period without the days when zero water was used due to operational or logistical issues was 30.42 cfs (19.66 mgd) and 32.43 cfs (20.96 mgd), respectively. Thus the Waiʻaleʻale Stream may contribute up to 50% of the flow in the tailrace. A seepage run on the ditch without contributions from the North Fork Wailua confirmed this (Figure 13-4). System inefficiencies identified by the seepage run result in a loss of 3.5 cfs out of a total of 24.5 cfs diverted from streams, or about 14% for the Iliiliula-North Wailua Ditch. Losses are from unlined portions of the open ditch as well as leakage from unsealed pani boards at tunnel adits throughout the system. Based on estimated median flows, each 1 mgd produces approximately 4% of the total combined power generated by the Upper and Lower Waiahi hydropower plants (1.3 MW), or approximately 52 kW per mgd. For comparison, the Wainiha Hydropower Plant on Kauai generates 4 MW of electricity from approximately 38 mgd (105 kW per mgd). This difference is largely due to topographic differences in the construction of the stream diversions and location of the hydropower plant and not due to the hydropower plant itself.

Economic Impact of Waiahi Hydropower Plants

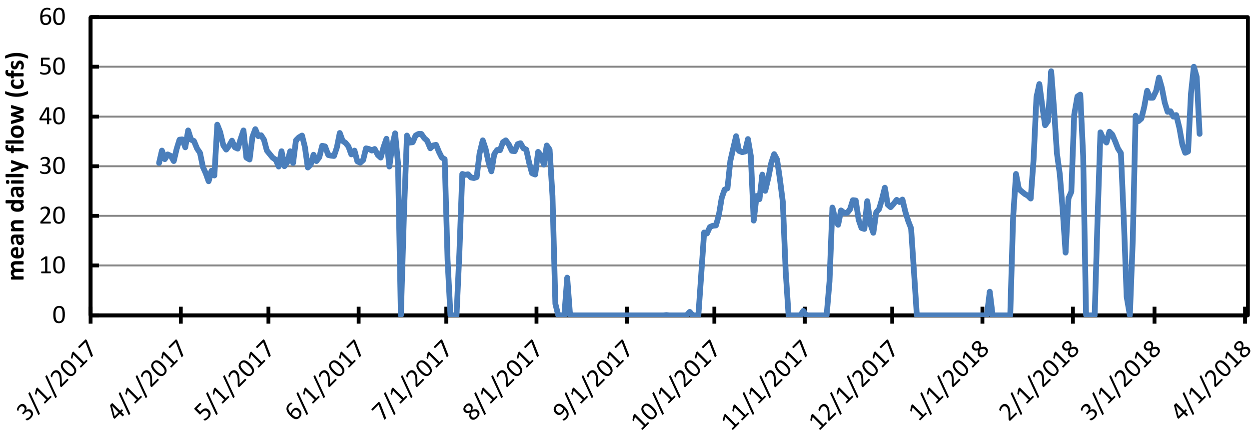
A number of factors can be used to determine the economic impact of the Waiahi hydropower plants: (1) the production cost of using an alternative source of energy for KIUC customers; (2) the fuel saved by not using diesel generators; and (3) the availability of alternative energy sources. The combined average annual energy output of the Upper and Lower Waiahi hydropower plants is 8760 megawatt hours. The fixed cost to maintain the plants is $240,000 per year plus administration/unplanned costs which equates to $400,000 per year (~$50 per megawatt hour). If the KIUC fuel contract is for ~$70 per barrel this equates to $18.62 per mmbtu for diesel fuel. The most efficient diesel generator produces 9.6 mmbtu per megawatt hour, equating to $179 per megawatt hour. Thus, these two hydropower plants combined produce a savings of $129 per megawatt hour or $1,130,000 per year for KIUC customers. By using hydropower, KIUC avoids purchasing 674,000 gallons of fuel per year. The greenhouse gas emissions equivalent of 8760 megawatt hours generated per year by diesel fuel generators burning 674,000 gallons (16,050 barrels) of diesel is 6,901 metric tons CO_2 equivalent per year. The 11.5 mgd and 3.5 mgd median flow diverted from the North Fork Wailua and Waikoko streams, respectively, equates to approximately 0.78 MW of electricity generated.

Figure 13-2. Location of hydropower plants in the Wailua Hydrologic Unit, Kauai. (Source: CWRM fieldwork)



Utility scale coupled solar-battery storage systems can provide some amount of alternative energy, but due to their reliance on solar radiation, power generation is vulnerable to extended periods of cloudy weather and is thus, not totally comparable. KIUC opened two solar-battery storage power plants in the last two years (13 MW and 28 MW capacity) with a third 19.3 MW plant approved for 2019.

Figure 13-3. Mean daily flow (cubic feet per second) at the Upper Waiahi Hydropower Plant tailrace in the Wailua hydrologic unit, Kauai. (Source: State of Hawaii, Office of Planning, 2015n)



Iliiliula-North Wailua Ditch

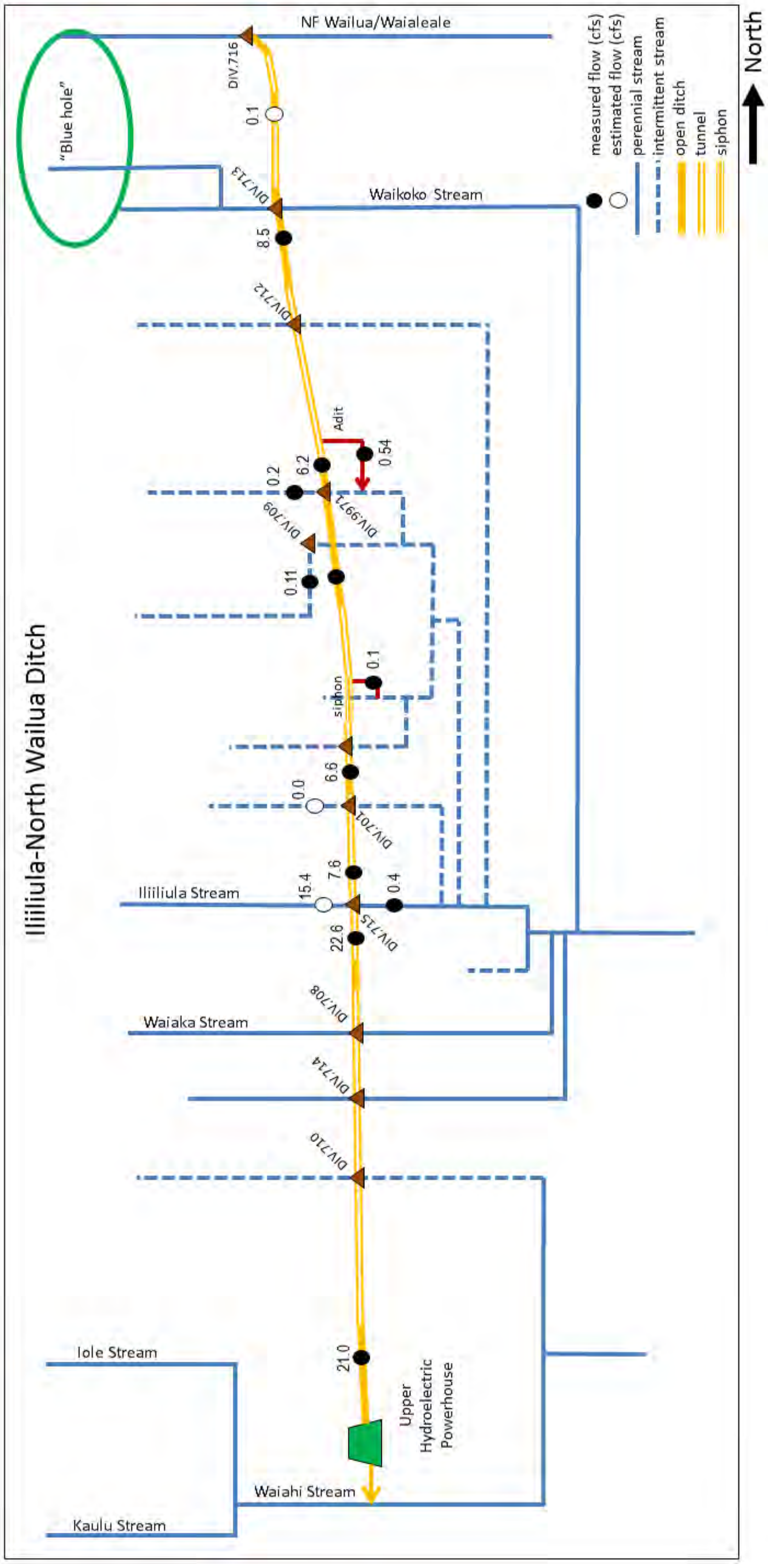
Water diverted from the West Branch of the North Fork Wailua (i.e., Waialeale Stream) at the Bluehole Intake is combined with water diverted at eight registered and two unregistered diversions. A seepage run on the ditch was conducted when the Bluehole Intake was clogged following a severe flood event on April 23, 2018. During the seepage run, flow measurements in the ditch, in small ephemeral tributaries, and leakage from the ditch in the system was measured in as many places as possible (Figure 13-2). Major losses identified in the system include about 1.5 cfs between Waikoko Stream and the adit before DIV.997, 0.54 cfs at an adit before DIV.9971, 0.1 cfs at the inverted siphon, and 1.6 cfs between the Iliiliula Stream and the Upper Waiahi Hydropower penstock. The loss in this last portion is likely due to a combination of seepage loss in the short unlined portions of the open ditch between Iliiliula Stream and Waiaaka Stream as well as loss through unsealed pani boards at tunnel adits. Using data from this seepage run, 21 cfs (13.6 mgd) was available at the end of the ditch without any contribution of stream flow from the Bluehole Intake. Thus estimates of total contributions to water flowing in the Iliiliula-North Wailua Ditch at the Upper Waiahi Hydropower penstock can be calculated as in Table (13-2). These flow estimates occurred during a relatively wet day. For comparison, the median flow at the Upper Waiahi Hydropower plant measured by Lihue Plantation from 1936-1938 was 18.70 mgd (Table 3-3).

Table 13-3. Estimated flow and percent contribution to the Iliiliula-North Wailua Ditch at the Upper Waiahi Hydropower Penstock, Wailua, Kauai. [Flows in cubic feet per second (million gallons per day)]

Stream		Estimated Flow	Estimated Percent Contribution
WB NF Wailua (Waialeale)[1]		23.0 (14.9)	49%
Waikoko[2]		8.5 (5.49)	18%
Iliiliula[2]		15.4 (10.0)	33%
	Total	46.9 (30.3)	100%

[1]estimated flow
[2]measured flow

Figure 13-4. Actual and estimated stream and ditch flow measurements during a seepage run on the Iliiliula-North Wailua Ditch on May 21, 2018.



Commercial Uses of Surface Water

The Kauai Department of Water (KDOW) estimates that island-wide, single-family water use comprises 53% of total water demand, with resort (25%), government (9%), and commercial (8%) making up the other largest categories (KDOW 2001). The 2020 estimated population in the Puhi-Lihue-Hanamaulu Water District is 14,606 with a projected 2050 population of 19,770. Residential water (domestic consumption) use is a public trust priority. Both commercial property and resort facilities are expected to increase by approximately 25% from 2000 to 2020. By 2020, the Puhi-Lihue-Hanamaulu Water District is expected to use approximately 4.066 mgd, with a 2050 projected demand of 5.503 mgd, a 35% increase. If the proportion of residential demand remains the same, only 2.91 mgd of the demand is a priority public trust usage. Of the 4.066 mgd of current usage, about 2.3 mgd is from the Waiahi Surface Water Treatment Facility, with groundwater sources making up the rest. The Hanamaulu aquifer system has a sustainable yield of 36 mgd, which is part of the larger Lihue Aquifer that has a sustainable yield of 131 mgd. The mean 10-year (2008-2017) average monthly pumpage from the Hanamaulu aquifer system was 1.682 mgd, and from the entire Lihue Aquifer was 8.724 mgd.

Modifications of Ditch Systems and Groundwater Recharge

Following the establishment of instream flow standards, one of the proposed measures to increase streamflow may be to decrease the amount of water diverted from streams. Such a measure has important implications to ground water recharge because it affects the amount of water available for irrigation. The effects of irrigation water on ground water recharge can be analyzed using the water budget equation[1]. Engott and Vana (2007) at the USGS conducted a study that estimated each of the water budget components for west and central Maui using data from 1926 to 2004. Components of the water budget include rainfall, fog drip, irrigation, runoff, evapotranspiration, and recharge. Results of the study were separated into six historical periods: 1926-79, 1980-84, 1985-89, 1990-94, 1995-99, and 2000-04. From 1979 to 2004, ground water recharge decreased 44 percent from 693 million gallons per day to 391 million gallons per day. The low recharge rate in 2004 coincides with the lowest irrigation and rainfall rates that were 46 percent and 11 percent lower than those in 1979, respectively. During this period, agricultural lands decreased 21 percent from 112,657 acres in 1979 to 88,847 acres in 2004. Further analysis revealed that a 20 percent decrease in irrigation rate could result in a 9 percent reduction in recharge. A similar study by Izuka et al. (2005) reported that a 34 percent decrease in irrigation rate constituted a 7 percent reduction in recharge in the Lihue basin in Kauai, Hawaii. Most streams in the Wailua hydrologic unit are gaining, that is, groundwater contributes to surface flows. This suggests that any restoration of surface flow to streams would not recharge groundwater resources.

Droughts, or periods of lower than average rainfall, have been shown to drastically decrease ground water recharge. The period of drought that occurred in 1998-2002, during which rainfall was at least 30 percent lower than the average annual rainfall was estimated to reduce recharge by 27 percent in west and central Maui (Engott and Vana, 2007). In the island of Kauai, the drought conditions reduced recharge in Lihue basin by 34-37 percent (Izuka et al., 2005). Even though droughts can have exacerbating effects on ground water recharge, these effects are transient and are usually mitigated by periods of higher than average rainfall (Engott and Vana, 2007). However, prolonged loss in irrigation water caused by decrease in the amount of water diverted at the ditches has greater effects on the long term trends of ground water levels.

[1] Water-budget is a balance between the amount of water leaving, entering, and being stored in the plant-soil system. The water budget method/equation is often used to estimate ground water recharge.

Utilization of Important Agricultural Lands

The Agricultural Lands of Importance to the State of Hawaii (ALISH) was a survey completed by the State Department of Agriculture (HDOA) in 1977, with the assistance of the Soil Conservation Service (SCS), U.S. Department of Agriculture, and the College of Tropical Agriculture, University of Hawaii. Three classes of agriculturally important lands were established for Hawaii in conjunction with the SCS in an effort to inventory prime agricultural lands nationwide. 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. ALISH was intended to serve as a long-term planning guidance for land use decisions related to important agricultural lands. HDOA is currently in the process of developing agricultural incentives based on classifications of Important Agricultural Lands. Wailua is comprised of approximately 22.7 percent of designated agricultural lands of importance (Table 13-4). Decreasing the amount of water diverted at the ditches located affects the amount of water available for the irrigation of crops on these important agricultural lands.

Table 13-4. Designated agricultural lands of importance by type in the Wailua hydrologic unit, Kauai. (Source:HDOA, 1977)

Commodity	Area (mi^2)	Percent of Unit
unclassified	0.57	1.08
Prime Lands	8.00	15.21
Unique Lands	0.01	0.02
Other Lands	3.36	6.39

From 1978 to 1980, HDOA prepared agricultural land use maps (ALUM) based on data from its Planning and Development Section and from SCS. The maps identified key commodity areas (with subclasses) consisting of: 1) Animal husbandry; 2) Field crops; 3) Orchards; 4) Pineapple; 5) Aquaculture; 6) Sugarcane; and Wetlands. Though both ALISH and ALUM datasets are considerably outdated, more recently the university of Hawaii at Hilo and DOA studied more current agricultural practices, which are listed in Table 13-5.

Table 13-5. Agricultural land uses and area distributions in the Wailua hydrologic unit, Kauai. (Source: University of Hawaii, 2015)

Commodity	Area (mi^2)	Percent of Unit
Diversified Crop	0.041	< 0.001
Pasture	7.50	14.26

The information is presented here to provide the Commission with present or potential noninstream use information (Figure 13-3 and 13-4). Most former sugarcane land in the region has been fallow, used for seed corn, or pasture since the closure of Lihue Plantation in 2002.

Figure 13-5. Agricultural land use for the Wailua hydrologic unit based on the Agricultural Lands of Importance for the State of Hawaii (ALISH) classification systems. (Source: State of Hawaii, Office of Planning, 2015g)

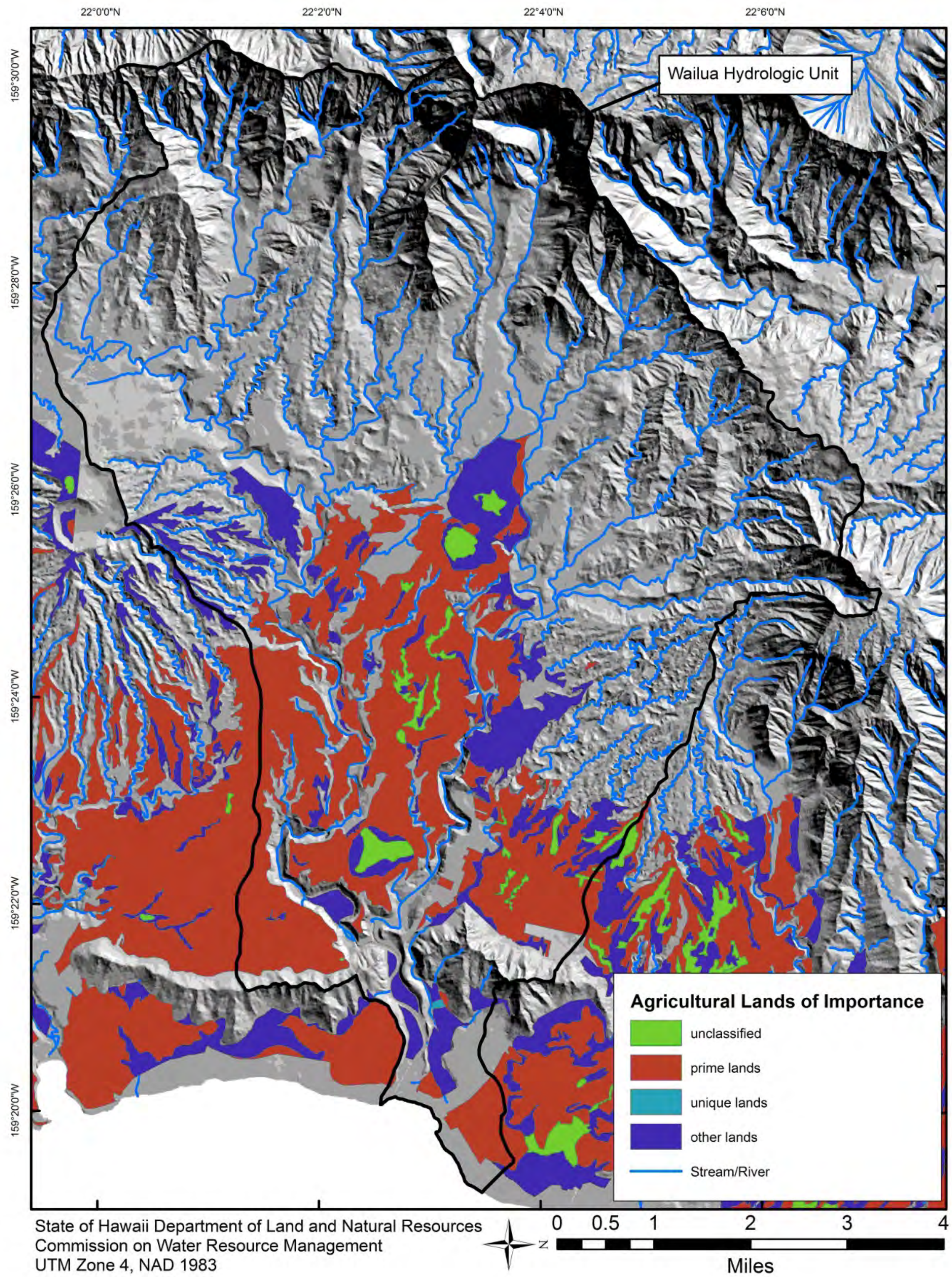
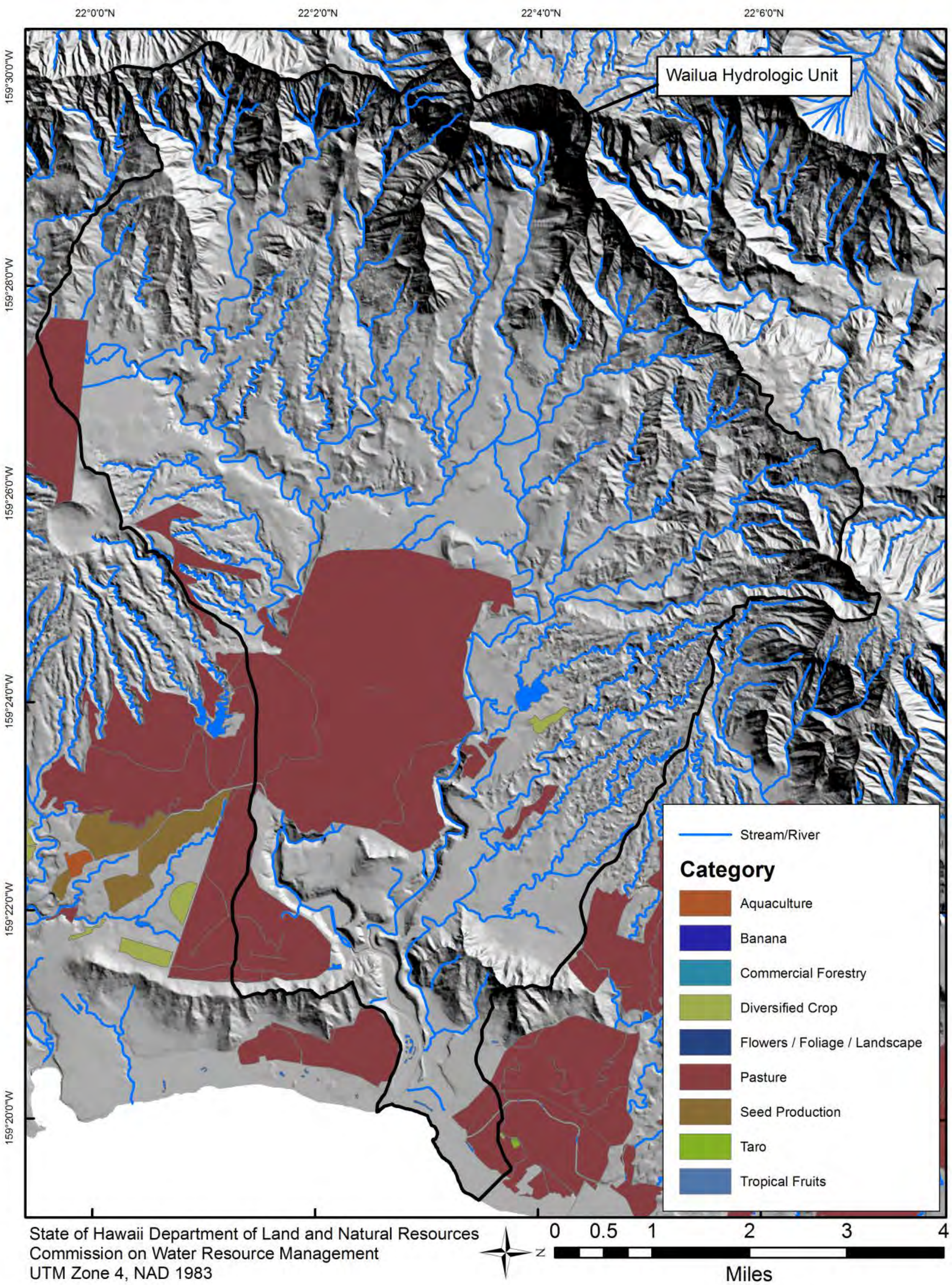


Figure 13-6. Agricultural commodities for the Wailua hydrologic unit, Kauai. (Source: University of Hawaii, 2015)



14.0 Bibliography

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

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

Bassiouni, M., and Oki, D.S. (2012). Trends and shifts in streamflow in Hawai'i, 1913-2008. Hydrological Processes, 27(10): 1484-1500.

Cheng, C.L. (2014). Low-flow characteristics of streams in the Lahaina District, West Maui, Hawaii. U.S. Geological Survey Scientific Investigations Report 2014-5087.

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

Coral Reef Assessment and Monitoring Program. (2007). Maui Watershed Information. Hawaii Institute of Marine Biology, Hawaii Coral Reef Assessment and Monitoring Program. Retrieved January 2008, from http://cramp.wcc.hawaii.edu/Watershed_Files/maui/WS_Maui.htm.

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

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

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

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

Engott, J.A., and Vana, T.T. (2007). Effects of Agricultural Land-Use Changes and Rainfall on Ground-Water Recharge in Central and West Maui, Hawai'i, 1926–2004: U.S. Geological Survey Scientific Investigations Report 2007–5103, 56 p.

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

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

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

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

Folk, W.H. (1990). A cultural Resources Reconnaissance for the Wailua River Hydropower Study. Addendum 6, Prepared for Ecosystem Research Institute.

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

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

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

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

Gingerich, S.B. (1999a). Estimating transmissivity and storage properties from aquifer tests in the Southern Lihue Basin, Kauai, Hawaii. U.S. Geological Survey Water-Resources Investigations Report 99-4066, 33 p.

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

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

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

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

Handy, E.S.C. (1940). The Hawaiian Planter—Volume 1. B.P. Bishop Museum Bulletin, 161. Honolulu.

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

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

Izuka, S.K. (2006). Effects of Irrigation, Drought, and Ground-Water Withdrawals on Ground-Water Levels in the Southern Lihue Basin, Kauai, Hawaii. U.S. Geological Survey Scientific Investigations Report 2006-5291, 42 p.

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

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

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

Kauai Department of Water. (2001). Water Plan 2020. http://www.kauaiwater.org/ce_waterplan2020app.asp Accessed 13 April 2018.

Kekaha Agriculture Association (2015). Response to Comission’s May 11, 2015 Letter. Schlack Ito LLC, 24 July 2015.

Kekua, L. Kehaulani, and Alapi, A. Aikane. (2010). A Cultural Study: Native Hawaiian Traditions, Customary Practices and Perspectives of the Natural and Cultural Resources of Puna, Kauai Island. Prepared for Kauai Island Utility Cooperation. L. Kehaulani Kekua- Native Kauai, LLC.

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

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

Kumu Pono Associates. (2001a). Wai o ke ola: He wahi moʻolelo no Maui Hikina, A collection of native traditions and historical accounts of the lands of Hāmākua Poko, Hāmākua Loa and Koʻolau, Maui Hikina (East Maui), Island of Maui: Prepared for East Maui Irrigation Company, 544 p.

Kumu Pono Associates. (2001b). Wai o ke ola: He wahi moʻolelo no Maui Hikina, Oral history interviews with families of Hāmākua Poko, Hāmākua Loa and Koʻolau, East Maui: Prepared for East Maui Irrigation Company, 512 p.

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

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

Macdonald, G.A. and Abbott. (1970). Volcanoes in the Sea. University of Hawaii Press, Honolulu, Hawaii, 441 p.

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

Modoski, M. (2018). Explore New Waters: From the mountains to the prairies to…New Jersey. Field & Stream, vol 123(2): 42-48.

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

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

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

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

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

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

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

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

Office of Hawaiian Affairs. Kipua Database. https://www.kipuadatabase.com Accessed July 2018.

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

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

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

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

Polhemus, D., and Asquith, A. (1996). Hawaiian Damselflies: A Field Identification Guide. Bishop Museum Press, Honolulu, HI.

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

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

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

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

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

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

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

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

State of Hawaii, Commission on Water Resource Management. (2015a). Irrigation Ditch GIS Layer [Database file]. Retrieved July 2015.

State of Hawaii, Commission on Water Resource Management. (2015b). Water Management Software to Estimate Crop Irrigation Requirement for Consumptive Use Permitting In Hawaii. Department of Land and Natural Resources, 61 p.

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

State of Hawaii, Commission on Water Resource Management. (2018). Well index database [Database file]. Retrieved January 2018.

State of Hawaii, Commission on Water Resource Management. (2015e). Diversion GIS Layer [Database file]. Retrieved July 2015.

State of Hawaii, Department of Agriculture. (2017). Agricultural Lands of Importance to the State of Hawaii for the islands of Kauai, Oahu, Maui, Molokai, Lanai, and Hawaii as of 1977. Retrieved April 2018.

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

State of Hawaii, Department of Health. (2004). Amendment and Compilation of Chapter 11-54, Hawaii Administrative Rules. Retrieved July 2015 from http://hawaii.gov/health/about/rules/ 11-54.pdf.

State of Hawaii, Department of Health, Environmental Planning Office. (2001). Hawaii's Water Quality Standards: A Public Guide [brochure]. Retrieved April 2015 from http://hawaii.gov/health/environmental/env-planning/wqm/wqsbrochure.pdf.

State of Hawaii, Department of Health, Environmental Planning Office. (2014). Final 2012 List of Impaired Waters in Hawaii Prepared Under Clean Water Act §303(d). Retrieved April 2017 from http://hawaii.gov/health/ environmental/env-planning/wqm/wqm.html.

State of Hawaii, Department of Health, Environmental Planning Office. (2007). 2006 State of Hawaii Water Quality Monitoring and Assessment Report: Integrated Report to the U.S. Environmental Protection Agency and The U.S. Congress Pursuant To Sections §303(D) and §305(B) Clean Water Act (P.L. 97-117). Retrieved January 2008 from http://hawaii.gov/health/environmental/ env-planning/wqm/wqm.html.

State of Hawaii, Division of Aquatic Resources. (1993). Native stream animals [Brochure].

State of Hawaii, Division of Aquatic Resources. (2017). Point-quadrat survey and other resources database. Accessed February 2017.

State of Hawaii, Division of Forestry and Wildlife. (2008a). Hawaii Forest Reserve System. Retrieved July 2015, from http://www.state.hi.us/dlnr/dofaw/frs/page2.htm.

State of Hawaii, Division of Forestry and Wildlife. (2008b). Watershed Partnership Program. Retrieved July 2015, from http://www.state.hi.us/dlnr/dofaw/wpp/index.html

State of Hawaii, Division of Forestry and Wildlife. (2010). Lihue-Koloa Forest Reserve. Retrieved July 2017, from http://dlnr.hawaii.gov/forestry/frs/reserves/management-plans/

State of Hawaii, Office of Planning. (1996). Stream gauges [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/strmgage.htm

State of Hawaii, Office of Planning. (1999). Parks [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/parks.htm

State of Hawaii, Office of Planning. (2002b). Hunting areas [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/huntareas.htm

State of Hawaii, Office of Planning. (2002c). Na Ala Hele state trails and access system [GIS data file]. Retrieved December 2007, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/nahtrails.htm

State of Hawaii, Office of Planning. (2002d). Public school locations [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/pubschools.htm

State of Hawaii, Office of Planning. (2003). National wetlands inventory [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/wetlnds.htm

State of Hawaii, Office of Planning. (2004a). Coastal resources [GIS data file]. Retrieved December 2007, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/cstrsrc.htm

State of Hawaii, Office of Planning. (2004b). Critical habitat [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/criticalhab.htm

State of Hawaii, Office of Planning. (2004c). Ditches [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/ditches.htm

State of Hawaii, Office of Planning. (2004d). Vegetation [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/veg.htm

State of Hawaii, Office of Planning. (2004e). 500 foot contours [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/cntrs500.htm

State of Hawaii, Office of Planning. (2005). Division of Aquatic Resources (DAR) stream [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/streams.htm

State of Hawaii, Office of Planning. (2007b). Reserves [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/reserves.htm

State of Hawaii, Office of Planning. (2008). Conservation District Subzones [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/cdsubzn.htm

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

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

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

State of Hawaii, Office of Planning. (2015d). State land use district [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/slud.htm

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

State of Hawaii, Office of Planning. (2015f). GAP Land Cover Analysis [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: ftp://ftp.gap.uidaho.edu/products/Hawaii.zip

State of Hawaii, Office of Planning. (2015g). ALISH [GIS data file]. Retrieved October 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/alish.htm

State of Hawaii, Office of Planning. (2015i). Areas of threatened and endangered plants [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/reserves.htm

State of Hawaii, Office of Planning. (2015j). Historic land divisions (Ahupuaa) for the island of Maui [GIS data file]. Retrieved December 2007, from Hawaii Statewide GIS Program Web site: http://hawaii.gov/dbedt/gis/histlanddiv.htm

State of Hawaii, Office of Planning. (2015k). C-CAP Land Cover Analysis: Impervious Surface and Land Cover Data [GIS data file]. National Oceanic and Atmospheric Administration, Coastal Services Center. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: ftp://ftp.gap.uidaho.edu/products/Hawaii.zip

State of Hawaii, Office of Planning. (2015l). census blocks [GIS data file]. Retrieved July 2015, from Hawaii Statewide GIS Program Web site: http://files.hawaii.gov/dbedt/op/gis/data/blocks10.htm

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

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

State of Hawaii, Office of Planning. (2018a). Landsat 7 satellite image for the islands of Kauai and Niihau [GIS data file]. Earthstar Geographics, LLC. Retrieved March 2018.

State of Hawaii, Office of Planning. (2018b). Kauai Street Centerlines [GIS data file]. County of Kauai, March 2008. Retrieved March 2018. http://files.hawaii.gov/dbedt/op/gis/data/kaustreets

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

Stearns, H.T. and MacDonald, G.A. (1942). Geology and Ground-Water Resources of the Island of Maui, Hawaii. [Hawaii Division of Hydrography, Bulletin 7]. [In cooperation with the Geological Survey, United States Department of the Interior.]

Strauch, A.M. (2017). Relative change in stream discharge from a tropical watershed improves predictions of fecal bacteria in near-shore environments. Hydrological Sciences Journal, 62(9): 1381-1393.

Strauch, A.M., MacKenzie, R.A. Bruland, G.L., Tingley III, R., C.P. Giardina. (2014). Climate change and land use drivers of fecal bacteria in tropical Hawaiian rivers. Journal of Environmental Quality, 43: 1475-1483.

Strauch, A.M., MacKenzie, R.A. Bruland, G.L., C.P. Giardina. (2015). Climate driven changes to rainfall and streamflow patterns in a model tropical island hydrological system. Journal of Hydrology, 523: 160-169.

Trust for Public Land. (1998). East Maui resource inventory: Prepared for National Park Service, Rivers, Trails, and Conservation Assistance Program, with the assistance of Bay Pacific Consulting, 101 p.

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

University of Hawaii. (2015). 2015 Hawaii Statewide Agricultural Land Use Baseline. University of Hawaii at Hilo Spatial Data Analysis and Visualization (SDAV) Laboratory.

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

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

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

U.S. Fish and Wildlife Service, (2018). Memo Trip Report – Makaleha Stream, Makaleha Springs, and North Fork Wailua Stream, Kauai. Pacific Islands Fish and Wildlife Office. 3 p.

U.S. Geological Survey. (1939). Summary of records of surface-water resources of the territory of Hawaii (1901-1938).

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

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

U.S. Geological Survey. (2001b). National Hydrography Dataset (NHD). Retreived July 2015, from http://nhd.usgs.gov/.

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

U.S. Geological Survey. (2018) National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), accessed May 2018 at URL [http://waterdata.usgs.gov/nwis/].

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

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

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

15.0 Appendices

Appendix A	Wailua Stream, Maui, Hawaii. June 2008.
State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources.

Appendix B	US Fish & Wildlife Service. Memo on trip report for Newcomb's snail survey. 3-12-18