Instream Flow Standard Assessment Report

Island of Molokai
Hydrologic Unit 4037
KAWELA

November 2021 **DRAFT PR-2021-04**

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

COVER
Satallite image of Kawela hydrologic unit with Kawela Stream flowing into the Pacific Ocean, Molokai [Google Earth, 2015].

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

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Acronyms and Abbreviations

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

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

1.0 Introduction

General Overview

The surface water hydrologic unit of Kawela is in the moku of Kona on the southern (leeward) flank of the East Molokai Volcano on Molokai Island (Figure 1-3). The Kawela hydrologic unit has an area of 5.385 square miles with a maximum elevation of 4,530 feet and a mean basin slope of 45 percent. Fifty-nine percent of the basin has a slope greater than 30 percent, with a mean basin elevation of 2440 feet and a mean annual precipitation of 63.4 inches, with mean annual rainfall ranging from approximately 10 inches near the coast to as much as 168 inches near the peak (Figures 1-4 and 1-5). The Kawela watershed is deeply incised by two main tributaries: the East Fork Kawela Stream and the West Fork Kawela Stream. The longest flow path in Kawela is the East Fork Kawela Stream at 6.75 miles in total length from the mouth to the headwaters. Above their confluence, the East Fork Kawela Stream is 5.88 miles in length and the West Fork Kawela Stream is 5.72 miles in length. Both streams drain narrow, v-shaped gulches. The geology and water resources are heavily influenced by the high permeability of the shield building phase making up the lower member of the East Molokai Volcanic Series, resulting in stream reaches that lose water to groundwater recharge, particularly below the 4,000-foot elevation. The gulch bottoms and the alluvial fan at the stream mouth are made up of older alluvium eroded from the upper elevations. The watershed is in the rain show of the former East Molokai Volcano, affecting rainfall-driven runoff and groundwater recharge. The basal aquifer discharges via spring flow along the coastline and as submarine groundwater discharge. Kawela's climate is characterized by persistent trade winds and mild temperatures in the mountainous portions with a high spatial gradient of rainfall, solar radiation, humidity, and wind leading to the hot and dry lower elevations. The dry summer season from May to September and wet winter season from October to April contrast greatly. Landcover in Kawela is composed of mostly grassland/herbaceous cover, shrubland, scrubland, and bare land characteristic of dryland and arid environments at middle to lower elevations. Evergreen forest and forested wetlands are located in the highest elevations where sufficient rainfall maintains wet forest and wetland. The area is part of the Kaunakakai census tract that has a 2010 total population of 4,503 people (U.S. Census Bureau, 2018). Three stream diversions were registered in 1989 in Kawela: one on the West Fork Kawela, one on the East Fork Kawela, and one on a tributary of the East Fork Kawela.

Current Instream Flow Standard

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

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

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

Instream Flow Standards

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

The 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.

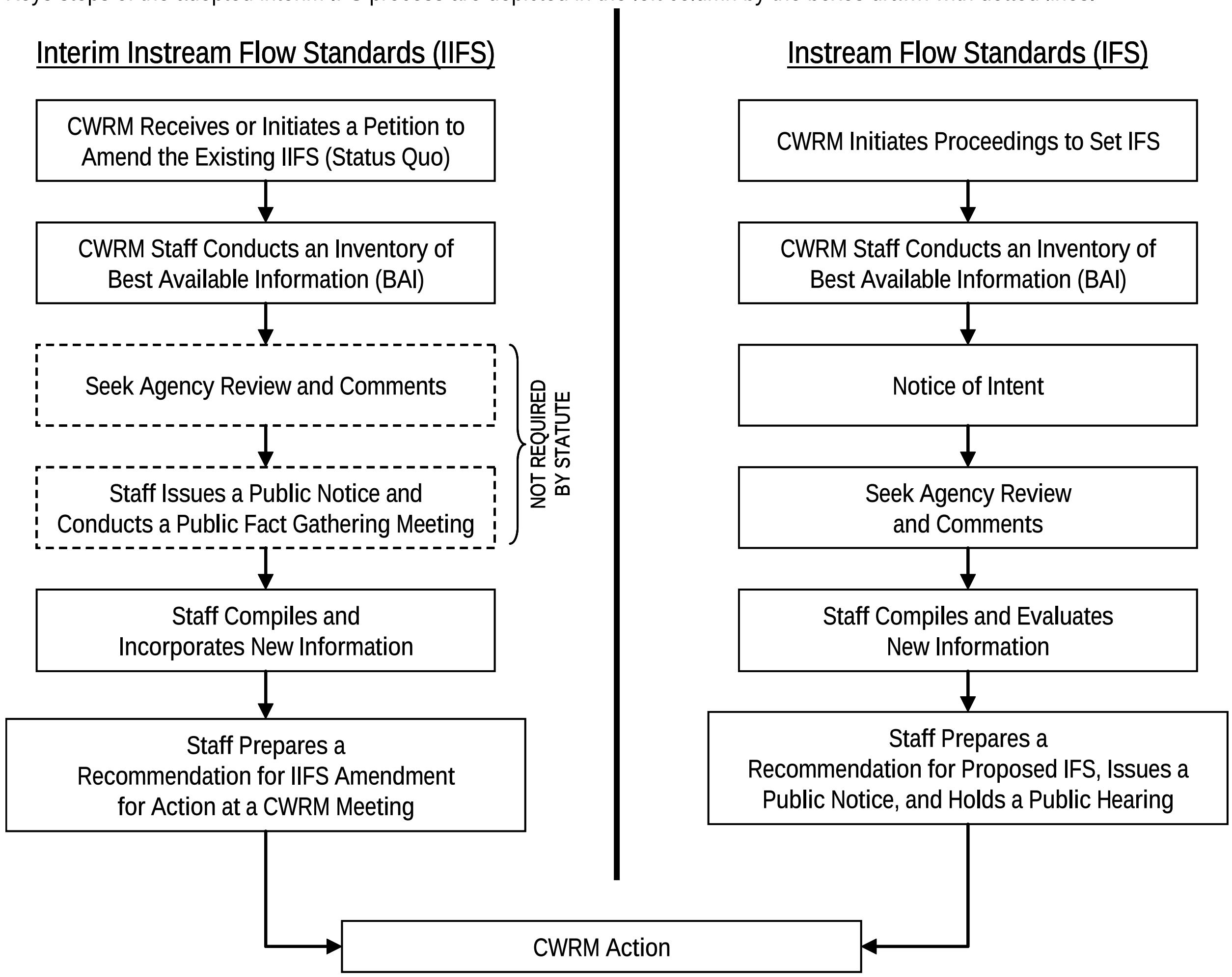
Figure 1-1. Information to consider in setting measurable instream flow standards.

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. Section 13.0 describes public trust uses of water not covered in other sections. Noninstream uses are summarized in Section 14.0. Maps are provided at the end of each section to help illustrate information presented within the section's text or tables. Finally, Section 15.0 provides a comprehensive listing of cited references and is intended to offer readers the opportunity to review IFSAR references in further detail.

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

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

Surface Water Hydrologic Units

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

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

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

Surface Water Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Figure 1-3. Quickbird World View 2 satellite imagery of the Kawela hydrologic unit and streams in Molokai, Hawaii.

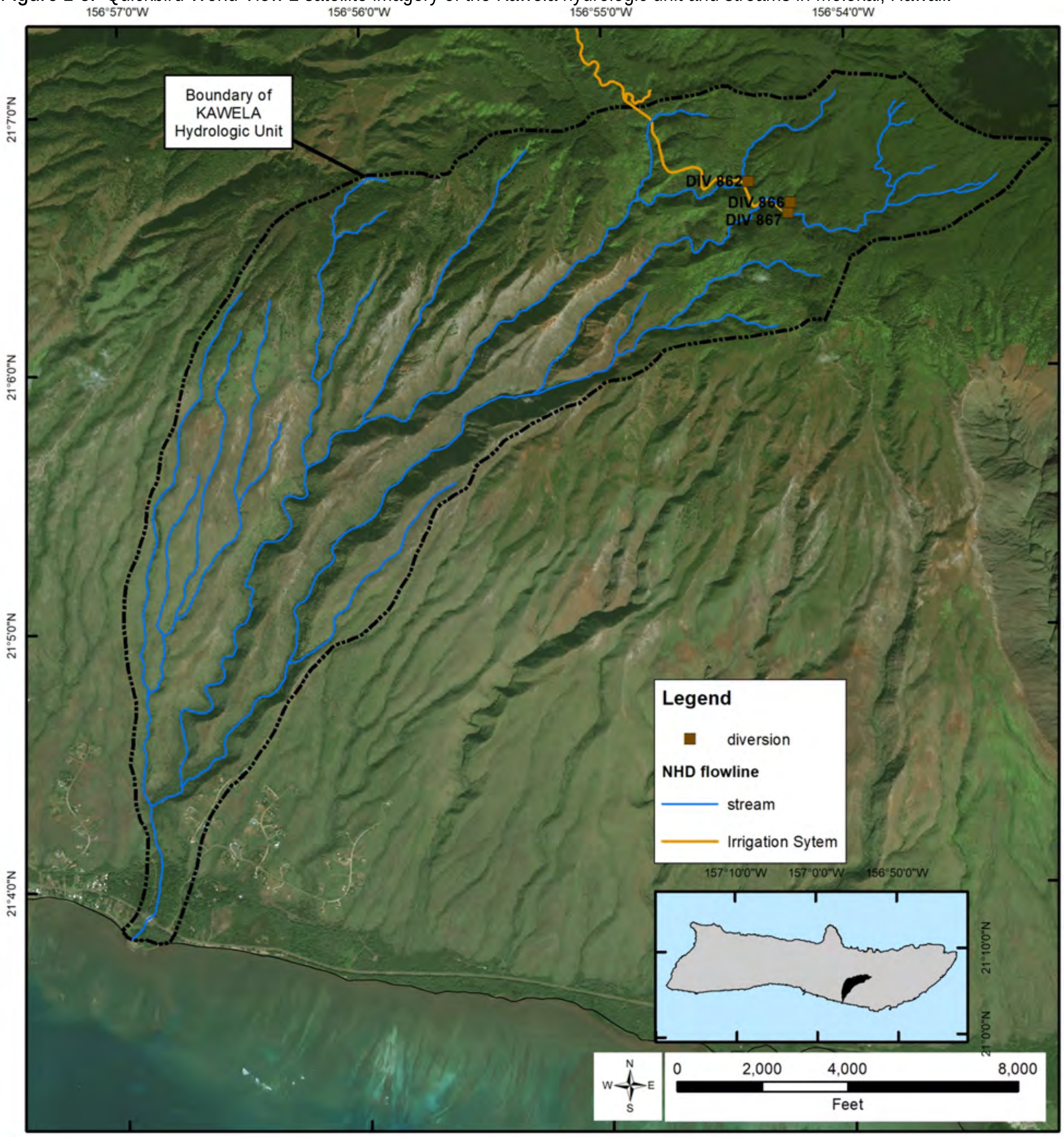


Figure 1-4. Elevation range of the Kawela hydrologic unit, Molokai. (U.S. Geological Survey, 2001)

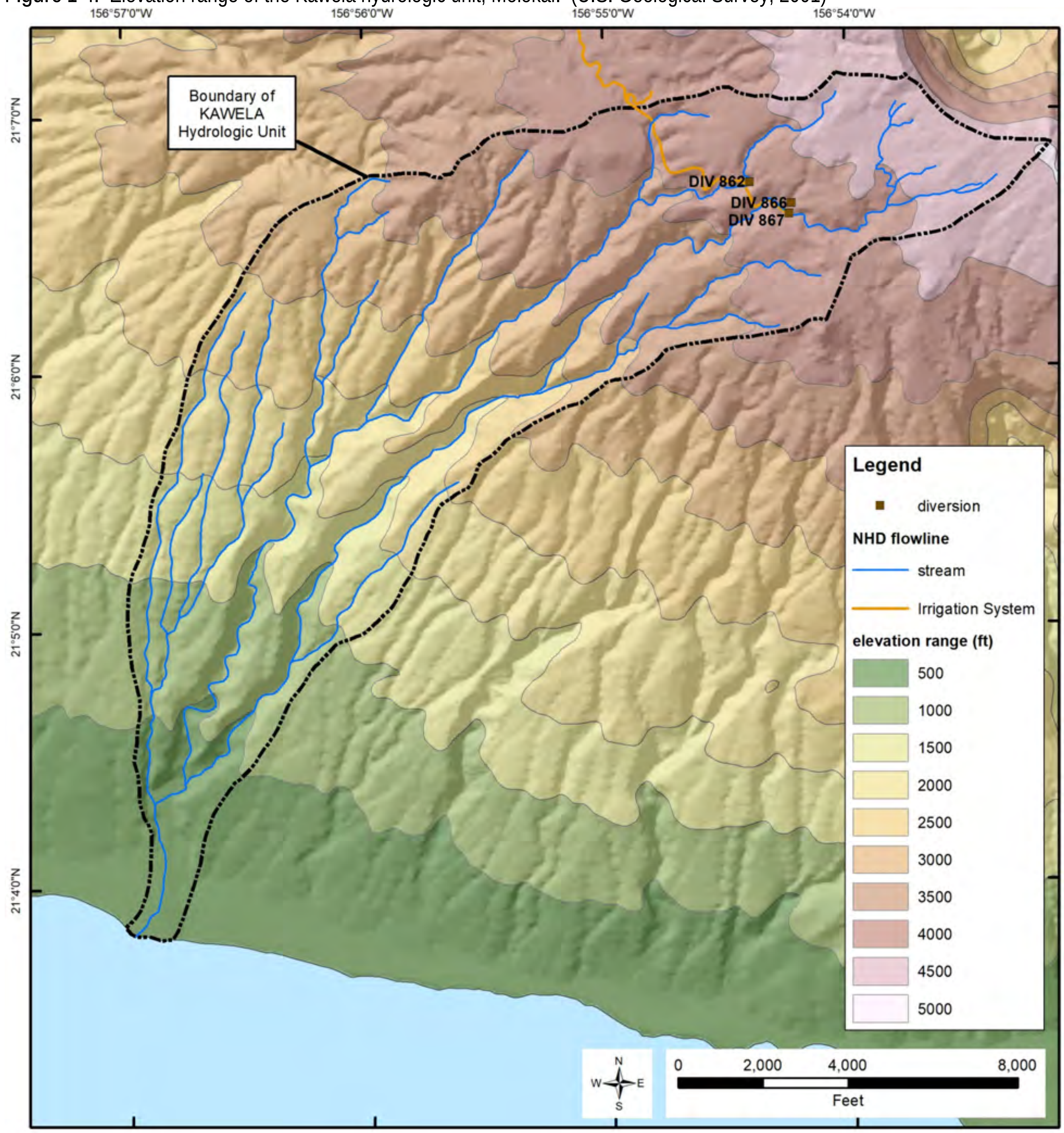


Figure 1-5. USGS topographic map of Kawela hydrologic unit, Molokai. (Source: U.S. Geological Survey, 1996)

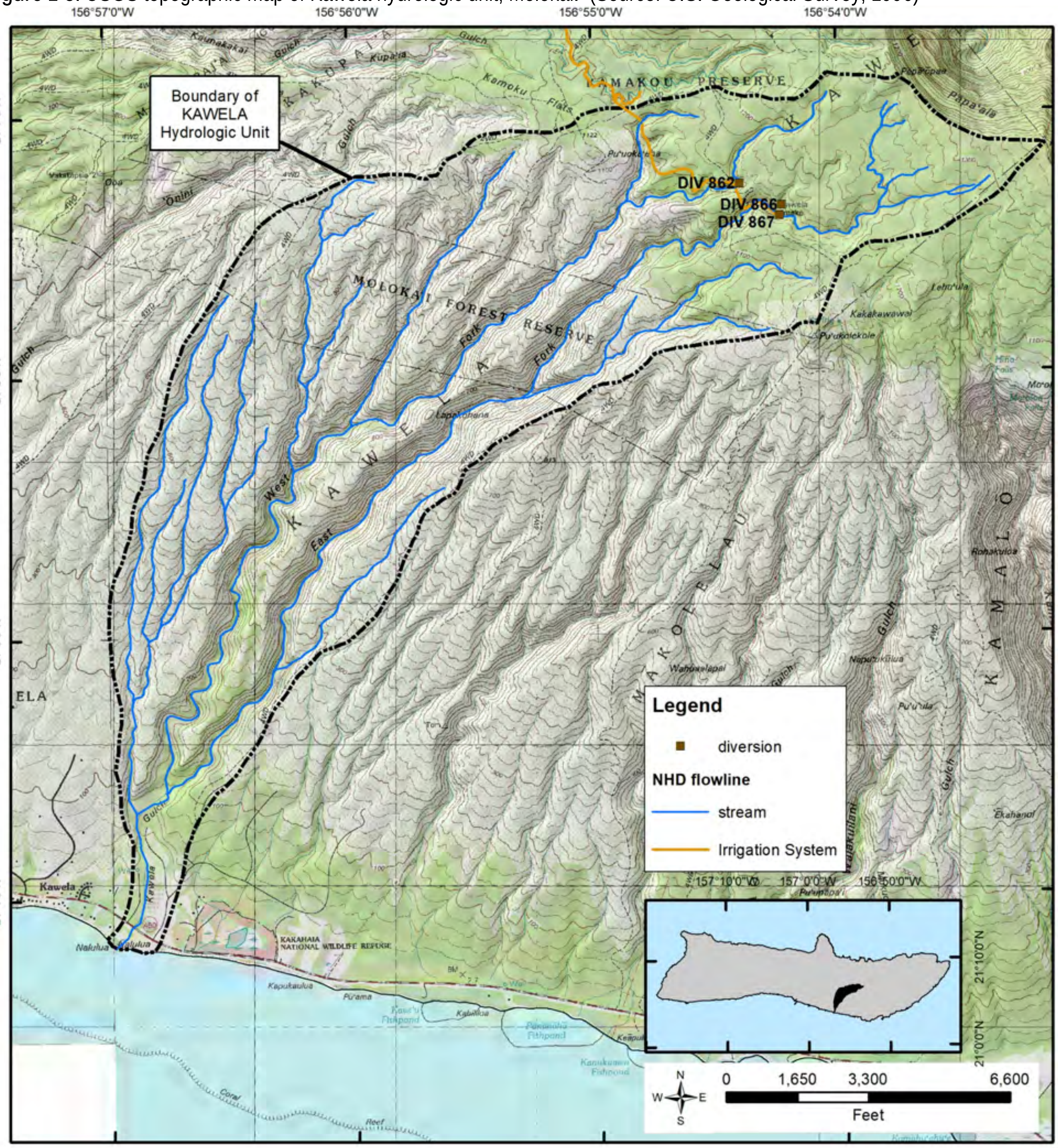
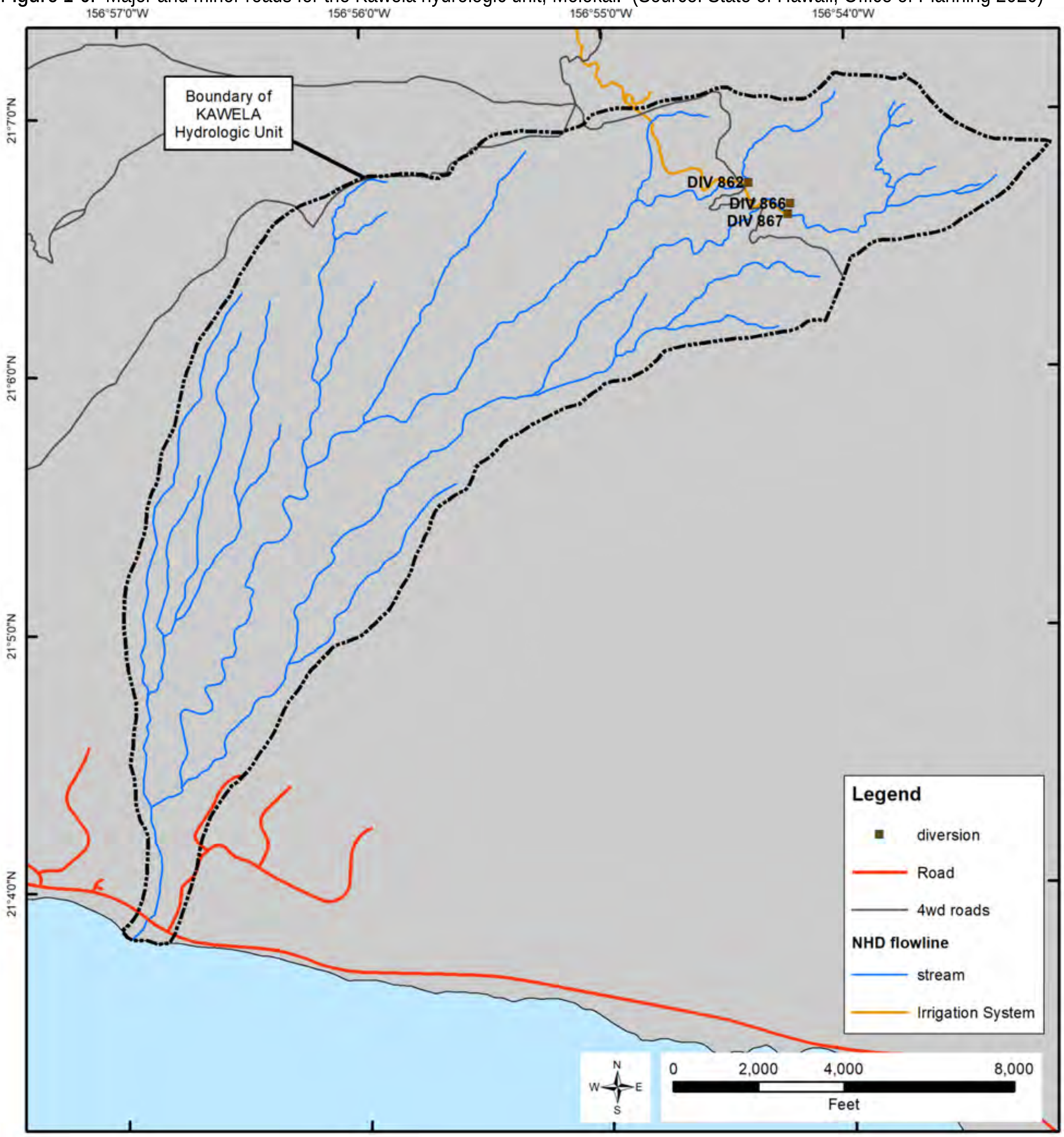


Figure 1-6. Major and minor roads for the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning 2020)



2.0 Unit Characteristics

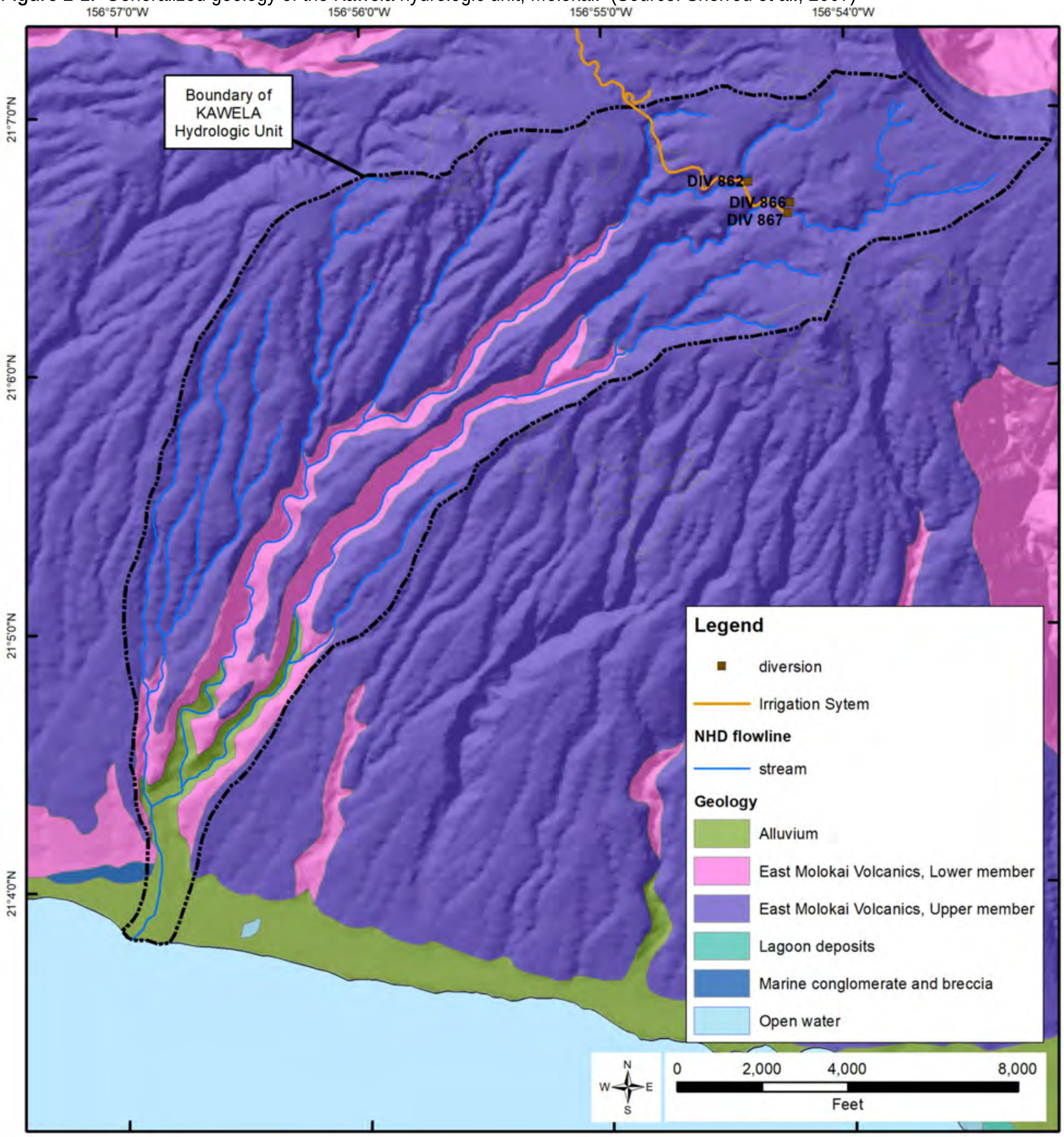
Geology

The surface geology of the Kawela hydrologic unit is characterized by East Molokai volcanics, which are mainly aa flows (lava characterized by jagged, sharp surfaces with massive, relatively dense interior) and pahoehoe flows (lava characterized by smooth, rope-like textures) poured out at progressively longer intervals so that numerous valleys were cut between the younger lava flows (Figure 2-2). The East Molokai Volcano covers an area 26 miles long by 8 miles wide and are 4,970 feet thick above sea level at the peak, extending down to the ocean floor approximately 12,000 feet. The East Molokai Volcano was built along a northwest rift zone and east rift zone with lava flows of andesites and trachytes composition overflowing the basalts of the West Molokai Volcano. There are two differing member series, the upper and lower members, with the caldera complex forming part of the lower member (Stearns and MacDonald, 1947). The lower member is composed of thin-bedded vesicular pahoehoe and aa lava flows ranging from a few feet to 75 feet in thickness and exposed wherever the upper member was not overlying or where the upper member was removed by erosion, primarily in heavily incised gulches. These basalts are dominated by nonporhyritic and porphyritic olivine basalts with olivine-augite porphyries common in the youngest flows. An ashy soil 3 to 12 inches thick separate the lower member from the upper member series. The upper member rocks are chiefly composed of oligoclase andesite and to a lesser extent andesine andesite and trachyte. These lava flows range from 20 to 100 feet thick aa and often with heavy clinker beds. Columnar jointed and platy form the most dense parts of the flows. The denser upper member protects the more easily eroded lower member, with stream channels “jumping” at cascades or waterfalls where they cut through into the weaker basalts. When the thick upper member lava flows spread out as they move down the slope, they force streams to diverge from their normal course radial to the dome and follow the edge of the flow, resulting in streams receiving more than expected share of water and cutting abnormally deep canyons. All of the volcanic rocks are very permeable except the dikes, which are primarily exposed on the windward slopes of the East Molokai Volcano, and not the leeward slopes where the Kawela hydrologic unit is located. Ash beds in the upper member result in some perched water bodies where rainfall is sufficient. The generalized geology of the Kawela hydrologic unit is depicted in Figure 2-2 and summarized in Table 2-1.

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

Name	Rock Type	Lithology	Age Range (mya)	Area (mi^2)	Percent of Unit (%)
East Molokai Volcanics	Lava flows	Aa	1.3-1.5	4.218	78.12
East Molokai Volcanics	Lava flows	Pahoehoe and Aa	1.5-1.8	0.806	14.97
East Molokai Volcanics	Vent deposits	Cinder and Spatter	1.3-1.5	0.093	1.73
Alluvium	Sand and Gravel			0.242	4.49
East Molokai Volcanics	Domes	Thick lava over vent sites	1.3-1.5	0.025	0.46
Marine conglomerate and breccia	Fossiliferous breccia	Shells, coral, and volcanic lithic clasts		0.001	0.02

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



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 fastest infiltration rates; group D soils have the slowest. In the Kawela hydrologic unit, soils are dominated (83.7%) by the Rough broken land, rough mountainous land, and stony alluvial land of the entisols and inceptisols series categorized as group D soils (Table 2-2). The hydrologic unit also has soils in group B (12.5%), in group C (3.7%), and in group A (<0.1%). The soil orders for the Kawela hydrologic unit are identified in Figure 2-2.

Kawela consists largely of soils that are deep, nearly level to moderately steep, and well-drained to excessively drained. There is much stony land and rock land associated with the hydrologic unit, especially in the uplands and gulches. The textures are generally moderately fine textured or fine, with small areas of coarse-textured to fine textured subsoil, especially on uplands. Rough broken land and Olli associated soils are shallw to deep, very steep to precipitous soils in gulches and moderately deep to deep, gently sloping to steeply sloping, well-drained soils with a medium-texutred and moderately fine textured subsoil on uplands. The Amalu, Olokui, and rough mountainous land soils make up shallow, very steep lands along the gulches and deep to shallow, gently sloping hills, with poorly drained soils over soft weathered rock. Kawela is characterized by a large alluvial fan and wide drainageway below the confluence of east and west branches.

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

Soil Series Unit	Hydrologic Soil Group	Area (mi²)	Percent (%)
Rock outcrop	D	2.315	21.50%
Rough mountainous land	D	2.076	19.29%
Rough broken land	D	1.494	13.88%
Rock land	D	0.970	9.01%
Very stony land	D	0.894	8.31%
Amalu	D	0.770	7.15%
Oli	B	0.660	6.13%
Olelo	B	0.368	3.42%
Tropaquods	C	0.288	2.68%
Olokui	D	0.258	2.40%
Very stony land, eroded	D	0.216	2.01%
Naiwa	B	0.180	1.67%
Pulehu	B	0.100	0.93%
Stony alluvial land	D	0.076	0.71%
Kahanui	B	0.042	0.39%
Niulii variant	C	0.038	0.35%
Kealia	B	0.014	0.13%
Jaucas	A	0.006	0.06%

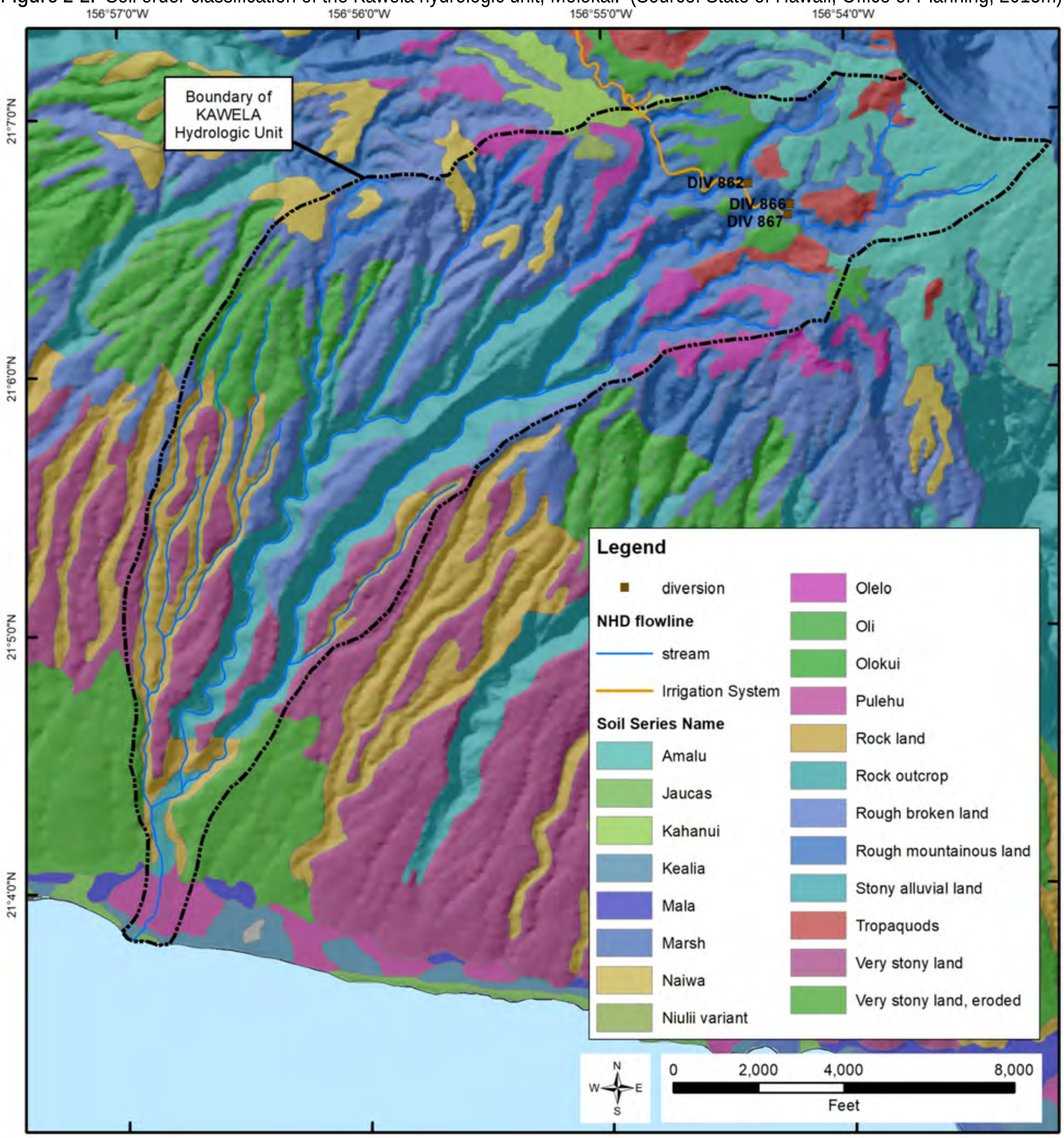
Rainfall

Rainfall on Molokai is affected by the orographic[1] effect and in Kawela specifically by the rainshadow effect (Figure 2-3). Orographic precipitation occurs when the prevailing northeasterly trade winds lift warm air up the windward side of the mountains into higher elevations where cooler temperatures persist. As moist air cools, water condenses, and the air mass releases precipitation. As a result, frequent and heavy rainfall is observed on the windward mountain slopes. Some of this rainfall is blown into the upper elevations of the leeward hydrologic units by the prevailing wind patterns. As the Kawela hydrologic unit

[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.

is situated on the leeward side of East Molokai Volcano, it does not receive substantial orographic rainfall except in the uppermost elevations (Figure 2-4).

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

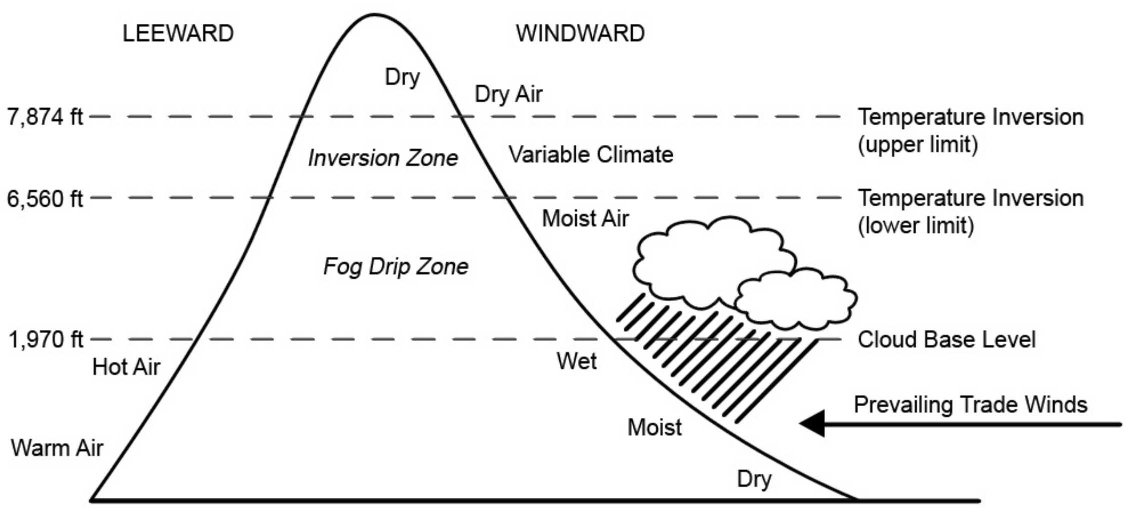


The temperature inversion zone, the range of elevations where temperature increases with elevation, typically extends from 6,560 feet to 7,874 feet. This region is identified by a layer of moist air below and dry air above (Giambelluca and Nullet, 1992). The fog drip zone occurs below the elevation where cloud height is restricted by the temperature inversion (Sholl et al., 2002). Fog drip is a result of cloud-water droplets impacting vegetation (Scholl et al., 2002) and can contribute significantly to groundwater recharge. Above the inversion zone, the air is dry and the sky is frequently clear (absence of clouds) with high solar radiation, creating an arid atmosphere with little rainfall. This region is found in the higher elevations of the largest volcanoes in Hawaii (e.g., Mauna Kea, Haleakala).

A majority of the mountains in Hawaii, including the East Molokai Volcano, peak in the fog drip zone, where cloud-water is intercepted by vegetation. In such cases, air passes over the mountains, warming and drying while descending on the leeward mountain slopes. The steep elevational gradient around the island forces moisture-laden air to rapidly rise in elevation (over 4,000 feet) in a short distance, resulting in a rapid release of rainfall. Some of this rainfall gets blown by the prevailing winds across the island peak towards the leeward side of the island. The high spatial variability in rainfall is evident across the hydrologic unit. Rainfall is greatest during the month of March, although rainfall is somewhat evenly distributed across the year (Table 2-3).

The fog drip zone on the windward side of islands extends from the cloud base level at 1,970 feet to the lower limit of the most frequent temperature inversion base height at 6,560 feet (Giambelluca and Nullet, 1992). Shade (1999) used the monthly fog drip to rainfall ratios for the windward slopes of Mauna Loa on the Island of Hawaii (Table 2-3) to calculate fog drip contribution to the water-budget in windward East Maui. The fog drip to rainfall ratios were estimated using: 1) the fog drip zone boundaries for East Maui (Giambelluca and Nullet, 1991); and 2) an illustration that shows the relationship between fog drip and rainfall for the windward slopes of Mauna Loa, Island of Hawaii (Juvik and Nullet, 1995). Based on the elevations above 2,000 feet, 3.412 square miles of the Kawela hydrologic unit (63.3%) lies in the fog drip zone. The total contribution from fog drip to the water budget based on percent of fog drig from monthly rainfall is 24.58 inches. Mean annual rainfall measured at Kaunakakai (station 536; elevation 10 feet; active from 1933-present) is 13.77 inches and measured at Pepeopae (station 541.1; 4,200 feet; active from 1956-1978) was 137.78 inches (Giambelluca et al. 2013). Mean annual rainfall for the entire the Kawela hydrologic unit is 63.4 inches, although it is 80.29 inches in the fog drip zone, with monthly rainfall provided in Table 2-3.

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



Solar Radiation

Solar radiation is the sun's energy that arrives at the Earth's surface after considerable amounts have been absorbed by water vapor and gases in the Earth's atmosphere. The amount of solar radiation to reach the surface in a given area is dependent in part upon latitude and the sun's declination angle (angle from the sun to the equator), which is a function of the time of year. Hawaii's trade winds and the temperature inversion layer greatly affect solar radiation levels, the primary heat source for evaporation. High mountain ranges block moist trade-wind air flow and keep moisture beneath the inversion layer (Lau and Mink, 2006). As a result, windward slopes tend to be shaded by clouds and protected from solar radiation, while dry leeward areas receive a greater amount of solar radiation and thus have higher levels of evaporation. In the Kawela hydrologic unit, average annual solar radiation ranged from 196.7 to 239.3 W/m^2 per day (Figure 2-5). It is greatest at the coast and decreases toward the uplands, where cloud cover is more of an influence (Giambelluca et al., 2014).

Table 2-3. Monthly rainfall above 2,000 feet and fog drip contribution in the Kawela hydrologic unit, Molokai.

Month	Ratio (%)	Mean Rainfall (in)	Contribution (in)
January	13	10.08	1.31
February	13	8.08	1.05
March	13	9.50	1.24
April	27	7.27	1.96
May	27	6.08	1.64
June	27	4.84	1.31
July	67	4.22	2.83
August	67	4.36	2.92
September	67	4.53	3.04
October	40	4.54	1.82
November	40	7.16	2.86
December	27	9.63	2.60

Evaporation

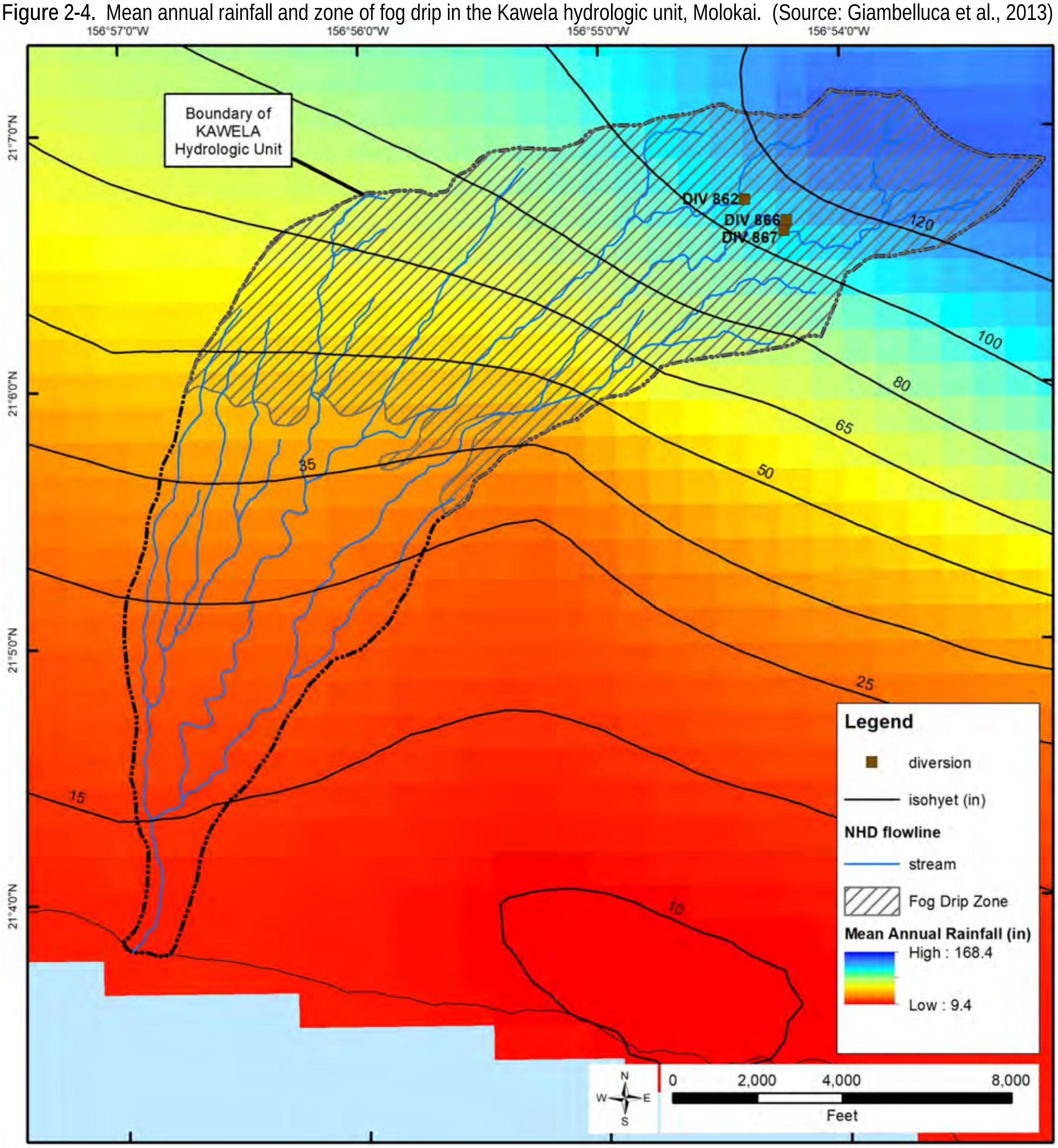
Evaporation is the loss of water to the atmosphere from soil surfaces and open water bodies (e.g. streams and lakes). Evaporation from plant surfaces (e.g. leaves, stems, flowers) is termed transpiration. Together, these two processes are commonly referred to as evapotranspiration, and it can significantly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

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

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

evaporation data for Hawaii, evaporation generally decreases with increasing elevation below the temperature inversion[4] and the cloud layer (Figure 2-6). At low elevations near the coast, pan evaporation rates are influenced by sensible heat advection from the ocean (Nullet, 1987).

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



Pan evaporation rates are enhanced in the winter by positive heat advection from the ocean, and the opposite occurs in the summer when pan evaporation rates are diminished by negative heat advection (Giambelluca and Nullet, 1992). With increasing distance from the windward coasts, positive heat advection from dry land surfaces becomes an important factor in determining the evaporative demand on

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

the landscape (Nullet, 1987). Shade (1999, Fig. 9) estimated pan evaporation rates of 30 inches per year below 2,000 feet elevation to 90 inches per year near the coast. Within the cloud layer, evaporation rates are particularly low due to the low radiation and high humidity caused by fog drip. Pan evaporation rates dropped below 30 inches per year in this area as reported in Shade (1999, Fig. 9). Near the average height of the temperature inversion, evaporation rates are highly variable as they are mainly influenced by the movement of dry air from above and moist air from below (Nullet and Giambelluca, 1990). Above the inversion, clear sky and high solar radiation at the summit causes increased evaporation, with pan evaporation rates of about 50 to 70 inches per year (Shade, 1999, Fig. 9). For example, Ekern and Chang (1985) reported evaporation increased to 50 percent more than surface oceanic rates near the Mauna Kea crest on the island of Hawaii. A common approach to estimating evaporation is to employ a relationship between potential evaporation and the available water in the watershed, estimated as potential evapotranspiration. Mean annual potential evapotranspiration in the Kawela hydrologic unit (Figure 2-6) averages 102.0 inches per year and ranges from 69.3 to 194.9 inches (Giambelluca et al. 2014). Annual actual evapotranspiration for the Kawela hydrologic unit ranges from 9.56 inches to 46.0 inches per year, with an average of 29.3 inches per year.

Land Use

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

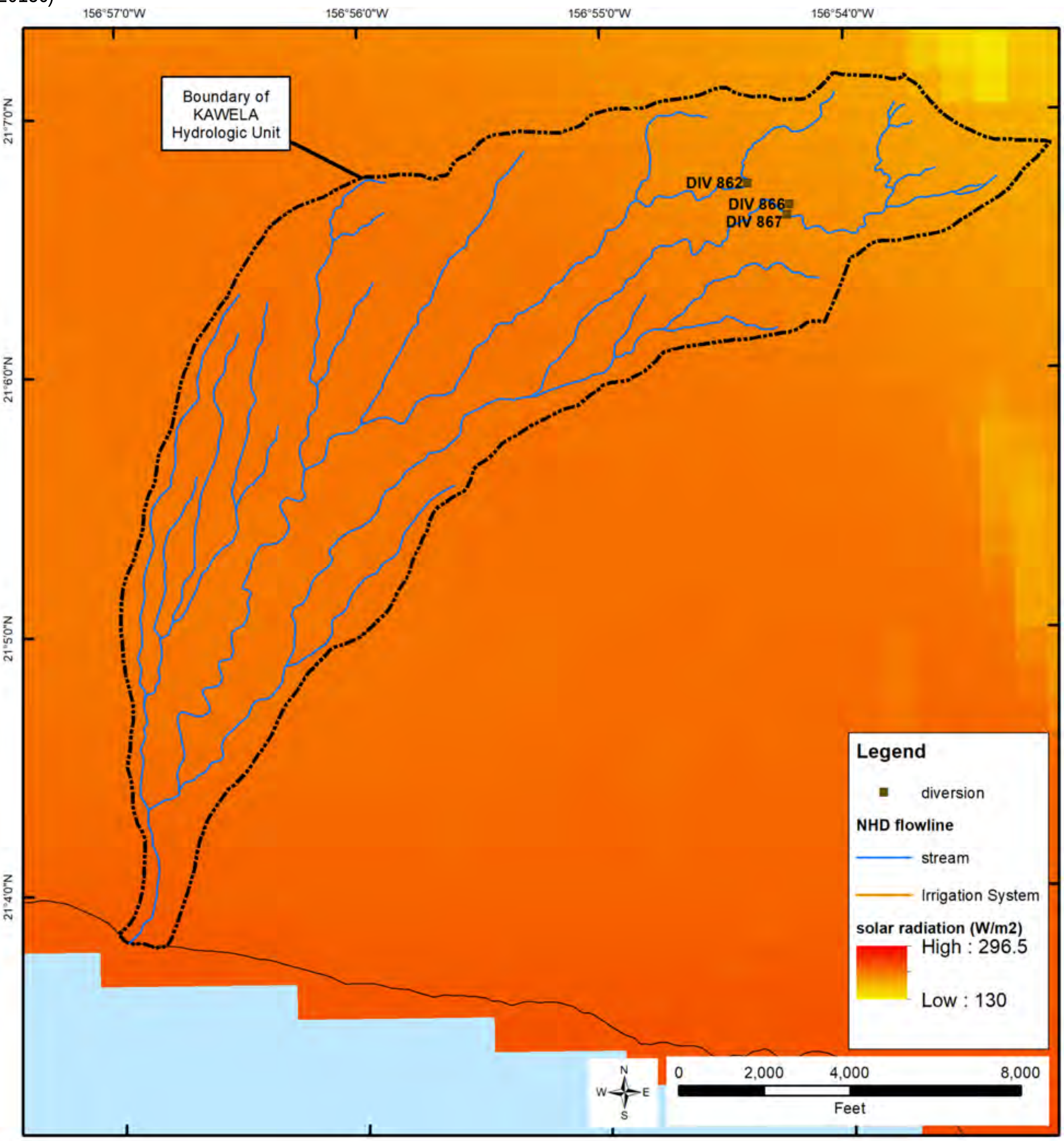
Land use classification is an important component of examining the benefits of protecting instream uses and the appropriateness of surface water use for noninstream uses. While some may argue that land use, in general, should be based upon the availability of surface and groundwater resources, land use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

As of 2014, 59.6 percent (3.208 square miles) of the land in Kawela is classified as conservation, 40.3 percent is classified as agriculture (2.168 square miles). Less than 0.1 percent of the hydrologic unit is classified as urban and none is classified as rural. The conservation district is in the upper elevation sections of the hydrologic unit (Figure 2-7).

Land Cover

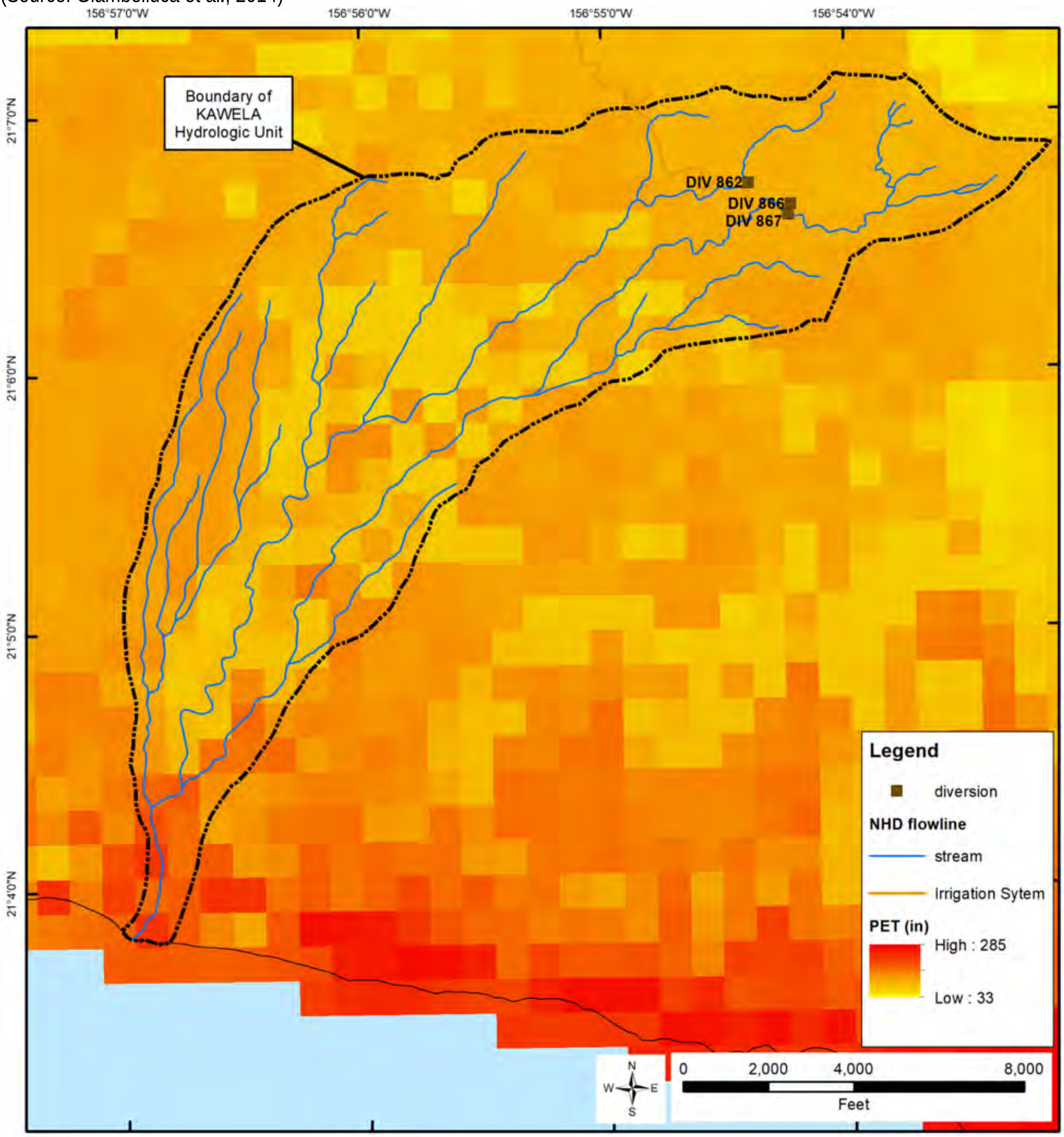
Land cover for the hydrologic units of Kawela is represented by two separate 30-meter Landsat satellite datasets. One of the datasets, developed by the Coastal Change Analysis Program (C-CAP), provides a general overview of the land cover types in Kawela, e.g., forested, wetland, grassland, shrub land, with minor developed areas, pasture and bare land (Table 2-4, Figure 2-8). The second is developed by the Hawaii Gap Analysis Program (HI-GAP), which mapped the National Vegetation Classification System (NVCS) associations for each type of vegetation, creating a more comprehensive land cover dataset (Table 2-5, Figure 2-9).

Figure 2-5. Mean annual solar radiation of the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2015c)



The land cover maps (Figures 2-8, 2-9) provide a general representation of the land cover types in Kawela hydrologic unit. Based on the two land cover classification systems, the land cover of Kawela consists mainly of alien shrubland, alien grassland and native shrubland. In the higher elevations, open ohia forest, and native shrubland with sparse ohia dominate, with kiewe forest shrubland dominating lower elevations. Given that the scale of the maps is relatively large, they may not capture the smaller cultivated lands or other vegetation occupying smaller parcels of land. Land cover types may also have changed slightly since the year when the maps were published, particularly regarding the use of pasture lands and the extent of native or non-native vegetation.

Figure 2-6. Mean annual potential evapotranspiration (Penman-Monteith method) of the Kawela hydrologic unit, Molokai. (Source: Giambelluca et al., 2014)



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.

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

Land Cover	Description	Area (mi²)	Percent of Unit
Scrub	Areas dominated by woody vegetation less than 6 meters in height	2.005	37.23%
Grassland	Natural and managed herbaceous cover	1.094	20.31%
Evergreen Forest	Areas where more than 67% of the trees remain green throughout the year	0.891	16.55%
Bare Land	Bare soil, gravel, or other earthen material with little or no vegetation	0.652	12.11%
Palustrine Forested Wetland	Included tidal and nontidal wetlands dominated by woody vegetation 5 meters in height or more	0.629	11.67%
Palustrine Scrub/Shrub Wetland	Includes tidal and nontidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity is below 0.5%	0.089	1.65%
Impervious surface		0.012	0.22%
Developed Open Space	Areas mostly managed grasses or low-lying vegetation planted for recreation, erosion control, or aesthetic purposes	0.010	0.19%
Palustrine Emergent Wetland	Includes tidal and nontidal wetlands dominated by persistent emergent vascular plants, mosses, or lichens	0.003	0.06%
Open Water		0.001	0.01%
Unconsolidated Shore		<0.001	<0.01%
Estuarine Emergent Wetland	Erect, rooted, herbaceous hydrophytes, excluding mosses and lichens	<0.001	<0.01%
Estuarine Scrub/Scrub Wetland	Areas dominated by woody vegetation less than 20 feet tall that are small or stunted in all water regimes except subtidal	<0.001	<0.01%

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

Peak floods in the Kawela hydrologic unit were monitored at USGS 16415000 on East Fork Kawela Gulch (basin area of 0.44 square miles) for 25 years from 1946-1971. The magnitude of the peak flows at this station for the 2-, 5-, 10-, 50-, and 100-year return intervals are: 255, 498, 729, 1510, and 1990 cfs, respectively. Peak floods in the Kawela hydrologic unit have also been monitored at USGS 16415600 on Kawela Gulch (basin area of 5.28 square miles) from 2001 to 2021. The largest magnitude peak flows at this station was 3,190 cfs measured on November 27, 2001. Using basin characteristics within the USGS

Streamstats GIS-based program, it is possible to model the magnitude of floods at the mouth of streams, even if they are not monitored (Rea and Skinner, 2012). The 2-, 5-, 10-, 50-, and 100-year flood magnitudes in Kawela Stream at the stream mouth are estimated as 249, 768, 1360, 3340, 4440 cfs, respectively. The Federal Emergency Management Agency (FEMA) developed maps that identify the flood-risk areas in an effort to mitigate life and property losses associated with flooding events. Based on these maps, the entire hydrologic unit has an area of minimal flood hazard (Figure 2-10).

Table 2-5. HI-GAP land cover classes and area distribution Kawela hydrologic unit, Molokai. (Source: USGS, 2005)

Land Cover	Area (mi^2)	Percent of Unit
Alien Shrubland	2.171	40.28%
Open Ohia Forest	1.216	22.55%
Native Shrubland / Sparse Ohia (native shrubs)	0.815	15.13%
Kiawe Forest and Shrubland	0.682	12.66%
Alien Grassland	0.237	4.40%
Alien Forest	0.122	2.26%
Very Sparse Vegetation to Unvegetated	0.057	1.05%
Developed, Low Intensity	0.038	0.70%
Mixed Native-Alien Forest	0.024	0.44%
Mixed Native-Alien Shrubs and Grasses	0.021	0.39%
Undefined	0.002	0.05%
Native Dry Cliff Vegetation	0.002	0.04%
Bog Vegetation	0.002	0.03%
Wetland Vegetation	0.002	0.03%

Drought

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

Impacts of drought are complex and can be categorized into three sectors: water supply; agriculture and commerce; and environment, public health, and safety sectors (State of Hawaii, Commission on Water Resource Management, 2005b). The water supply sector encompasses urban and rural drinking water systems that are affected when a drought depletes ground water supplies due to reduced recharge from rainfall or surface water due to reduced stream flow. The agriculture and commerce sector includes the reduction of crop yield and livestock sizes due to insufficient water supply for crop irrigation and maintenance of ground cover for grazing. The environmental, public health, and safety sector focuses on wildfires that are both detrimental to the forest ecosystem and hazardous to the public. It also includes the impact of desiccating streams, such as the reduction of instream habitats for native species. Droughts have affected the islands throughout Hawaii's recorded history. The most severe events of the recent past years are associated with the El Niño phenomenon. In January 1998, the National Weather Service's network of 73 rain gauges throughout the State did not record a single above-normal rainfall, with 36 rain gauges recording less than 25 percent of normal rainfall (State of Hawaii, Commission on Water Resource Management, 2005b). The most recent drought occurred in 2000-2002, affecting all islands, especially the southeastern end of the State.

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 Molokai are summarized in Table 2-6. Based on the 12-month SPI, the Western and Central regions of Molokai has the greatest risk to drought impact regions because of its dependence on limited surface and groundwater resources. The growing population in the already densely populated area further stresses the water supply.

Table 2-6. Drought risk areas for Molokai. (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	--	--	--
Agriculture and Commerce	Western Molokai	--	--
Environment, Public Health and Safety	--	Central Molokai	--

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

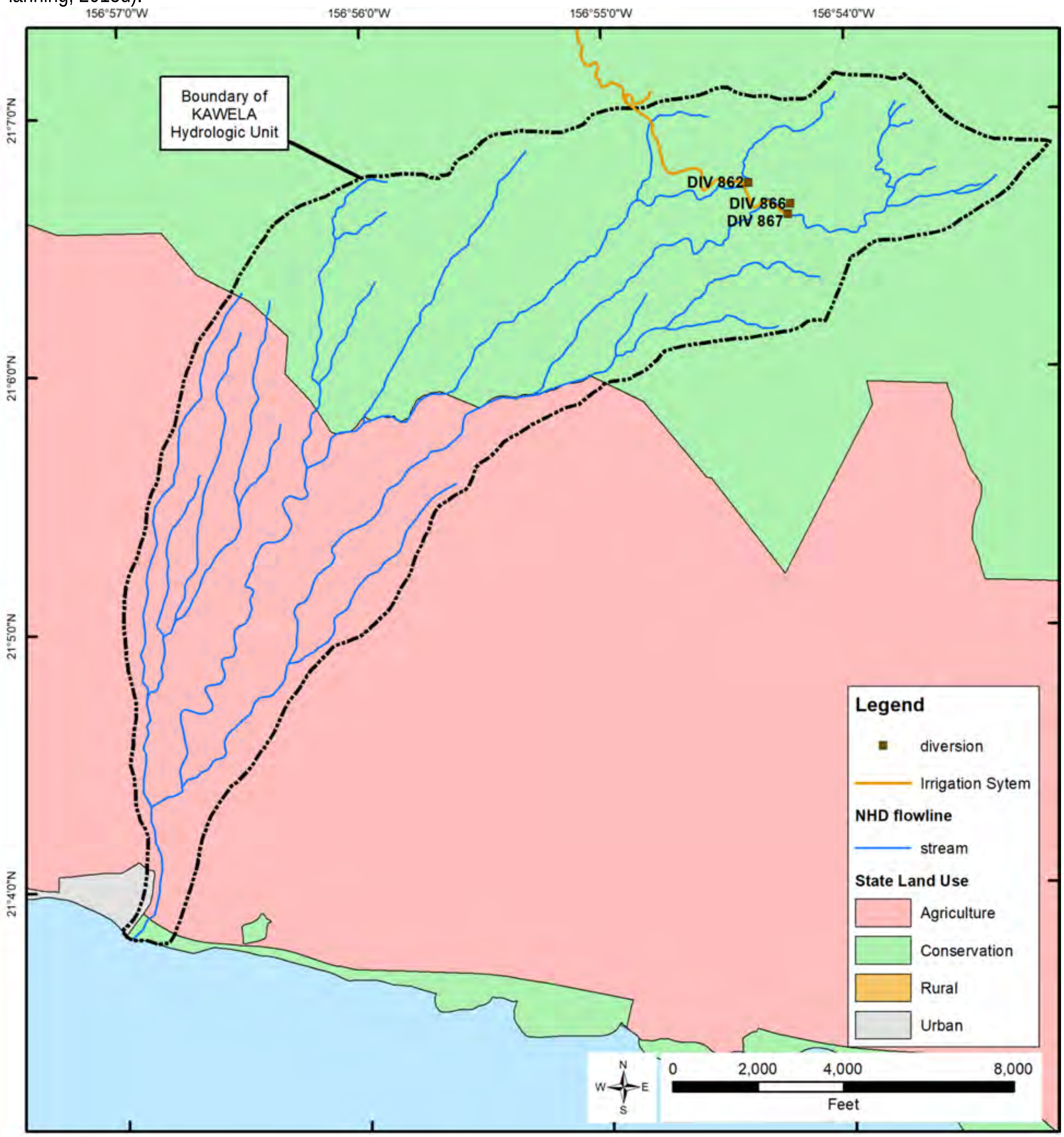


Figure 2-8. C-CAP land cover of the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2015k).

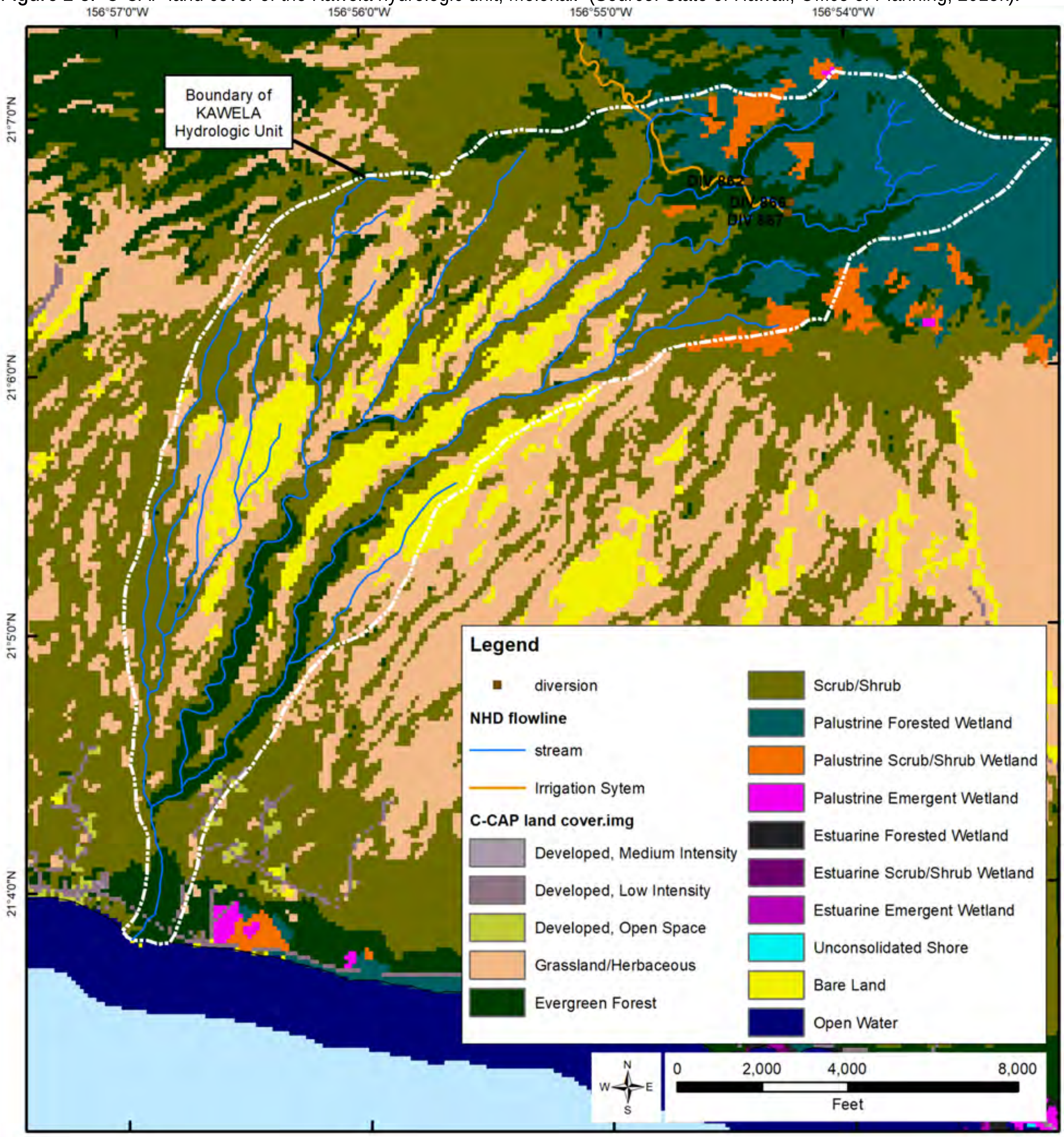
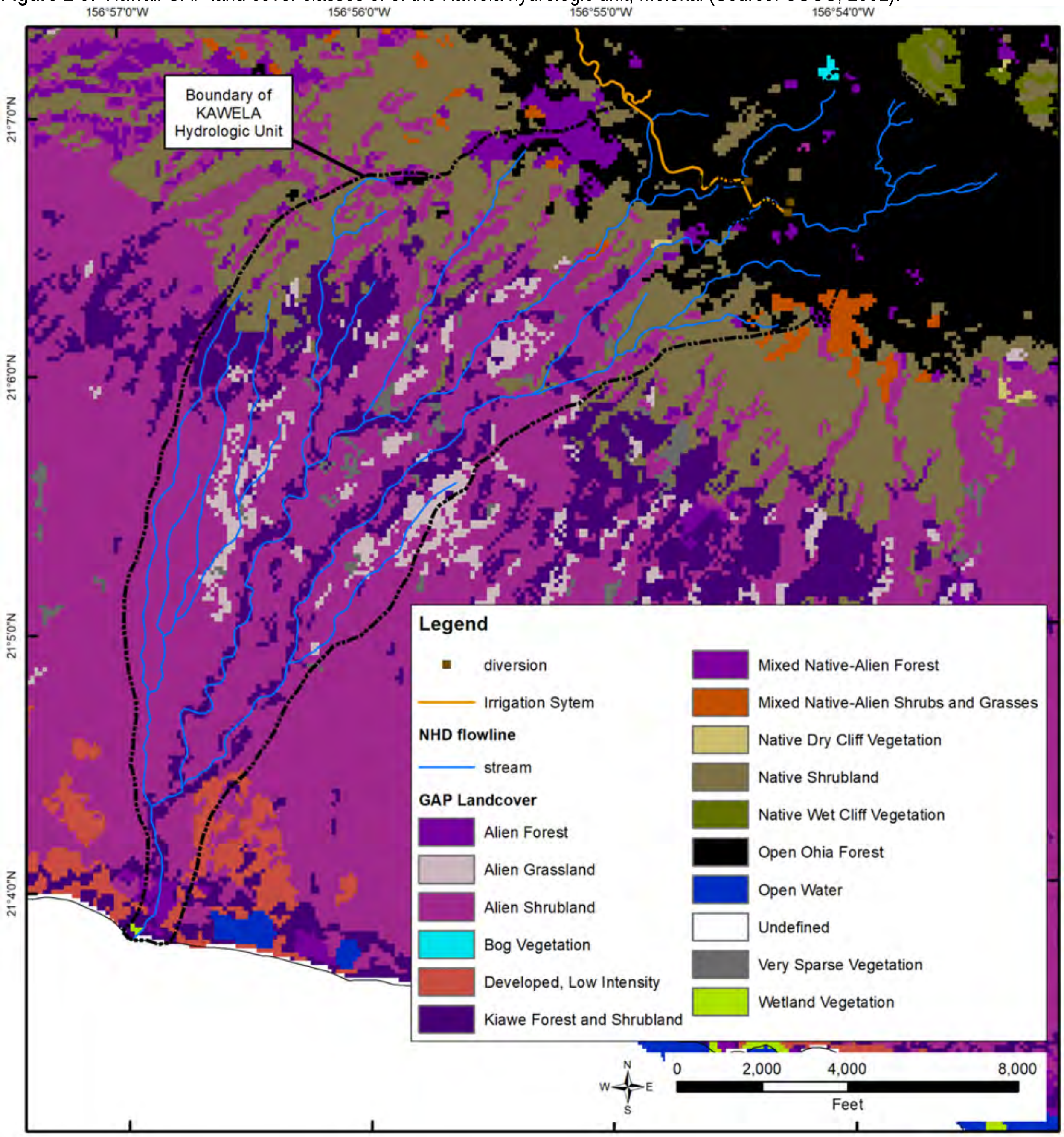
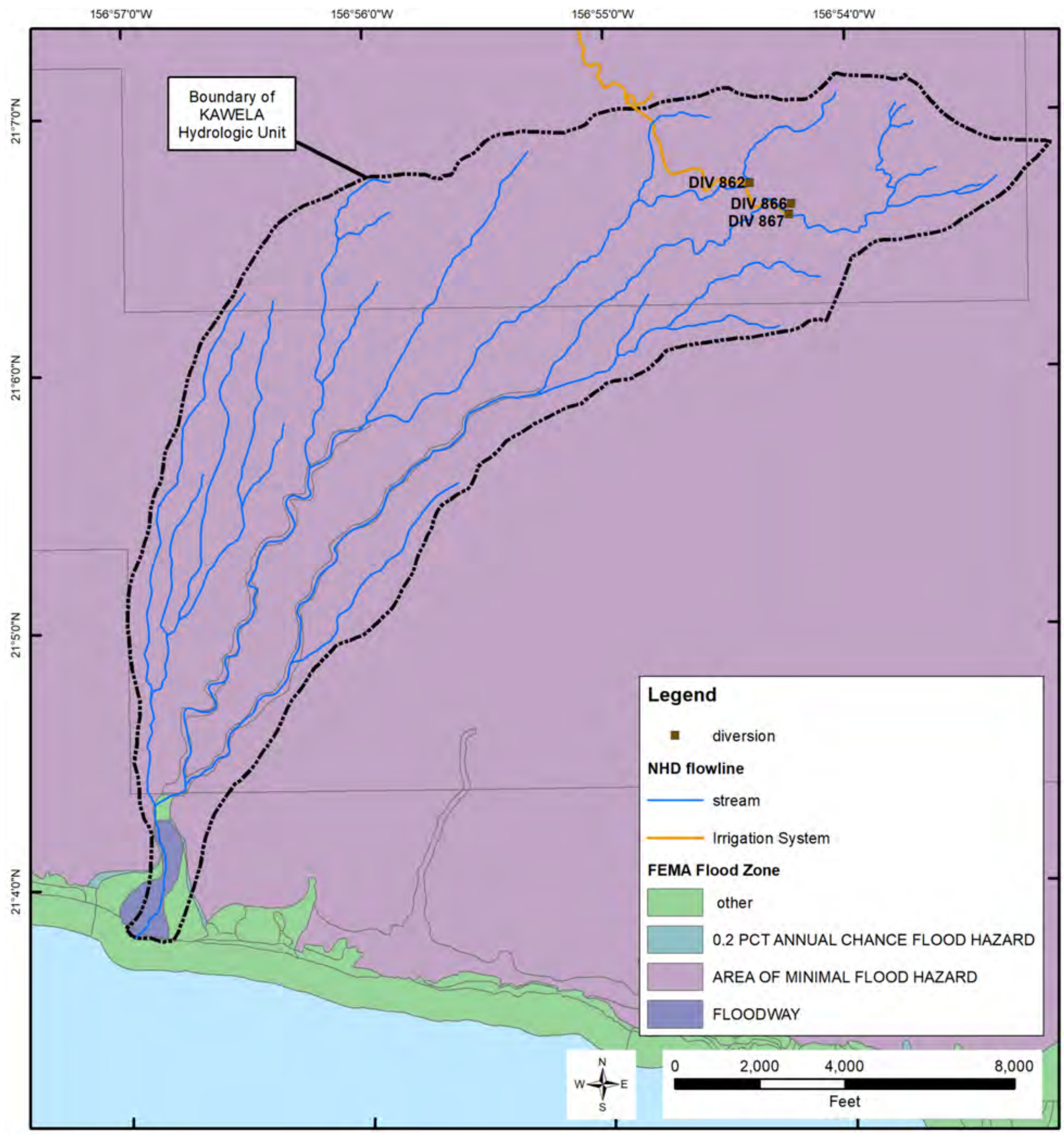


Figure 2-9. Hawaii GAP land cover classes of of the Kawela hydrologic unit, Molokai (Source: USGS, 2001).




156°57'0"W
156°56'0"W
156°55'0"W
156°54'0"W
21°7'0"N
21°6'0"N
21°5'0"N
21°4'0"N
Boundary of KAWELA Hydrologic Unit
DIV 862
DIV 866
DIV 867
Legend
diversion
NHD flowline
stream
Irrigation System
FEMA Flood Zone
other
0.2 PCT ANNUAL CHANCE FLOOD HAZARD
AREA OF MINIMAL FLOOD HAZARD
FLOODWAY
N
W
E
S
0
2,000
4,000
8,000
Feet

3.0 Hydrology

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

Streams in Hawaii

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

Streams in Hawaii can either gain or lose water at different locations depending on the geohydrologic conditions. A stream gains water when the ground water table is above the streambed. When the water table is below the streambed, the stream can lose water. Where the streambed is lined with concrete or other low-permeability or impermeable material, interaction between surface water and ground water is unlikely. Another way that ground water influences streamflow is through springs. A spring is formed when a geologic structure (e.g., fault or fracture) or a topographic feature (e.g., side of a hill or a valley) intersects ground water either at or below the water table. It can discharge ground water onto the land surface, directly into the stream, or into the ocean. Figure 3-1 illustrates a valley that has been incised into a high-level water table, resulting in groundwater and springs that contribute to streamflow. At places where erosion has removed the caprock, ground water discharges either as springs or into the ocean as seeps along the coast.

Kawela Stream flows perennially in the highest reaches of the east and west forks, draining high elevation perched water bodies in the East Molokai caldera. In its first publication detailing the water resources of Molokai, the U.S. Geological Survey (USGS) detailed wet season and dry season surface flows as described in Table 3-1.

The USGS monitored streamflow at station 16415000 on the East Fork Kawela Stream at 3,625 feet above sea level from 1946-1971. In 2018, USGS installed a temporary low-flow monitoring station at station 16415000 as part of the statewide low-flow analysis. This station has been added to the annual CWRM-USGS cooperative agreement as part of the Statewide Monitoring Needs Assessment for quantifying the consequences of climate change on watershed hydrology and water availability. The USGS has monitored streamflow at station 16415600 on Kawela Stream 40 feet above sea level from 2004 to present. Historic data from these stations are available in Table 3-2.

Table 3-1. Select average seasonal streamflow values in cubic feet per second (million gallons per day) for streams at the given elevations in 1903, Molokai, Hawaii. (Source: USGS, 1903) [Flows are in cubic feet per second (million gallons per day)]

Stream name	Elevation (ft)	Wet Season (Nov-Jun)	Dry Season (Jun – Aug)
Waihanau	2,046	5.02 (3.25)	1.55 (1.00)
Waialeia	2,760	0.46 (0.30)	0.15 (0.10)
Waikolu	3,600	1.93 (1.25)	0.46 (0.30)
Kahapakai	2,000	0.39 (0.25)	0.23 (0.15)
Mokamoka	2,200	0.31 (0.20)	0.15 (0.10)
Luahine Fork	2,350	0.31 (0.20)	0.12 (0.075)
Kamiloloa	3,050	0.43 (0.275)	0.15 (0.10)
Makakupaia (Kaunakakai)	2,650	0.66 (0.425)	0.23 (0.15)
West Fork Kawela	3,220	0.31 (0.20)	0.08 (0.05)
East Fork Kawela	3,220	1.86 (1.20)	0.46 (0.30)

Table 3-2. Select streamflow values for the period of record in the Kawela hydrologic unit, Molokai, Hawaii. (Source: USGS 2020) [Flows are in cubic feet per second (million gallons per day)]

station ID	station name	period of record	mean daily flow	14-day low flow	discharge (Q) for a selected percentage (xx) discharge was equaled or exceeded			
					Q_{50}	Q_{70}	Q_{90}	Q_{95}
16415000	EF Kawela Stream	1946-1971	2.39 (1.55)	0.00 (0.00)	0.39 (0.25)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
16415000	EF Kawela Stream	2018-2021	3.21 (2.07)	0.06 (0.04)	0.52 (0.34)	0.25 (0.16)	0.12 (0.08)	0.10 (0.06)
16415600	Kawela Stream	2004-2021	3.00 (1.94)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

Groundwater

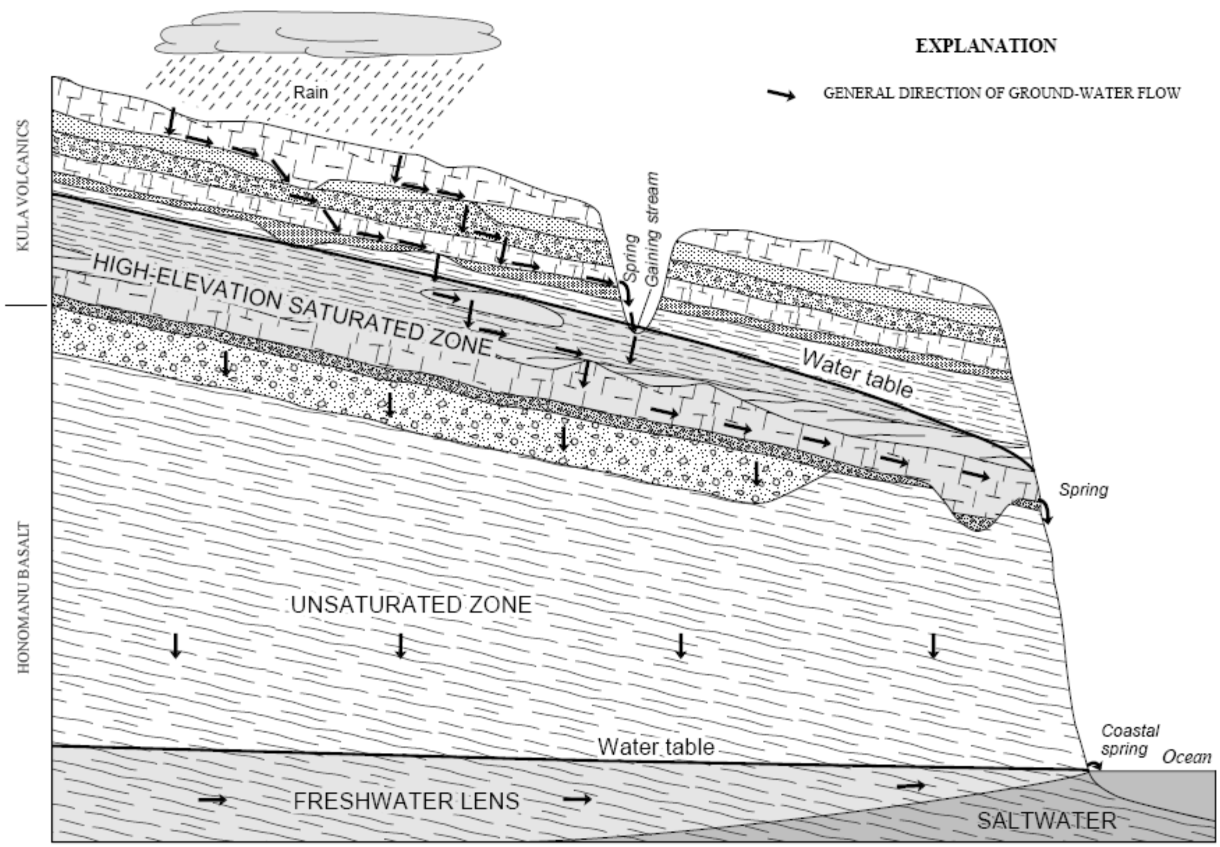
Groundwater is an important component of streamflow as it constitutes the base flow[5] of Hawaiian streams. Groundwater can also be an alternative source to diverting stream flow. When groundwater is withdrawn from a well, the water level in the surrounding area is lowered. Nearby wetlands or ponds may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

In Hawaii, groundwater is replenished by recharge from rainfall, fog drip, and irrigation water that percolate through the plant root zone to the subsurface rock. Recharge can be captured in three major

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

groundwater systems: 1) fresh water-lens system; 2) dike-impounded system; and 3) perched system. The fresh water basal aquifer provides the most important sources of ground water. It includes a lens-shaped layer of fresh water, an intermediate transition zone of brackish water, and underlying salt water. The Ghyben-Herzberg principle describes the displacement of higher density saltwater by lower density fresh water in an aquifer for a condition where two fluids do not mix and the freshwater flow is primarily horizontal. In such a situation, for every one-foot above sea level of freshwater, there are approximately 400 feet of freshwater below sea level. Thus, a vertically extensive fresh water-lens system can extend several hundreds of feet below mean sea level. By contrast, a dike-impounded system is found in rift zones or a caldera where low-permeability dikes compartmentalize areas of permeable volcanic rocks, forming high-level water bodies. On Molokai, dikes impound water to as high as 3,300 feet above mean sea level, primarily in the windward valleys of the East Molokai Caldera. A perched system is found in areas where low-permeability rocks impede the downward movement of percolated water sufficiently to allow a water body to form in the unsaturated zone above the lowest water table (Gingerich and Oki, 2000). The water-bearing properties of various rock structures largly depends on their composition, and therefore their permeability. Where a dike complex exists, 100 or more dikes per mile, occupying 5% or more of the rock, is not uncommon and can hold substantial quantities of water in the permeable layers between the dikes.

Figure 3-1. Diagram illustrating the ground water system west of Keanae Valley, northeast Maui, Hawaii. Arrows indicate general direction of ground water flow (Source: Gingerich, 1999b).



The lavas of the East Molokai Volcanic Series and West Molokai Volcanic Series contain water at and near sea level, but under the West Molokai Volcanic Series, the Hoolehua Plain, and southern shore of the East Molokai Mountain, the water is brachish (Stearns and MacDonald, 1947). The caldera complex is generally poorly permeable but yields some high-level springs. Ash layers in the lower member of the

East Molokai Volcanic Series perch water in wet areas, but little or none elsewhere. Ash beds in the upper member locally perch small quantities of water. The non-calcareous sedimentary deposits are poorly permeable, as thus yield fresh or brachish water along the south shore. The hydrologic unit of Kawela lies within the Kamalo aquifer system with an area of 20.409 square miles. The illustratation by Gingerich (1999b), although originally drawn for East Maui, depicts the general overview of the groundwater occurrence, movement, and interactions with surface water in streams that incise high-elevation water in Molokai (Figure 3-1). Groundwater is found at high elevation saturated zones in the upper member geologic series and not present near the coast, where only the lower member geologic series is present. The groundwater reservoir is recharged primarily in the upper elevations.

Wells in the Kawela Hydrologic Unit

The Kawela surface water hydrologic is located in the Kamalo Aquifer System which is part of the Southeast Aquifer Sector on the leeward side of Molokai (Figure 3-2). The 2019 update to the Water Resources Protection Plan maintained the sustainable yield of the Kawela Aquifer at 5 mgd (State of Hawaii Commission on Water Resource Management, 2019). There are six wells in the Kawela surface water hydrologic unit and 27 within 8,000 feet of Kawela Stream. The location of these wells and the boundaries to the aquifer systems are depicted in Figure 3-2 with detailed information for each well specified in Table 3-4.

Historic data suggests that the basal lense was thicker but no less saline than present day. Stearns and MacDonald (1947) documented the drilling of nine wells in Kawela ranging from altitude of 11 feet to 20 feet and from depths of 46 feet to 75 feet with chloride levels ranging from 156 ppm to 364 ppm (Table 3-3). In test borings between Kawela and Kaunakakai, basal water appears to stand abnormally high, presumably due to the confining effect of the fringe sediments. However, the west of Kawela the water is brachish due to a low rate of recharge. The basal water in the shallow sedimentary rocks of Kawela are brachish due to their close location near the coast, but better in quality due to a stronger connection to upland and inland recharge. Spring flow (x3) was documented at Kanoa fishpond and at Kakahaia fishpond.

Kawela Shaft (well 4-0457-001) operated by Maui County Department of Water Supply (DWS) and Kawela Plantation wells 2A (well 4-0456-018) and 3A (well 4-056-019) are the largest production wells in the Kawela aquifer system (Figure 3-4). Pumpage and chloride statistics for these wells within the last 20 years are provided in Table 3-5. Kawela shaft serves a 5.1-mile segment of the coast from Kaunakakai to Kawela Gulch. The primary storage is in the 0.1 million gallon tank at an elevation of 260 ft in Kanoa.

Groundwater discharge along the north and south coastlines of Molokai impacts the presence of wetlands, nearshore ecosystems, and the operation of fishponds (Figure 3-4). Groundwater withdrawals from the basal aquifer within Kawela or at higher elevations in the Kualapuu and Kamala aquifers are expected to have a negative effect on coastal and submarine groundwater discharge. There are a large number of wells that are located within and near to the Kawela hydrologic unit. The initial well head can provide information regarding the elevation of the basal aquifer in relation to the distance inland from the coastline. The date of well construction may influence the interpretation of initial well head as pumpage from older wells may affect the initial well head of newer wells (Figure 3-5).

The Kawela Plantation wells were drilled to support a 210-acre agricultural subdivision project with lots of two acres in size. The domestic water system is composed of three 6-inch cased wells east of Kawela Gulch located at about 230 feet in elevation and approximately 1500 feet apart, with a design capacity of approximately 1000 gpd per lot or about 0.21 mgd total. The non-potable supply is sourced from two wells: the breadfruit tree shaft (4-0456-004) to the east of Kawela Gulch and a brachish well (4-0457-002) to the west of Kawela Gulch (Belt, Collins, & Associates, 1982).

Table 3-3. Elevation (ft), depth (ft), initial chloride level (ppm), and remarks for wells drilled in Kawela prior to 1947 and test borings (TB). (Source: Stearns and MacDonald, 1947)

USGS Plate No.	Elevation (ft)	Depth (ft)	Chloride (Cl^-) (ppm)	remarks
13A	12	46	156	Head 1.25 ft
13B	12	50	187	Head 2 ft
13C	11	56	197	Head 2.25 ft
13D	20	--	260-364	
14A	17	58	--	Head 2.5 ft
14B	12	75	364	
14C	18	60	260	
14D	--	59	--	
14E	--	58	--	
TB8	6.4	7.4	420	Head 1.22 ft
TB9	10.5	14.0	144	Head 1.96 ft
28	13.9	14.6	230	Head 1.39 ft
29	9	10	232	
30	17.1	19.0	34	Head 1.77 ft
31	14	15	32	

Table 3-4. Information of wells located in or nearby the Kawela surface water hydrologic units in the Kawela Aquifer System (Source: State of Hawaii, Commission on Water Resource Management, 2020c).
[elevation values indicate feet above mean sea level; depth values indicate feet below ground elevation; -- indicates value is unknown; DUG = dug well; ROT = rotary; PER = percussion; SHF = shaft]

well number	well name	Tax Map Key	Type	Pump Size (mgd)	Ground Elevation (ft)	Well Depth (ft)	Initial Head Elevation (ft)
4-0352-015	Kamalo-Schultz 2	(2) 5-6-007:050	DUG	0	0	15	0
4-0355-001	Makolelau	(2) 5-5-001:033	DUG	0	8	10	0
4-0355-002	Makolelau	(2) 5-5-001:032	DUG	0	17	18	0
4-0355-003	Makolelau	(2) 5-5-001:037	DUG	0	4	5	0
4-0355-005	Bruce 1	(2) 5-5-001:015	DUG	0.37	0	17	0
4-0356-001	Makolelau	(2) 5-5-001:031	DUG	0	20	19	3.5
4-0356-002	Kamalo-Steele	(2) 5-4-001:043	DUG	0	0	7	0
4-0456-001	Kamakana	(2) 5-4-001:011	DUG	0	17	0	1.7
4-0456-002	Kawela	(2) 5-4-001:084	DUG	0	17	19	1.8
4-0456-003	Kawela TH	(2) 5-4-001:023	ROT	0	10	14	2
4-0456-005	Nalulua	(2) 5-4-001:005	DUG	0	16	15	0.6
4-0456-006	Kawela DW3 Monitor	(2) 5-4-014:017	PER	0.108	223	233	3.37
4-0456-007	Kawela Expl 2	(2) 5-4-003:028		0	54	63	2.4
4-0456-008	Kawela DW2 Monitor	(2) 5-4-014:024	PER	0.11	232	243	1.5
4-0456-009	Kawela DW1	(2) 5-4-014:050	PER	0.11	225	235	1.5
4-0456-010	Sutcliffe-Mulloy	(2) 5-4-001:012	DUG	0.003	39	15	0
4-0456-011	Perrels 1	(2) 5-4-001:020	DUG	0.007	0	16	0
4-0456-012	Perrels 2	(2) 5-4-001:020	DUG	0	0	10	0
4-0456-013	Kawela-Foster	(2) 5-5-001:031	ROT	0.02	0	20	0
4-0456-014	Kawela-Iaea 1	(2) 5-4-001:020	DUG	0	0	11	0
4-0456-015	Kawela-Iaea 2	(2) 5-4-001:021	DUG	0	0	11	0
4-0456-016	Kawela-Iaea 3	(2) 5-4-001:052	DUG	0	0	16	0
4-0456-017	Kawela-Johnson	(2) 5-4-001:011	DUG	0.09	0	16	0
4-0456-018	Kawela Plantation 2A	(2) 5-4-014:024	ROT	0.144	225	233	3.17
4-0456-019	Kawela Plantation 3A	(2) 5-4-014:017	ROT	0.144	224	233	3.18
4-0457-001	Kawela Shaft	(2) 5-4-001:050	SHF	0.43	36	39	1.9
4-0457-004	Kawela Ag 1	(2) 5-4-003:028	PER	0.216	235	244	0

Table 3-5. Mean, median, and maximum monthly pumpage (million gallons per day, mgd) and monthly chloride value (parts per million, ppm) for the three largest production wells in the Kawela hydrologic unit. (Source: State of Hawaii, Commission on Water Resource Management, 2020a)

well number	well name	Period of Record	Pumpage (mgd)			Chloride (ppm)		
			mean	median	maximum	mean	median	maximum
0456-001	Kawela Shaft	1999-2021	0.206	0.175	0.487	86	55	325
0457-018	Kawela Plantation 2A	2011-2021	0.091	0.095	0.140	156	152	658
0457-019	Kawela Plantation 3A	2011-2021	0.100	0.098	0.201	71	66	280

Figure 3-2. Well locations and numbers in and nearby the Kamala hydrologic unit with aquifer system sustainable yields, Kawela Aquifer System, Molokai. (Source: State of Hawaii, Commission on Water Resource Management, 2020c).

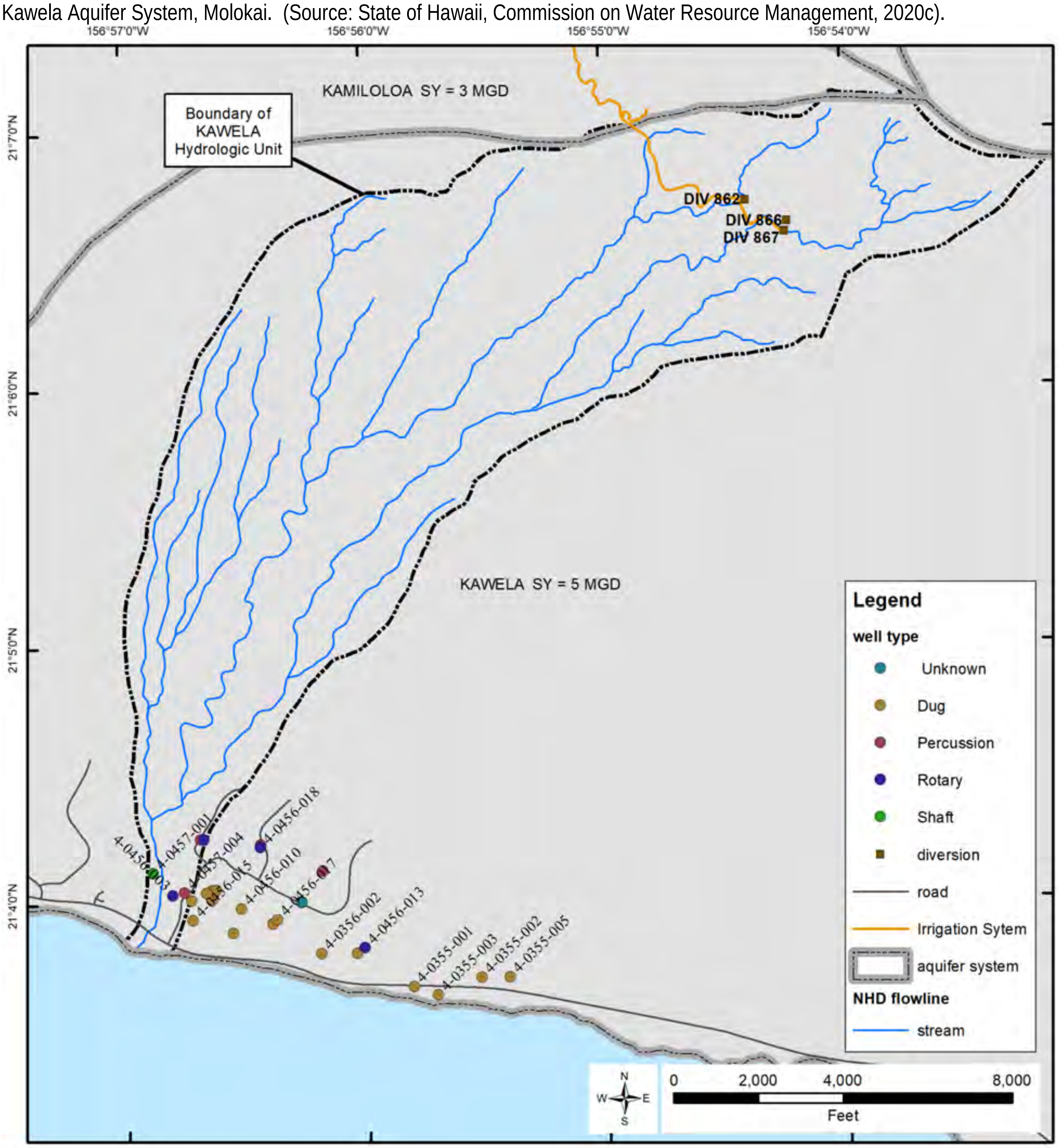


Figure 3-3. Monthly mean daily pumpage (million gallons per day, mgd) and monthly chloride measurements at Kawela Shaft (well 4-0457-001) (top), Kawela Plantation 2A (well 4-0456-018) (middle), and Kawela Plantation 3A (well 4-0456-019) (bottom).] (Source: State of Hawaii, Commission on Water Resource Management, 2020a)
[Note: different x-axis based on the available period of record]

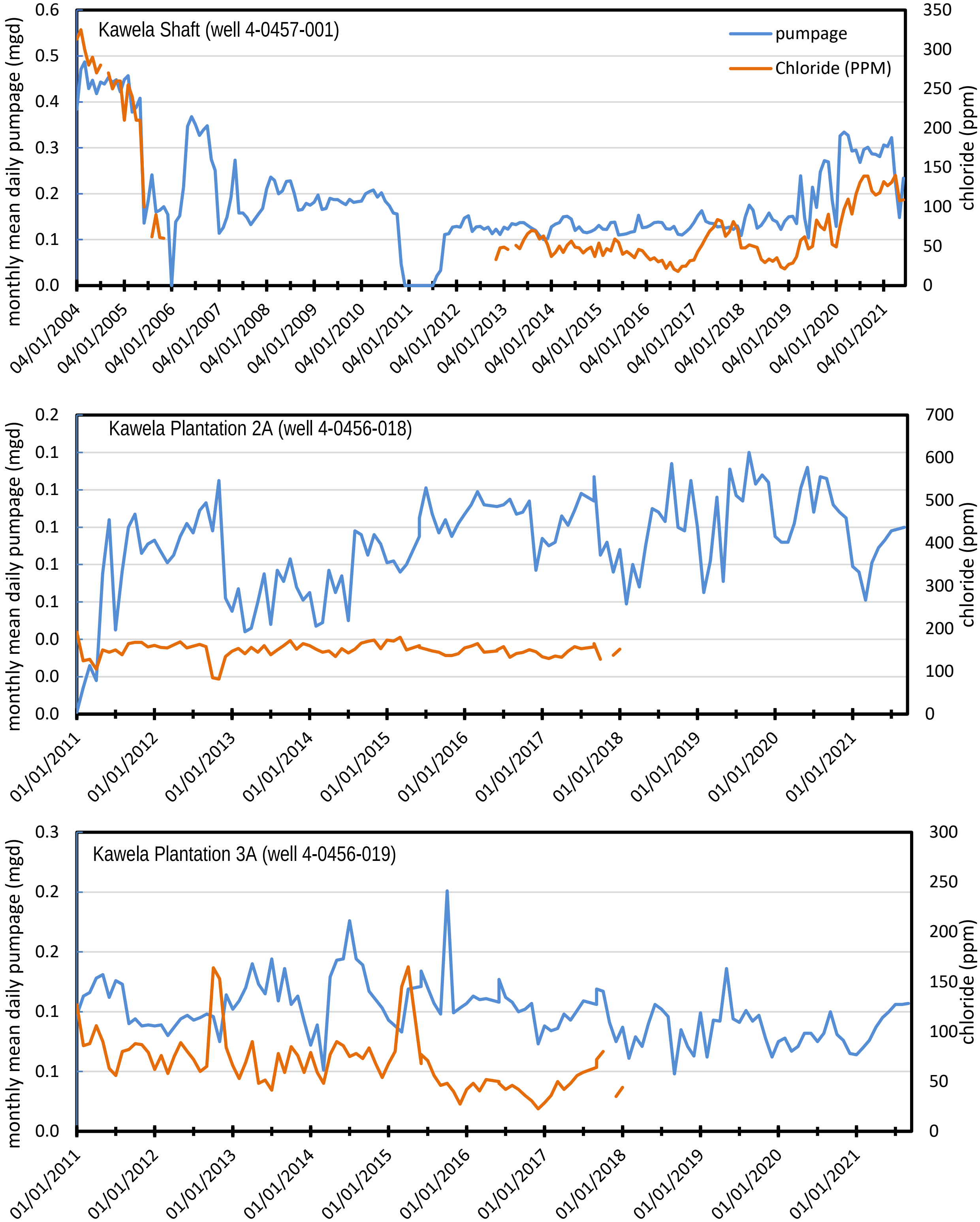


Figure 3-4. Baseline groundwater withdrawal rates from wells and fresh groundwater discharge along coastal regions of central Molokai. (Source: Oki et al., 2019).

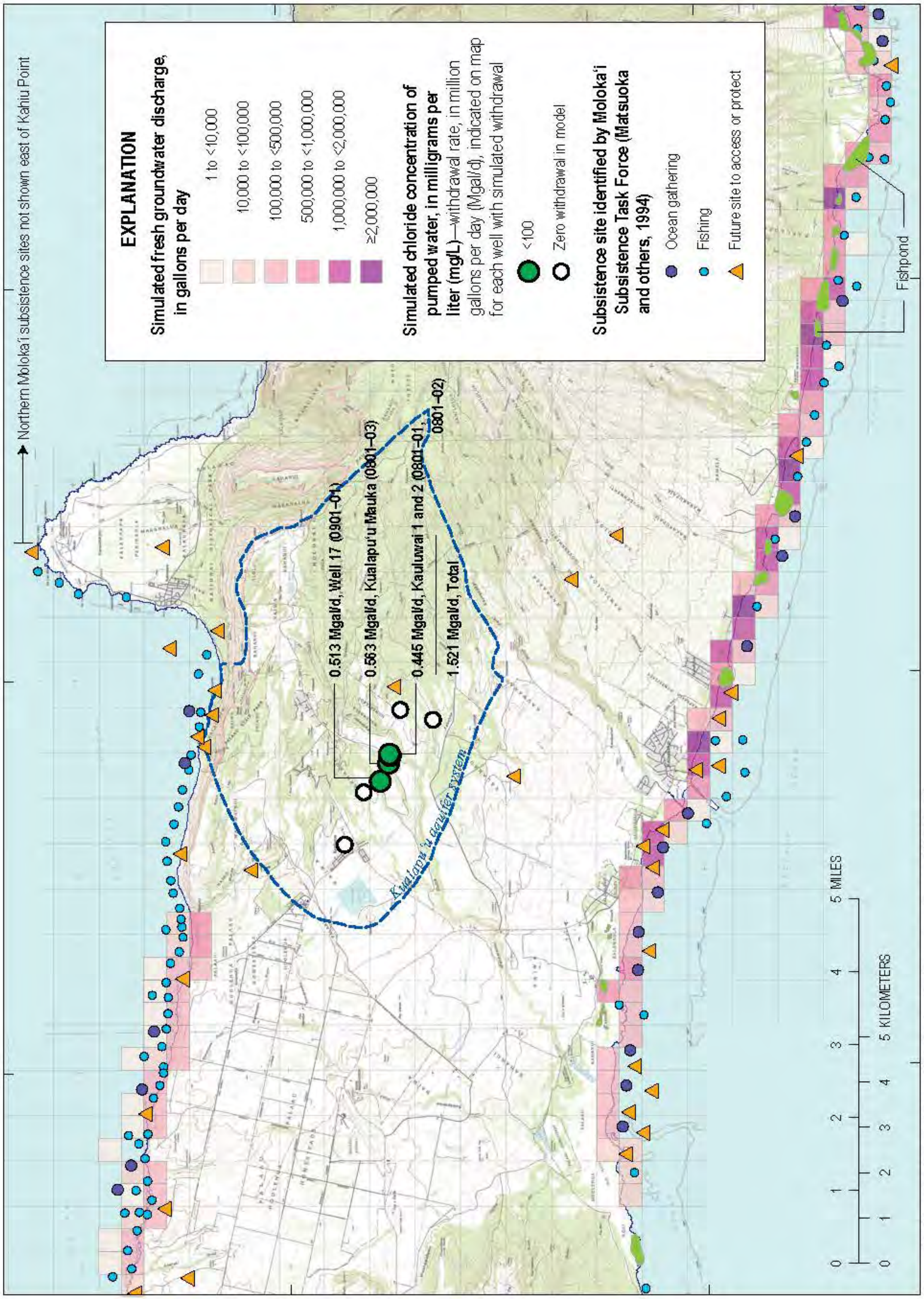
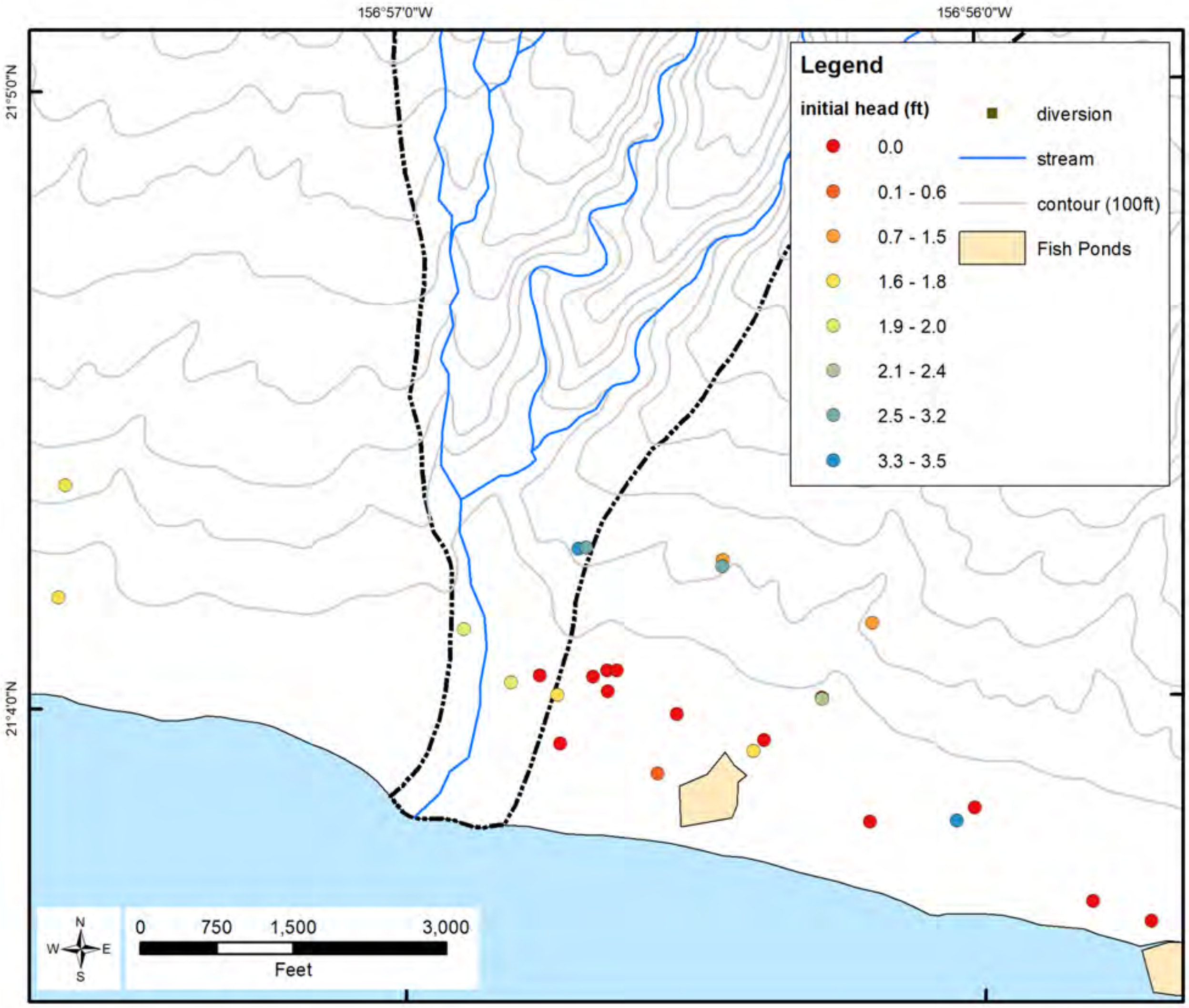


Figure 3-5. Initial well head (ft) for wells in and near the Kamalo hydrologic unit, Molokai.



Streamflow Characteristics

One of the most common statistics used to characterize streamflow is the median value of flow in a particular time period. This statistic is also referred to as the flow at 50 percent exceedence probability, or the flow that is equaled or exceeded 50 percent of the time (TFQ_{50}). The longer the time period that is used to determine the median flow value, the more representative the value is of flow conditions in the stream. Median flow is typically lower than the mean or average flow because of the bias in higher flows, especially during floods, present when calculating the mean flow. The flow at the 90 percent exceedence probability (TFQ_{90}) is commonly used to characterize low flows in a stream. In Hawaii, the baseflow is usually exceeded less than 90 percent of the time, and in many cases less than 70 percent of the time (Oki, 2003).

The East Fork Kawela stream was gaged continuously from 1946 to 1971, although this may have represented regulated flow below the intake (Figure 3-6). A new 16415000 station was recently reestablished as a low-flow continuous record station and then added to the CWRM-USGS cooperative agreement as a continuous monitoring station. Continuous low-flow data are available at USGS 16415000 from 2018 to 2021 (Figure 3-7). From 11/08/2018 to 8/16/2021 median flow was 0.52 cfs (0.34 mgd) and low (Q_{90}) flow was 0.12 cfs (0.06 mgd).

A station on the West Fork Kawela has been operated as a partial record site from 2018 to 2021 as part of the statewide low-flow modeling project. Point measurements at this station as well as recent measurements made by CWRM are provided in Table 3-6.

Table 3-6. Point measurements on West Fork Kawela Stream above diversion 862 made by USGS and CWRM

date	Agency	Measurement (cfs)
7/28/2010	USGS	0.02
11/29/2018	USGS	0.06
8/31/2018	CWRM	0.09
5/1/2019	USGS	0.07
8/13/2019	USGS	0.00
9/5/2019	USGS	0.00
11/13/2019	USGS	0.0019
7/17/2020	USGS	0.01
10/20/2020	USGS	0.00
11/19/2020	USGS	0.07
8/17/2021	USGS	0.04

The closest long-term continuous stream flow monitoring station currently in operation is on Halawa Stream (USGS station 1640000) on Molokai (Figure 3-9).

Figure 3-6. Mean monthly flow (million gallons per day, mgd) at USGS station 16415000 on EF Kawela Stream, Molokai. (Source: USGS, 2020)

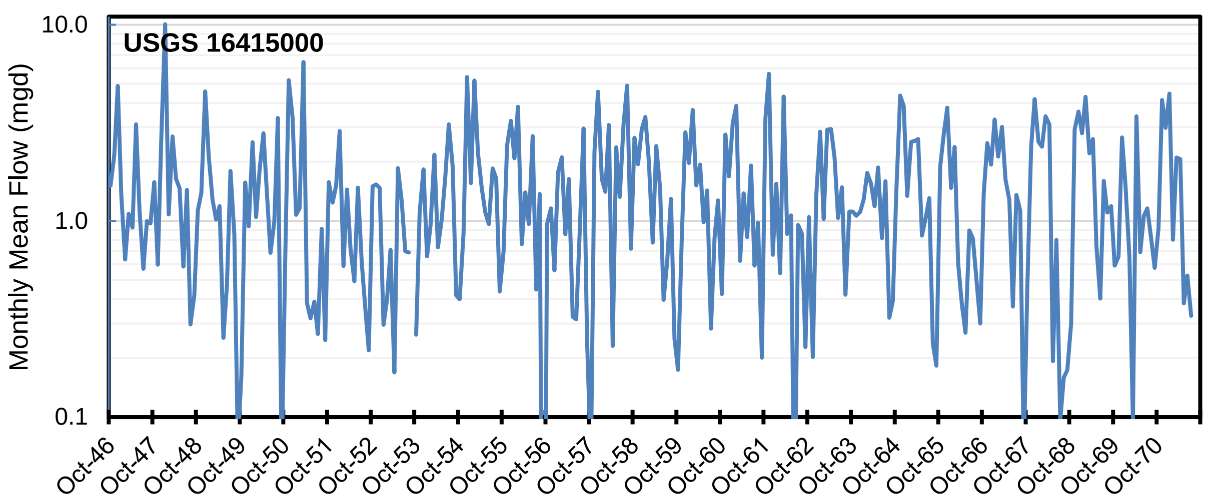
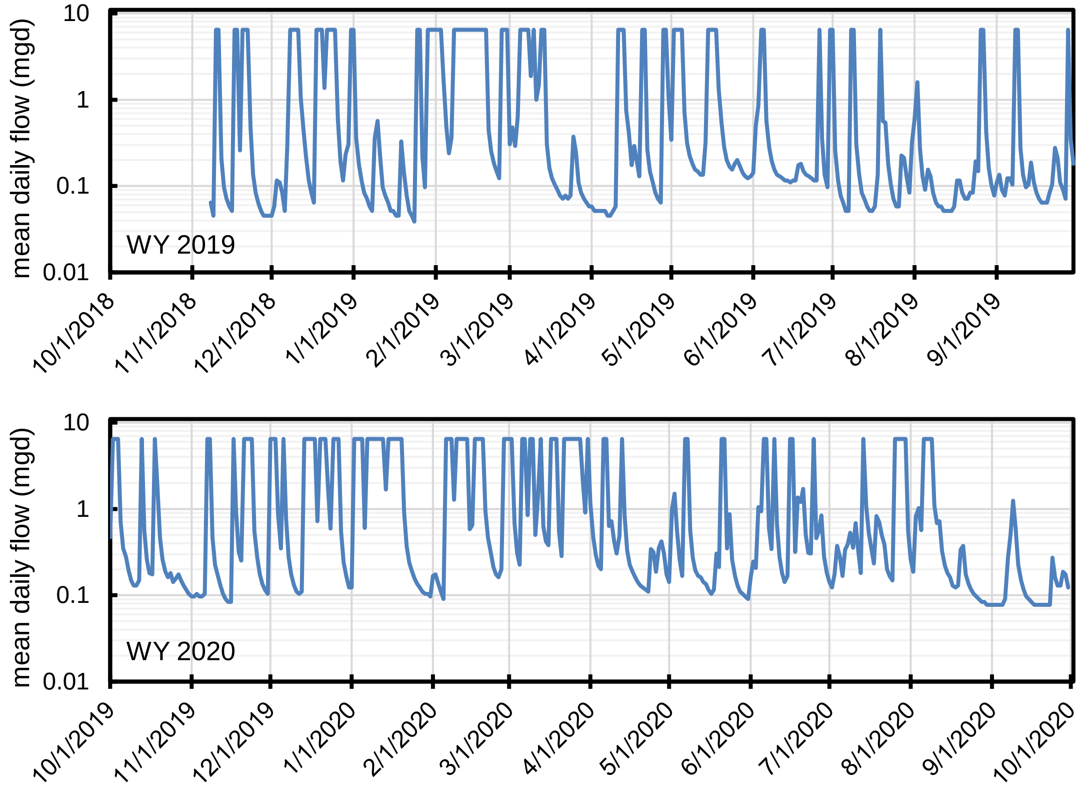


Figure 3-7. Water Year 2019 (top) and water year 2020 (bottom) mean daily low-flow flow (million gallons per day, mgd) from continuous gaging at USGS station 16415000 on EF Kawela Stream, Molokai. (Source: USGS, 2020)



In 2010, USGS made a series of synoptic measurements to characterize the gains and losses of streamflow in the East Fork Kawela. A visualization of these measurements is provided in Figure 3-8. Stearns and MacDonald (1947) recounted that Kawela stream is generally dry below an altitude of about 2,500 ft and that the tributaries of Kawela Stream lose heavily by seepage between the 3,600 ft elevation, where the Molokai Ranch intakes are, to 2,500 ft in elevation.

Long-term trends in rainfall and streamflow

The climate has profound influences on the hydrologic cycle and in the Hawaiian Islands, shifting climate patterns have resulted in an overall decline in rainfall and streamflow. Rainfall trends are driven by large-scale oceanic and atmospheric global circulation patterns including large-scale modes of natural variability such as the El Nino Southern Oscillation and the Pacific Decadal Oscillation, as well as more localized temperature, moisture, and wind patterns (Frazier and Giambelluca, 2017; Frazier et al, 2018). Long-term trends in surface water on Molokai are difficult to assess as few stations have continuous records for sufficient length of time. However, USGS station 16400000 on Halawa Stream has been in operation since 1917 (Figure 3-9). Using monthly rainfall maps, Frazier and Giambelluca (2017) identified regions that have experienced significant ($p<0.05$) long-term decline in annual, dry season, and wet season rainfall from 1920 to 2012 and from 1983 to 2012. On Molokai, some areas have experienced a significant decline in annual and seasonal rainfall in the 1920 to 2012 period, and for large parts of the island from 1983-2012 (Figure 3-10). Since 1983, Hoolehua region has experienced a significant ($p < 0.05$) decline in annual (5-20% per decade) and dry season (20-40% per decade) rainfall. Similarly, west Molokai has experienced a 5-10% per decade decline in dry season rainfall.

Figure 3-8. Streamflow gains and losses measured by USGS during seepage runs in 2010 that span multiple dates for different reaches. (Source: U.S. Geological Survey, 2021)

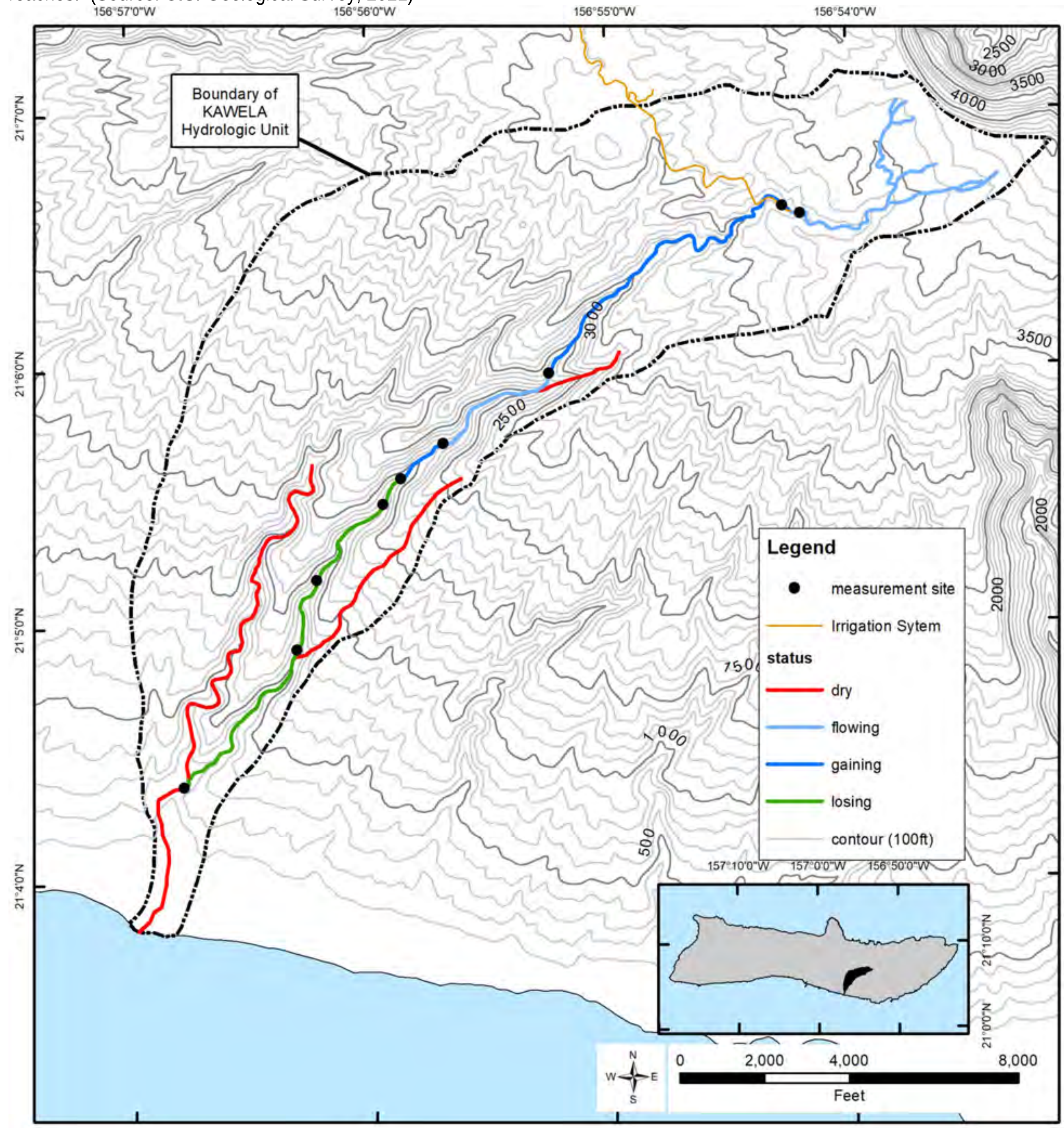
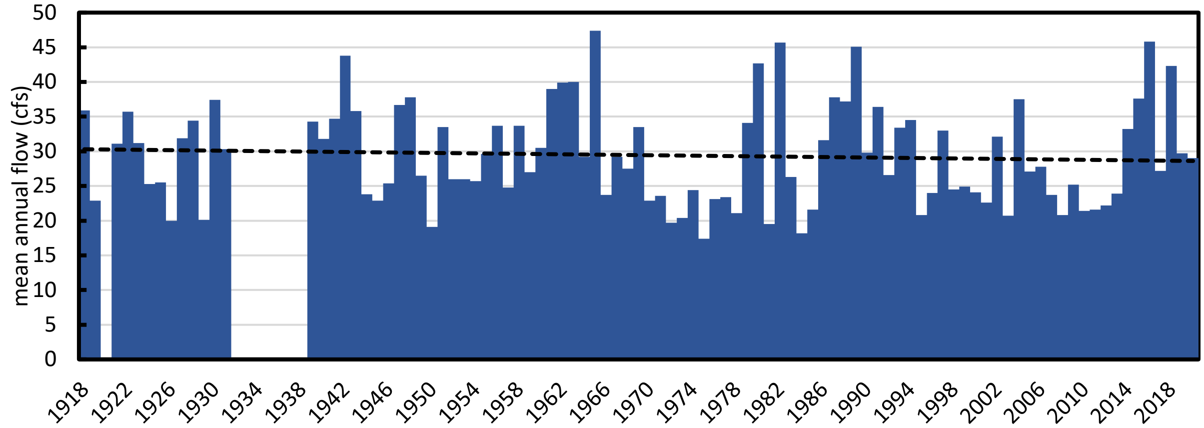


Figure 3-9. Mean annual flow (million gallons per day, mgd) at USGS station 16400000 on Halawa Stream, Molokai. Line represents linear regression trend over the period of record. (Source: USGS, 2020)



In a different study, 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, one of which is located in Halawa Stream near on Molokai (station 16400000). For the 90-year period 1913-2002, monthly mean base flows generally followed an increasing trend above the long-term average from 1913 to early 1940s, and a decreasing trend after the early 1940s to 2002 (Figure 3-11). Monthly mean total flows follow a similar pattern with the exception that the monthly mean total flow increased from mid-1980s to mid-1990s and decreased from mid-1990s to 2002. Downward trends in the annual total low flow percentiles, TFQ_{75} and TFQ_{90}, were statistically significant at the 5 percent level of significance. This is consistent with the annual base flow percentiles (Oki, 2004).

Figure 3-10. Annual, wet season (Nov-Apr) and dry season (May-Oct) rainfall trends for the 1920-2012 (A) and 1983-2012 (B) periods, Molokai and Lanai. Hashed line areas represent significant trend over the period.
(with permission from Frazier and Giambelluca, 2017)

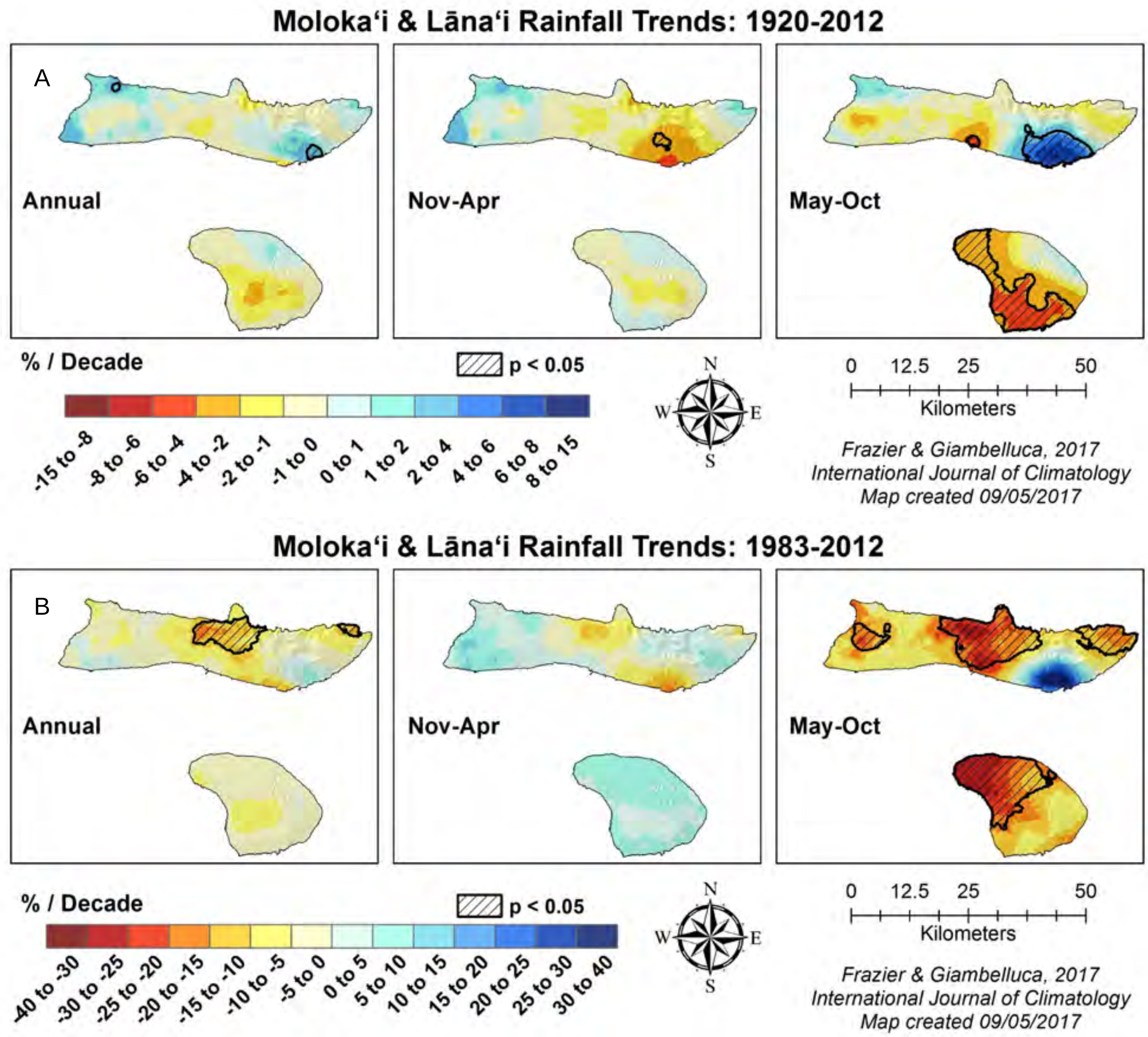
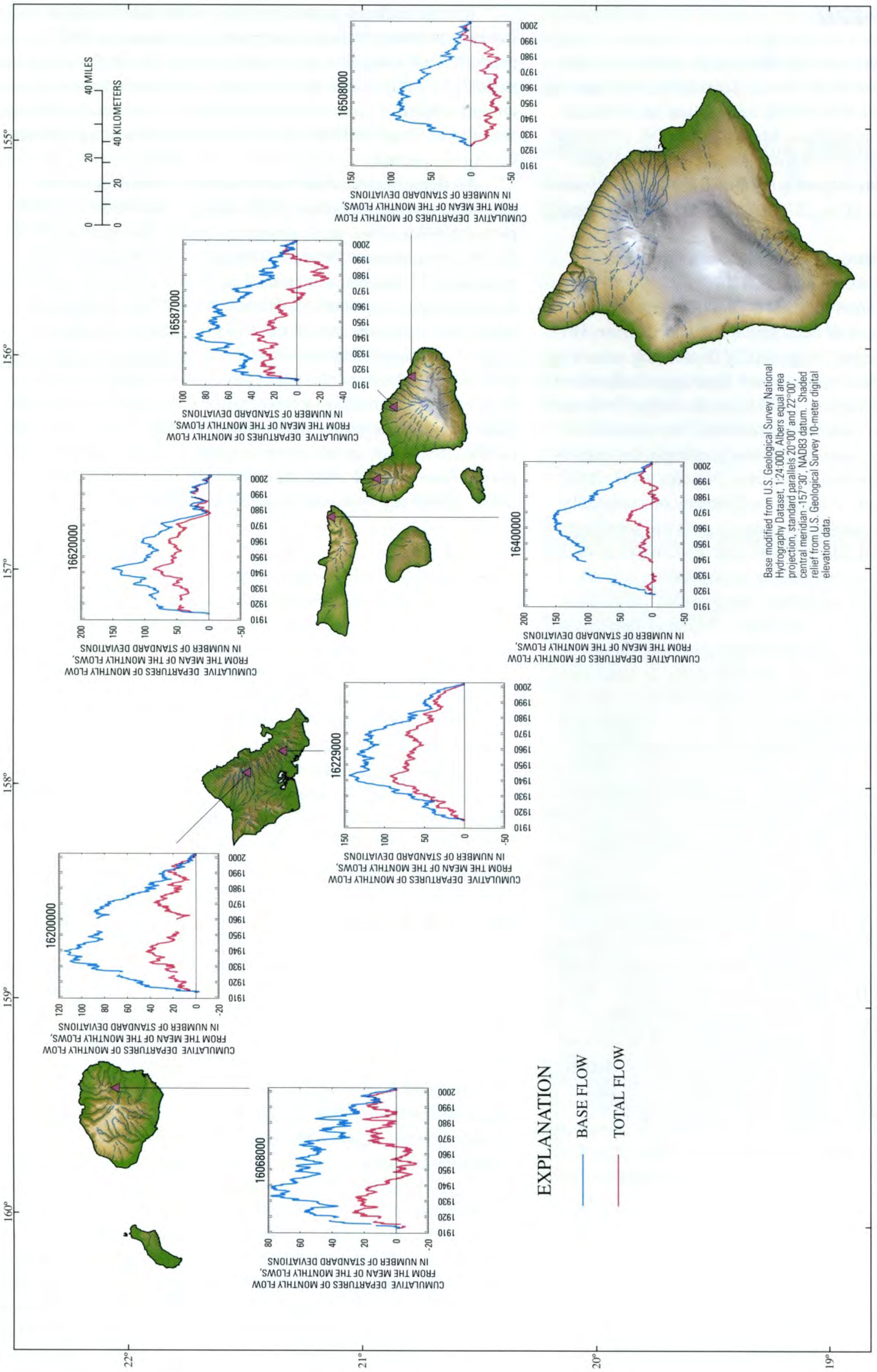


Figure 3-11. Cumulative departures of monthly mean flow from the mean of the monthly flows, Hawaii. This data is based on complete water years from 1913 through 2002. (Oki, 2004, Figure 4)



4.0 Maintenance of Fish and Wildlife Habitat

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

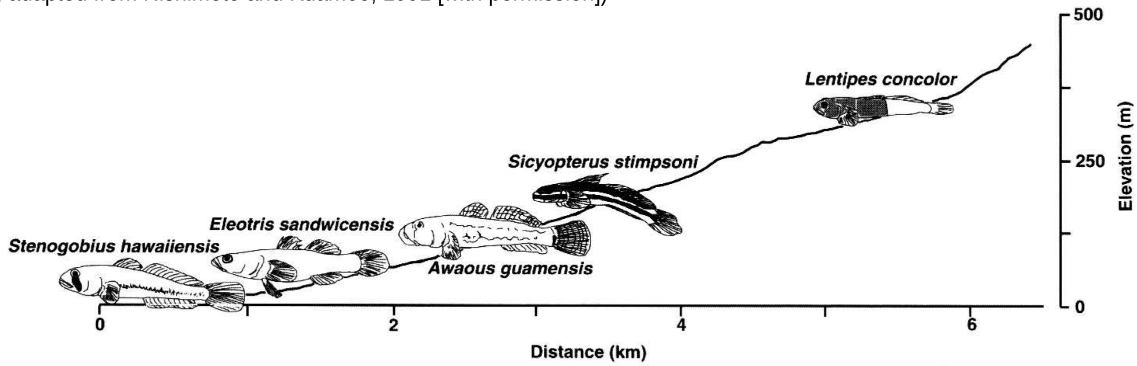
Table 4-1. List of commonly mentioned native stream organisms. (Source: State of Hawaii, Division of Aquatic Resources, 1993)

Scientific Name	Hawaiian Name	Type
Awaous stamineus	‘O‘opu nakea	Goby
Lentipes concolor	‘O‘opu hi‘ukole (alamo‘o)	Goby
Sicyopterus stimpsoni	‘O‘opu nopili	Goby
Stenogobius hawaiiensis	‘O‘opu naniha	Goby
Eleotris sandwicensis	‘O‘opu akupa (okuhe)	Eleotrid
Atyoida bisulcata	‘Opae kala‘ole	Shrimp
Macrobrachium grandimanus	‘Opae ‘oeha‘a	Prawn
Neritina granosa	Hihiwai	Snail
Neritina vespertina	Hapawai	Snail

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

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

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



Hawaii Stream Assessment

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

Due to the broad scope of the HSA inventory and assessment, it continues to provide a valuable information base for the Commission's Stream Protection and Management Program and will continue to be referred to in various sections throughout this report. The HSA did not recommend that the Kawela Stream be listed as a candidate stream for protection based on its aquatic resources. Kawela also did not have any "blue ribbon" resources identified by the HSA for protection.

DAR Atlas of Hawaiian Watersheds

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

- **Point Quadrat Survey.** Two stream surveys were conducted in 1982 and in 1983, five stream surveys were conducted in 1990, and three stream surveys were conducted in 1991. In the estuarine reaches, stripped mullet (*Mugil cephalus*), āholehole (*Kuhlia sandvicensis*), ʻoʻopu nākea (*Awaous stamineus*),), ʻoʻopu akupa (*Eleotris sandwicensis*) and ʻoʻopu naniha (*Stenogobius hawaiiensis*) were observed in 1982 and 1983. At higher elevations, ʻoʻopu alamoʻo (*Lentipes concolor*), ʻoʻopu nopili (*Sicyopterus stimpsoni*), and ʻōpae kalaʻole (*Atyid bisulcata*) were each observed at multiple locations (Figures 4-2 to 4-7).

- **Insect Survey.** Insect surveys were conducted in Kawela in 1991 and 1995, with multiple species of Magalagrion identified in the headwaters (Figure 4-8)

- **Watershed and Biological Rating.** The Kawela watershed has a moderate rating for Molokai and statewide for land cover due to the percentage of forest cover. There is some wetland and estuarine reaches in the lowest elevations giving the watershed a moderate rating for shallow waters on Molokai and statewide. The watershed rates moderate for stewardship due to land use, biodiversity protection, and invasive species. Kawela Stream has a moderately-high rating for stream size, a poor rating for wetness, but a high rating for reach diversity for Molokai and for the state, resulting in a moderately-high total watershed rating for Molokai and statewide. The watershed is rated moderately-high for number of native species found and for introduced species, giving it a moderately high rating for all species and a moderately high total biological rating.

Figure 4-2. Location and date of stream biota surveys with presence and absence of ʻoʻopu ʻakupa (*Eleotris sandwensis*), Kawela, Molokai.

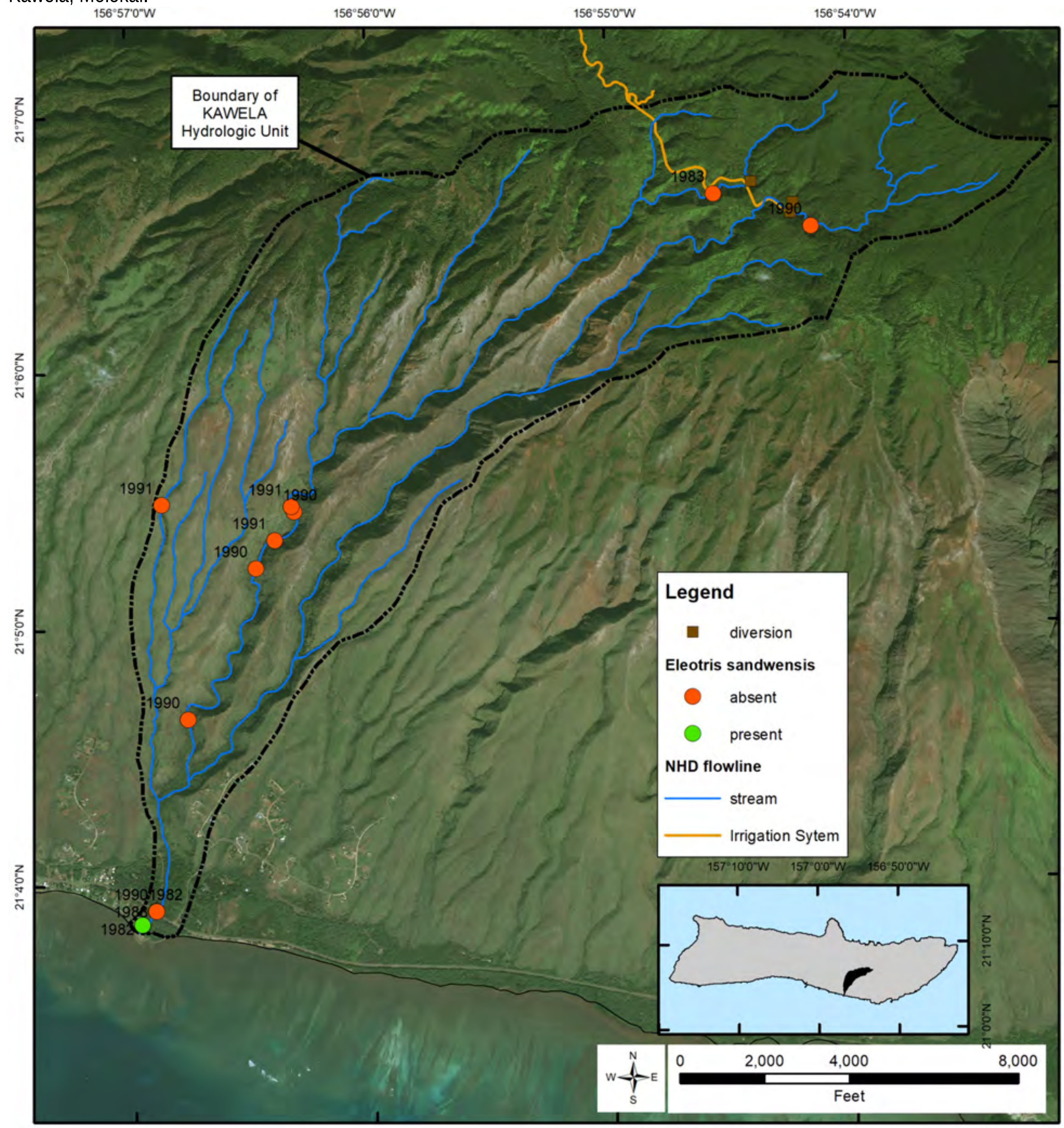


Figure 4-3. Location and date of stream biota surveys with presence and absence of ʻoʻopu nākea (*Awaous stamineus*), Kawela, Molokai.

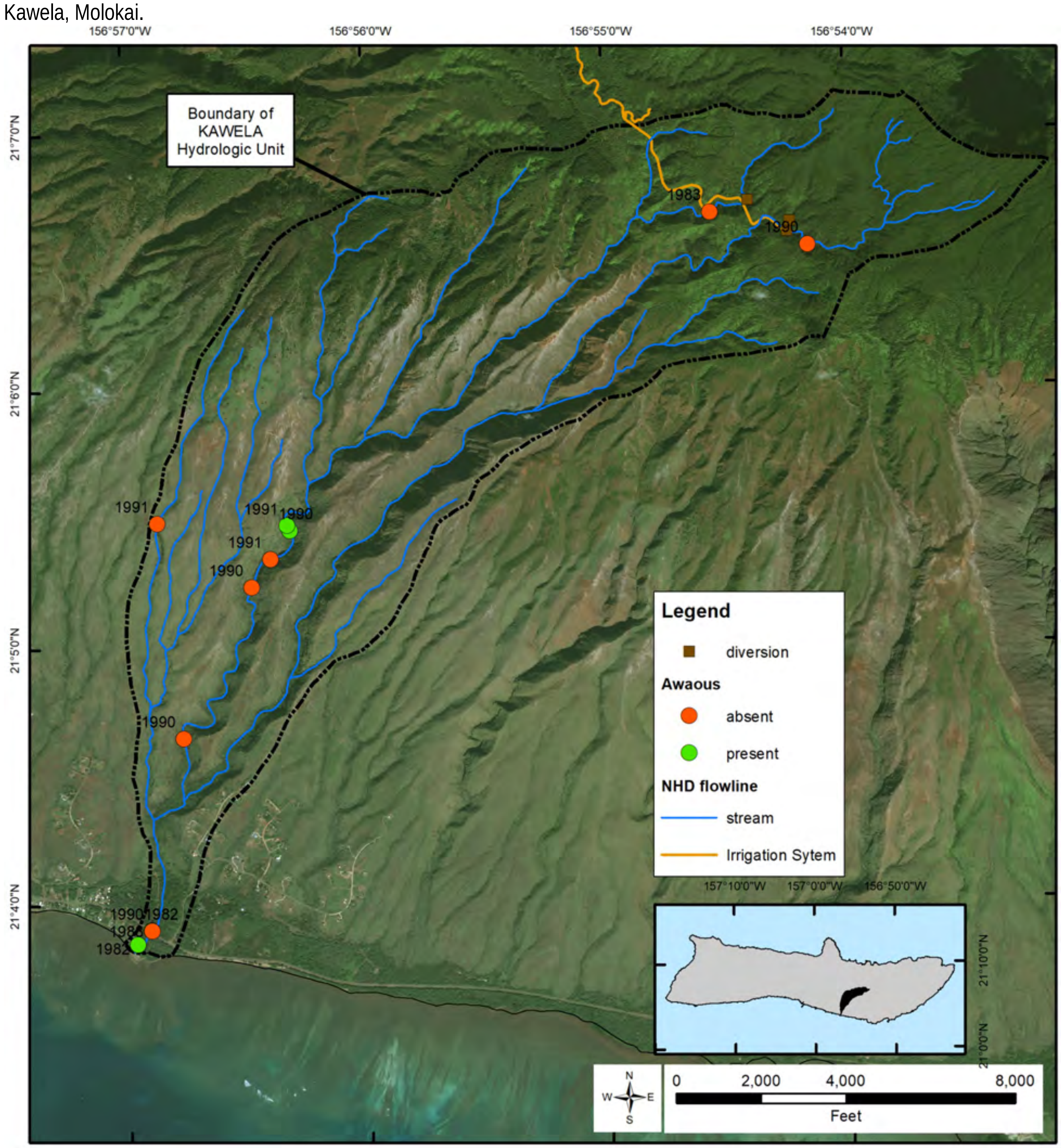


Figure 4-4. Location and date of stream biota surveys with presence and absence of ‘o‘opu naniha (*Stenogobius hawaiiensis*), Kawela, Molokai.

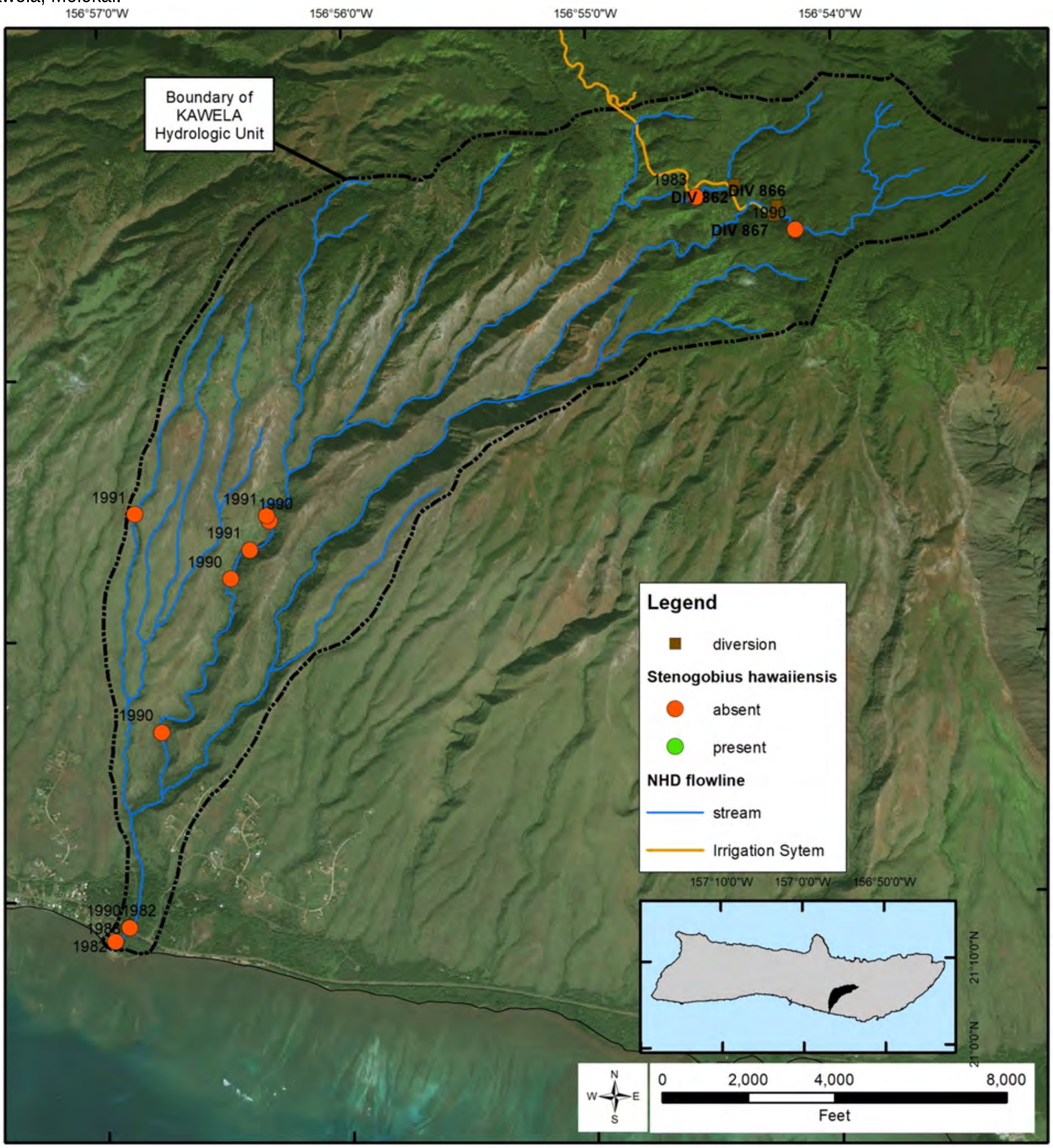


Figure 4-5. Location and date of stream biota surveys with presence and absence of ʻoʻopu nōpili (*Sicyopterus stimpsoni*), Kawela, Molokai.

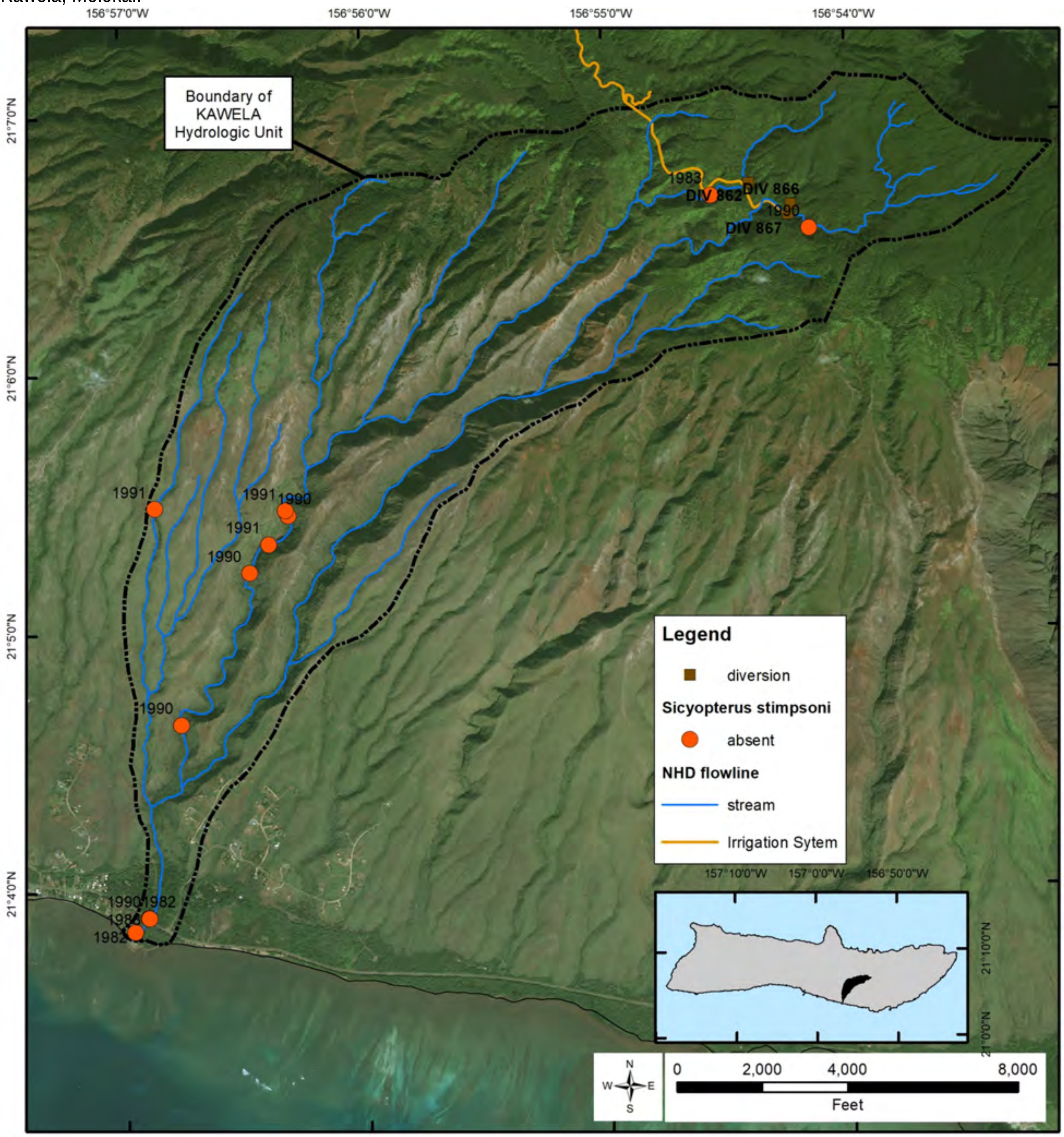


Figure 4-6. Location and date of stream biota surveys with presence and absence of ʻoʻopu alamoʻo (*Lentipes concolor*), Kawela, Molokai.

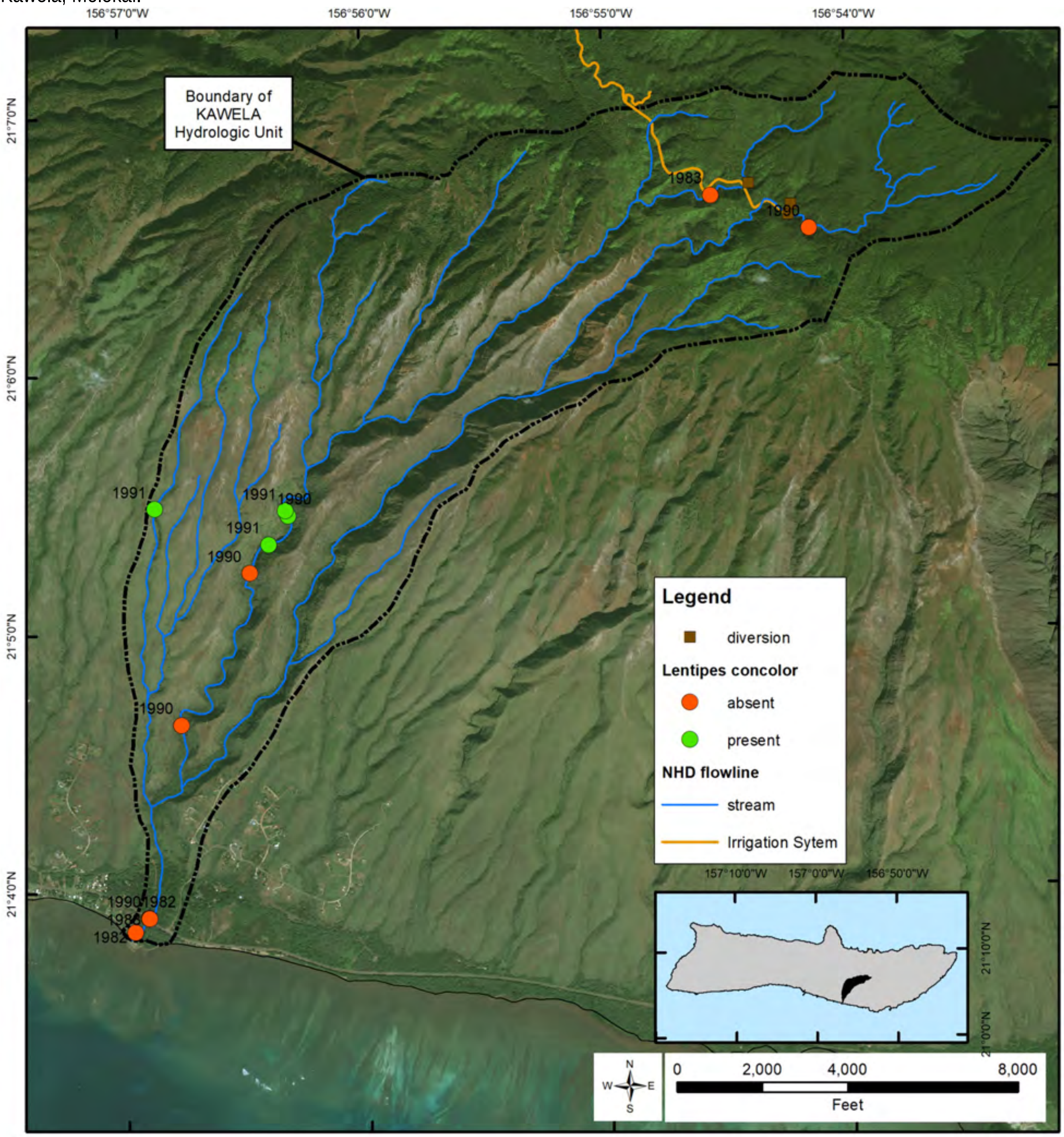


Figure 4-7. Location and date of stream biota surveys with presence and absence of ʻōpae kalaʻole (*Atyoida bisulcata*), Kawela, Molokai.

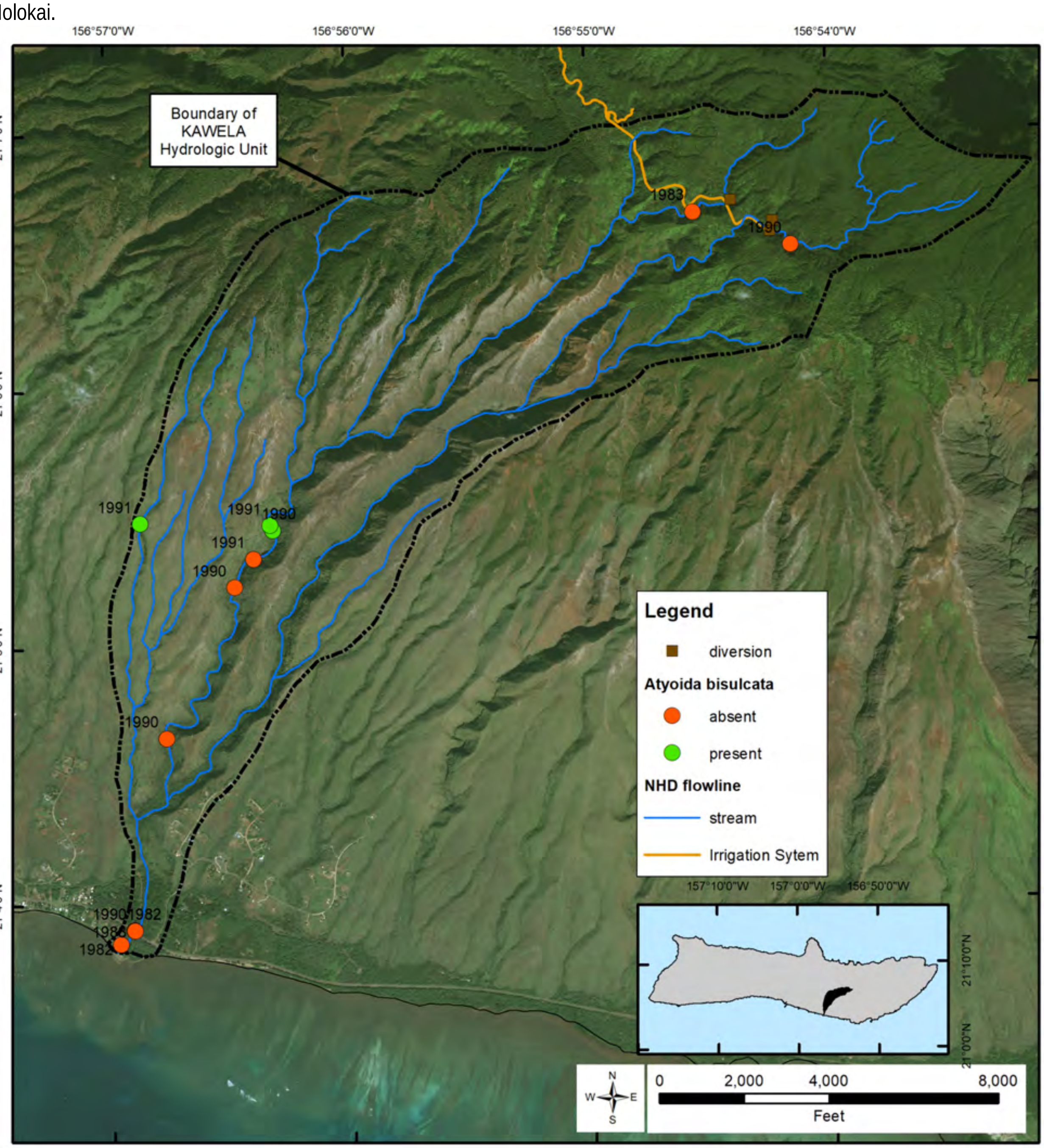
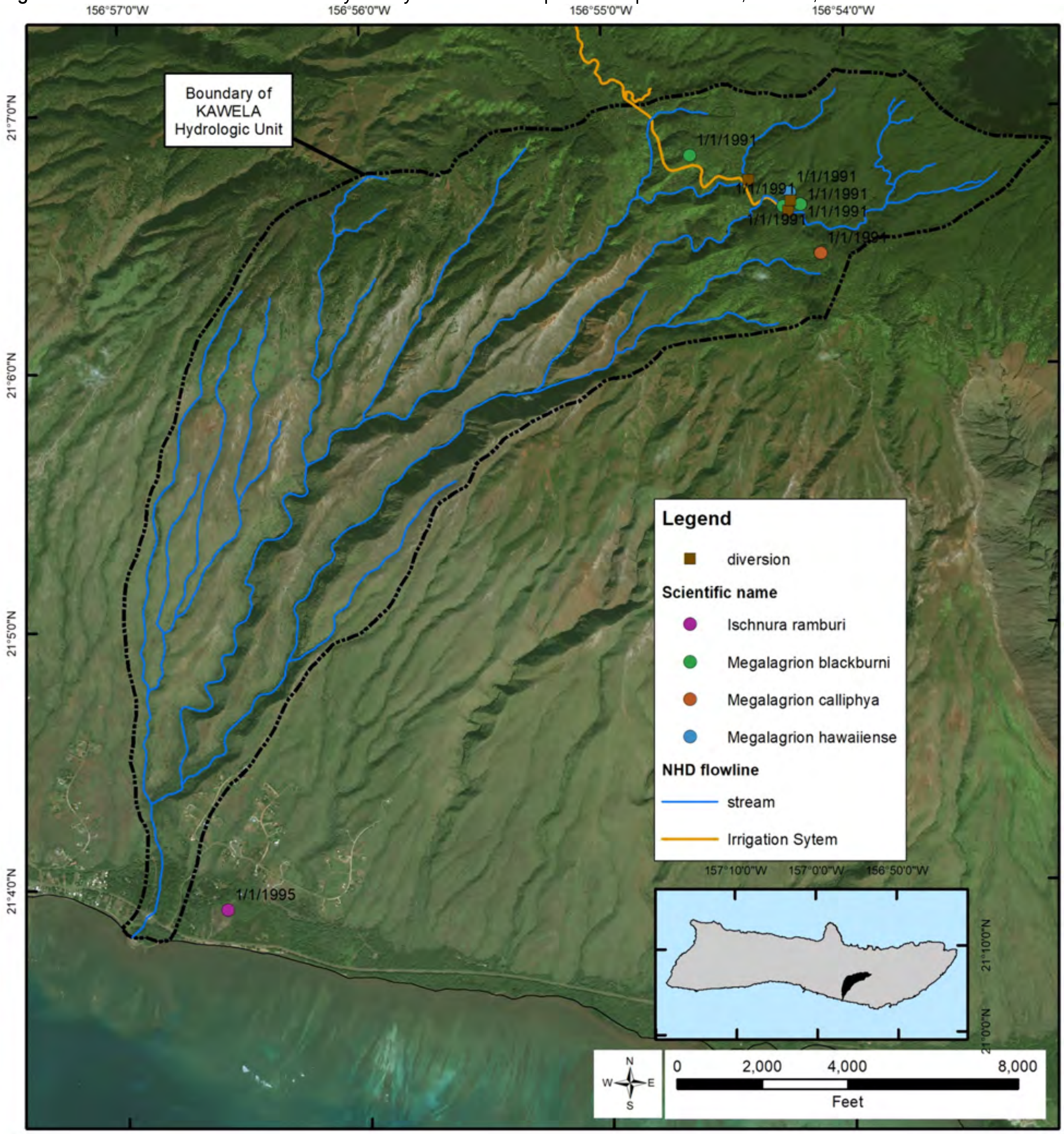


Figure 4-8 Location and date of damselfly surveys and date with presence species noted, Kawela, Molokai.



5.0 Outdoor Recreational Activities

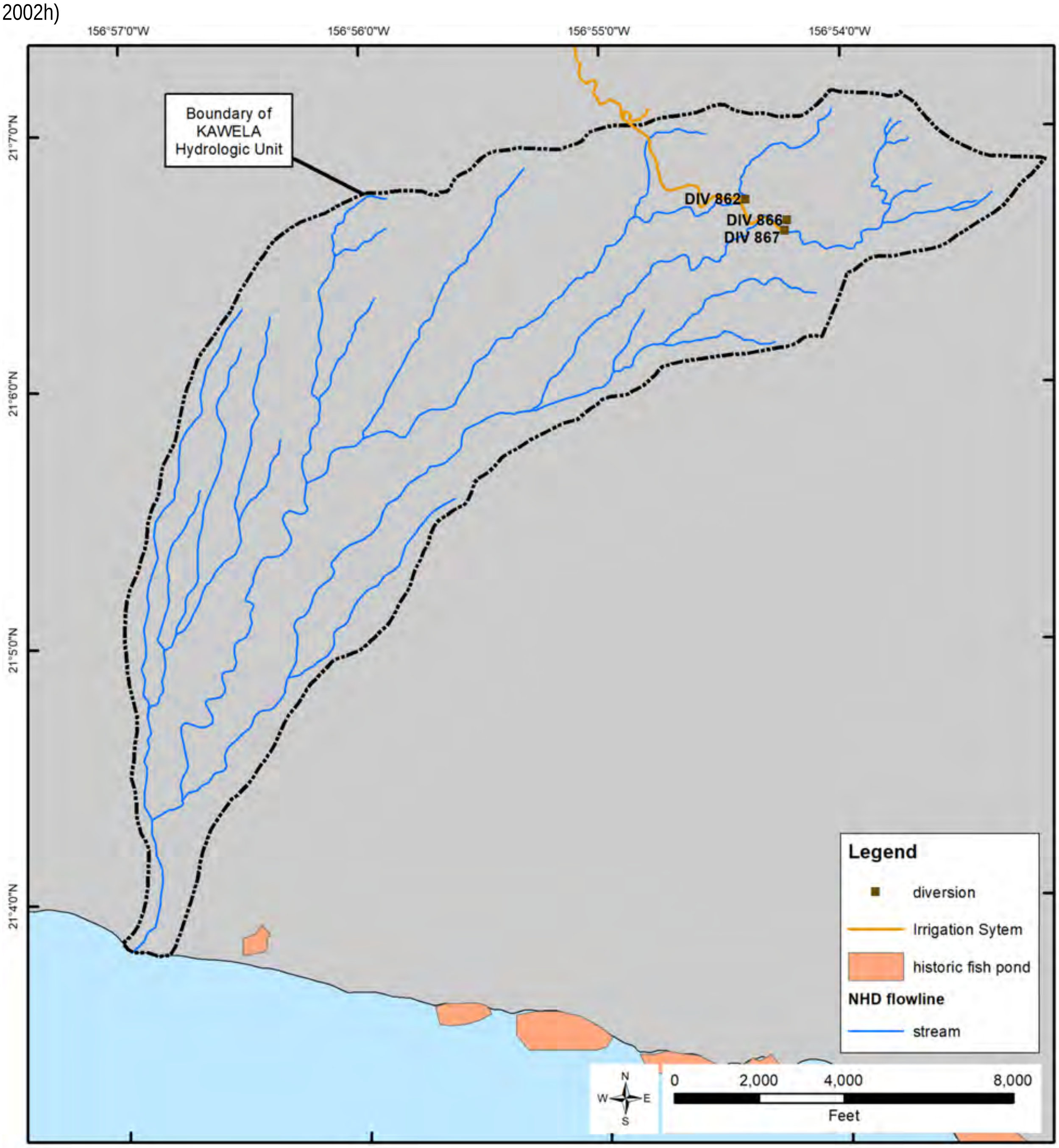
Water-related recreation is an integral part of life in Hawaii. Though beaches may attract more users, the value of maintaining streamflow is important to sustaining recreational opportunities for residents and tourists alike. Streams are often utilized for water-based activities, such as boating, fishing,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

The Hawaii Stream Assessment identified camping, hiking, fishing, swimming, hunting, and scenic views as recreational opportunities in the Kawela hydrologic unit with eight total experiences and two high quality experiences, providing a "outstanding" regional ranking, but not recommending it for statewide ranking (National Park Service, 1990). None of the Kawela hydrologic unit is open for mammal hunting.

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 Kawela Stream. A 1981 Hawaii Resource Atlas, prepared by the State of Hawaii Department of Transportation's Harbors Division, inventoried coral reefs and coastal recreational activities. Looking at available GIS data, in the immediate vicinity of the Kawela hydrologic unit, there are nearby fishponds and limu was collected along the coast (Figure 5-1). Historically, limu played a vital role in the Hawaiian diet. Limu gathering was entirely within the purview of the womens' role not only to gather and prepare, but to provide for its consumption and use by the entire community (McGregor, 2019). It is not surprising, then, that women became the foremost limu experts. Limu was as integral to a meal as fish and poi, and although it was considered a condiment that was eaten primarily to spice up other foods, the minerals and nutrients that it provided were essential to a healthy diet. While the word limu encompasses marine and freshwater algae, mosses, liverworts, lichens, and even some corals, there were specific names for each limu. Different limu were used for different purposes, including consumption, medicine, and ceremonies. Limu that didn't serve any purpose were often not given a name, and were simply referred to as ‘opala limu, or rubbish limu.

John Clark, in his book *The Beaches of Maui County* (1989), describes One Alii Beach Park and Kakahala Beach Park near the Kawela area.

Figure 5-1. Locations of fishponds in and near the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2002h)

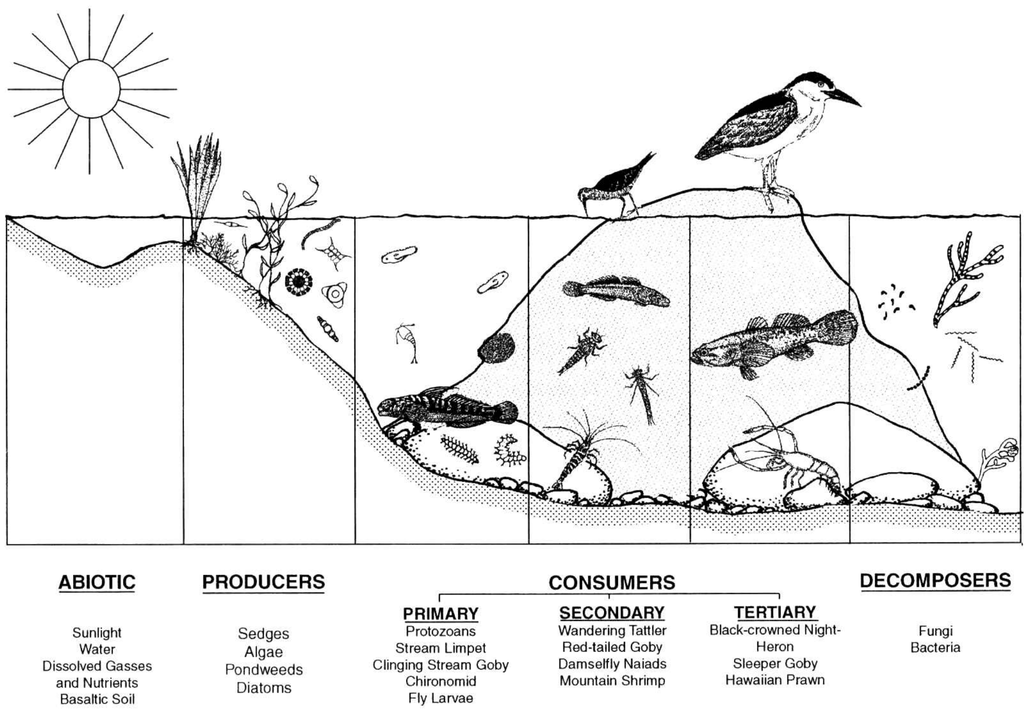


6.0 Maintenance of Ecosystems

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

The HSA determined that Kawela Stream deserved to be a candidate stream for protection based on its substantial riparian resources.

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



The riparian resources of Kawela 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 Kawela hydrologic unit. (National Park Service, 1990)

Category	Value
Listed threatened and endangered 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.	1
Recovery habitat: Recovery habitat consists of those areas identified by the USFWS and DLNR as essential habitat for the recovery of threatened and endangered species. Streams that have recovery habitat anywhere along their length were included.	none[1]
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.	4
Protected areas: The riparian resources of streams that pass through natural area reserves, refuges and other protected areas are accorded special protection from degradation. Protected areas were so designated because of features other than their riparian resources. The presence of these areas along a stream, however, indicates that native processes are promoted and alien influences controlled.	none[2]
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 (< 0.5 square mile)
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.	Mangrove, Pigs, Axis Deer, Goats

[1]The HSA was completed before the US Fish and Wildlife Service designated any critical habitat areas in Kawela.

[2]The HSA was completed before The Nature Conservancy began to manage the land owned by Molokai Ranch as a protected area in Kamakou Preserve.

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 Kawela, about 1.903 square miles (35 percent) falls within the Kamakou Preserve managed by The Nature Conservancy (Figure 6-2).

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 Molokai. Including other areas not part of designated reserves, 5.248 square miles (97.4 percent) of the Kawela hydrologic unit is part of the East Maui Watershed Partnership (Table 6-2, Figure 6-3). Table 6-2 provides a summary of the partnership area, partners, and management goals of the East Maui Watershed Partnership.

Table 6-2. Watershed partnerships associated with the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Division of Forestry and Wildlife, 2020a)

Management Area	Year Established	Total Area (mi²)	Area (mi²)	Percent of Unit
East Molokai Watershed Partnership	1999	51.536	5.248	97.4
The East Molokai Watershed Partnership (EMoWP) is comprised of Kamehameha Schools Bishop Estate, Kapualei Ranch, County of Maui, State Department of Land and Natural Resources, Kawela Plantation Homeowners Association, National Parks Service, and The Nature Conservancy. The partnership uses a traditional Hawaiian land division (ahupuaa) approach to managing watershed landscapes, with protecting upper native forest ecosystems the highest priority, while promoting a mountain top to sea perspective. The management priorities of the EMoWP include: 1) Reduction of feral animal and priority weed species; 2) fencing to protect upper forests from feral animal intrusion; 3) resource monitoring to guide and document management actions; 4) community outreach that engages and educates the local communities; 5) Cultivate additional partnerships and capacity building. The EMoWP has conducted various projects including the construction of over seven miles of fence and on-going fence maintenance, the survey and removal of invasive plant species, eradication of animal species through an expanded hunting program, implementation of runoff and stream protection measures, water quality monitoring, and extensive public education and outreach campaigns.				

In 1974, the U.S. Fish and Wildlife Service (USFWS) initiated a National Wetlands Inventory that was considerably broader in scope than an earlier 1954 inventory that had focused solely on valuable waterfowl habitat. The inventory for Hawaii was completed in 1978 and utilized a hierarchical structure in the classification of various lands. The USFWS defines wetlands as "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" (Cowardin et al., 1979). Cummulatively, about 12.5 percent (0.68 square miles) of the Kawela hydrologic unit is classified as wetlands (freshwater forested), almost exclusively occurring in the upper elevations of the hydrologic unit (Table 6-3 and Figure 6-4), although a small portion of the hydrologic unit is estuarine wetland near the stream mouth.

Table 6-3. Wetland classifications for Kawela hydrologic unit, Molokai. (Source: US Fish and Wildlife Service, 2018)

System Type	Class	Area (mi²)	Percent of Unit
Palustrine	Freshwater Forested/Shrub Wetland	0.672	12.48%
Palustrine	Freshwater Emergent Wetland	0.002	0.04%
Marine	Estuarine and Marine Deepwater	0.002	0.04%

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. The Kawela hydrologic unit provides approximately 0.71 square miles of critical ecosystem habitat in the headwaters for endangered picturewing habitat. The lowest elevations of the Kawela hydrologic unit are dominated by non-native vegetation but there is a high or very high density of threatened or endangered plant species at elevations above 200 feet (Table 6-4, Figure 6-5).

Coastal Areas of Biological Importance

To represent the connectivity of inland habitat to areas of Hawai'i's nearshore marine environment that support high levels of marine biodiversity, The Nature Conservancy used existing marine data, local ecological knowledge, and modeling to determine areas of biological significance (ABS) as part of TNC's Marine Ecoregional Assessment of the Hawaiian Islands (Weiant, 2009). These nearshore areas in Hawai'i serve as nursery or feeding grounds for many organisms (e.g., finfish, sea turtles, mok seals) and include valued and diverse habitat types (e.g., coral reefs, seagrass beds, salt marshes). Tsang et al. (2019) identified local catchments within stream networks that directly influence ABS as well as areas directly adjacent to an ABS and potentially hydrologically connected to these important nearshore marine habitats. Figure 6-6 depicts the Kawela hydrologic unit in relation to areas of high coastal biological significance for Molokai Island. A small portion of Kawela is hydrologically connected to the ABS.

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

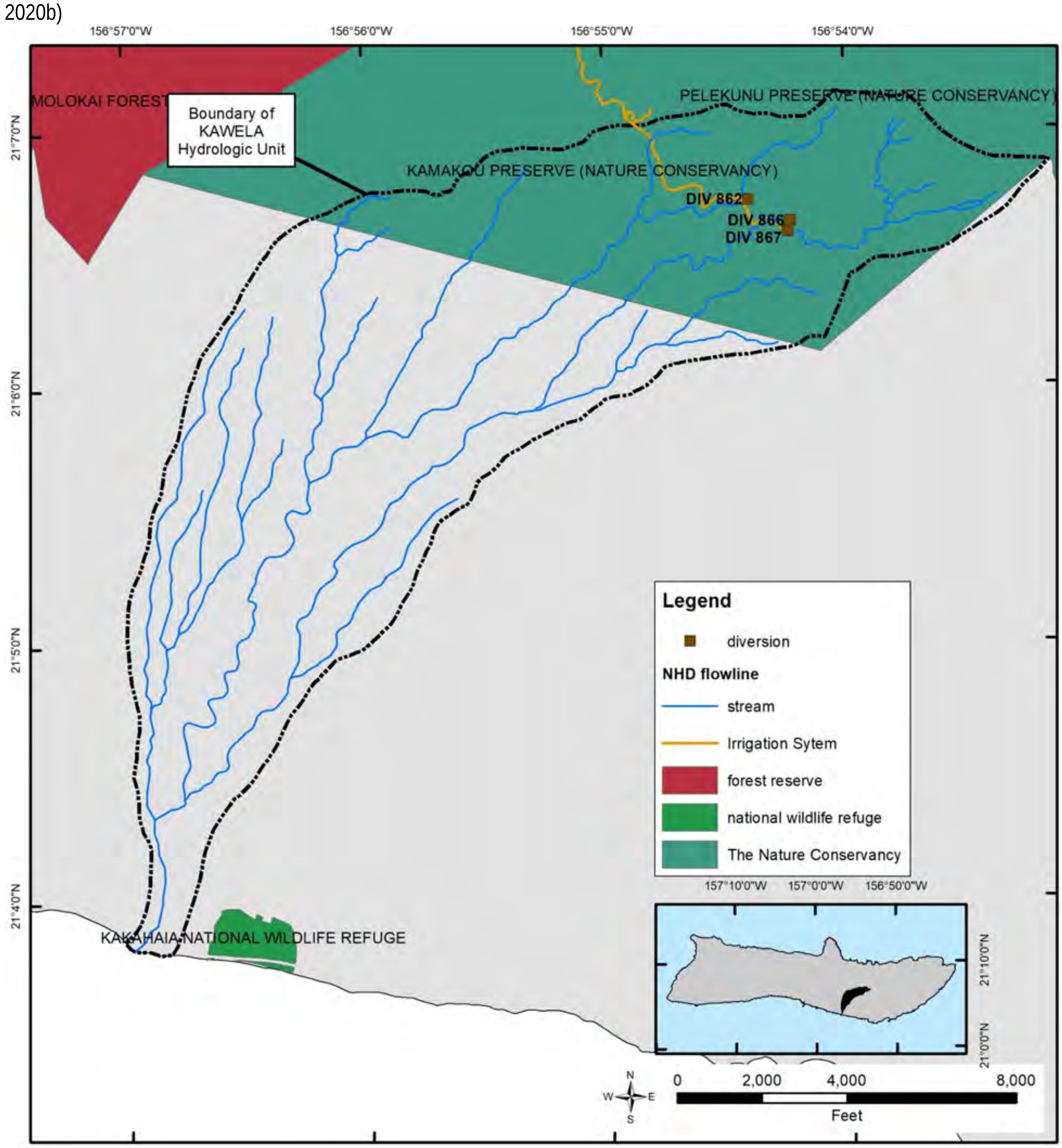


Table 6-4. Distribution of threatened or endangered plant species for Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2015f)

Canopy Type	Area (mi²)	Percent
Very High concentration of threatened and endangered species	2.456	45.6%
High concentration of threatened and endangered species	2.391	44.4%
Medium concentration of threatened and endangered species	0.426	7.9%
Low concentration of threatened and endangered species	0.000	0.0%
Little or no threatened and endangered species	0.113	2.1%

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 6-7. Following the results of the Oahu Koolau case study, some of the most valuable aspects of the forested areas are believed to be ecotourism, aesthetic pleasure, species habitat, water quality, and water quantity. The majority of Kawela provides no critical habitat for native forest birds, endangered plants or invertebrates. However, there are some areas that are listed as critical habiat for *Manduca blackburni* (Blackburn's Sphinx Moth) and *Drosophila differens*, a picturewing fly as depicted in Figure 6-7.

Table 6-5. Estimated Net Present Value (NPV) for Koolau [Oahu] Forest Amenities. (Source: Kaiser, B. et al., n.d.)

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

Figure 6-3. The East Molokai Watershed Partnership members in the the Kawela hydrologic unit, Molokai. (Source: State of Hawaii Division of Forestry and Wildlife, 2020a)

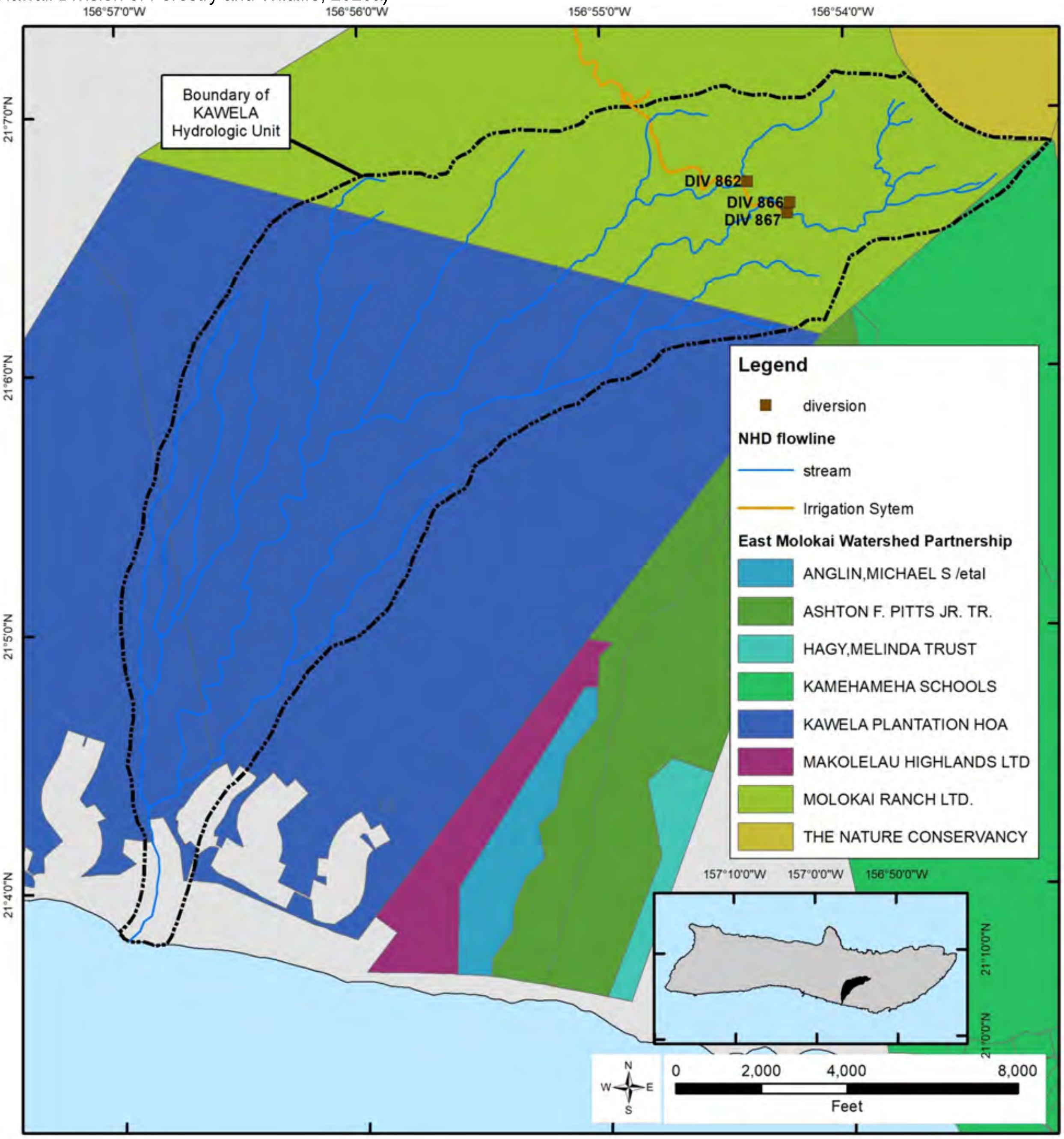


Figure 6-4. Wetlands in the Kawela hydrologic unit, Molokai. (Source: US Fish and Wildlife Service, 2018)

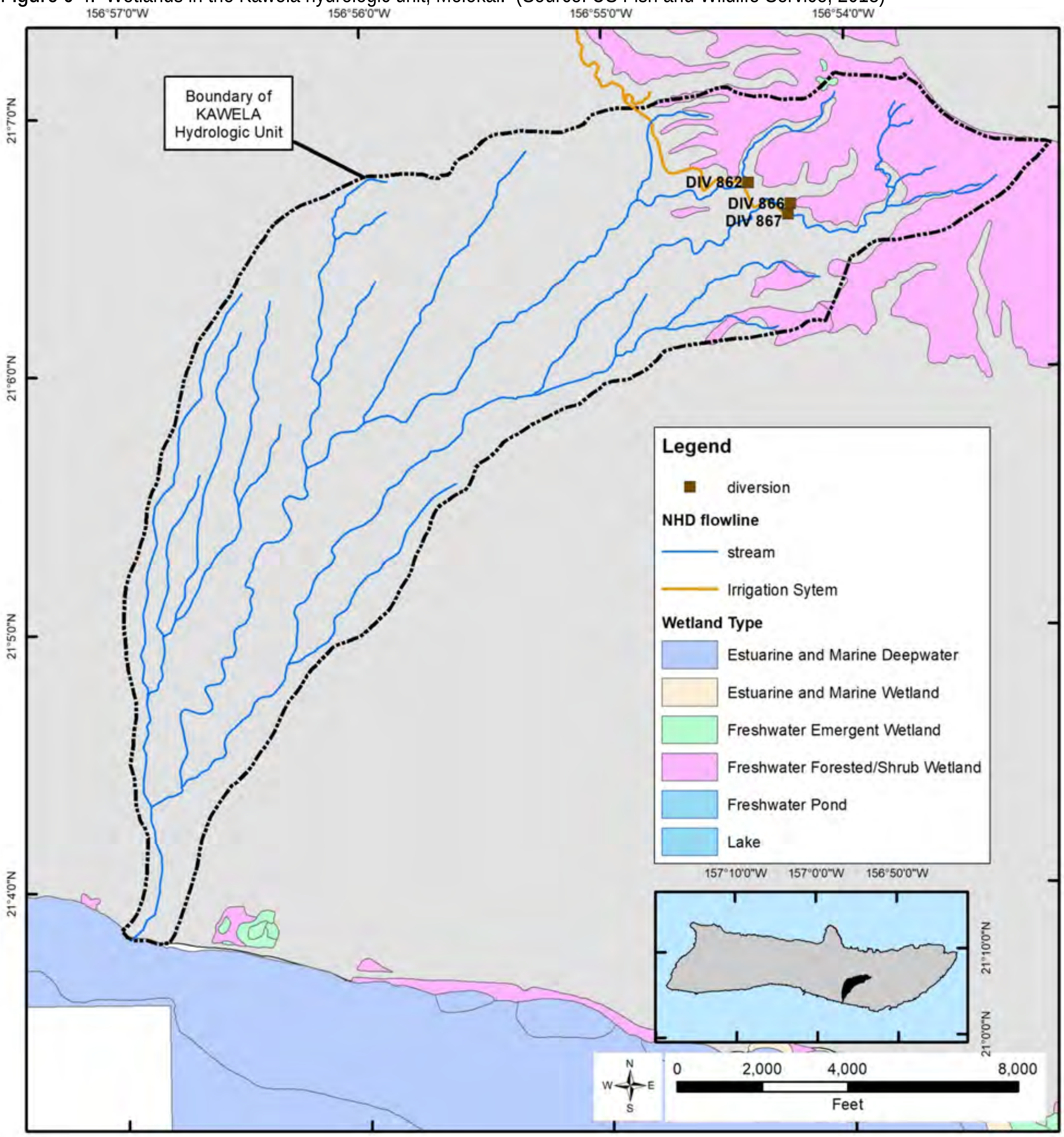


Figure 6-5. Density of threatened and endangered plants in Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2015h)

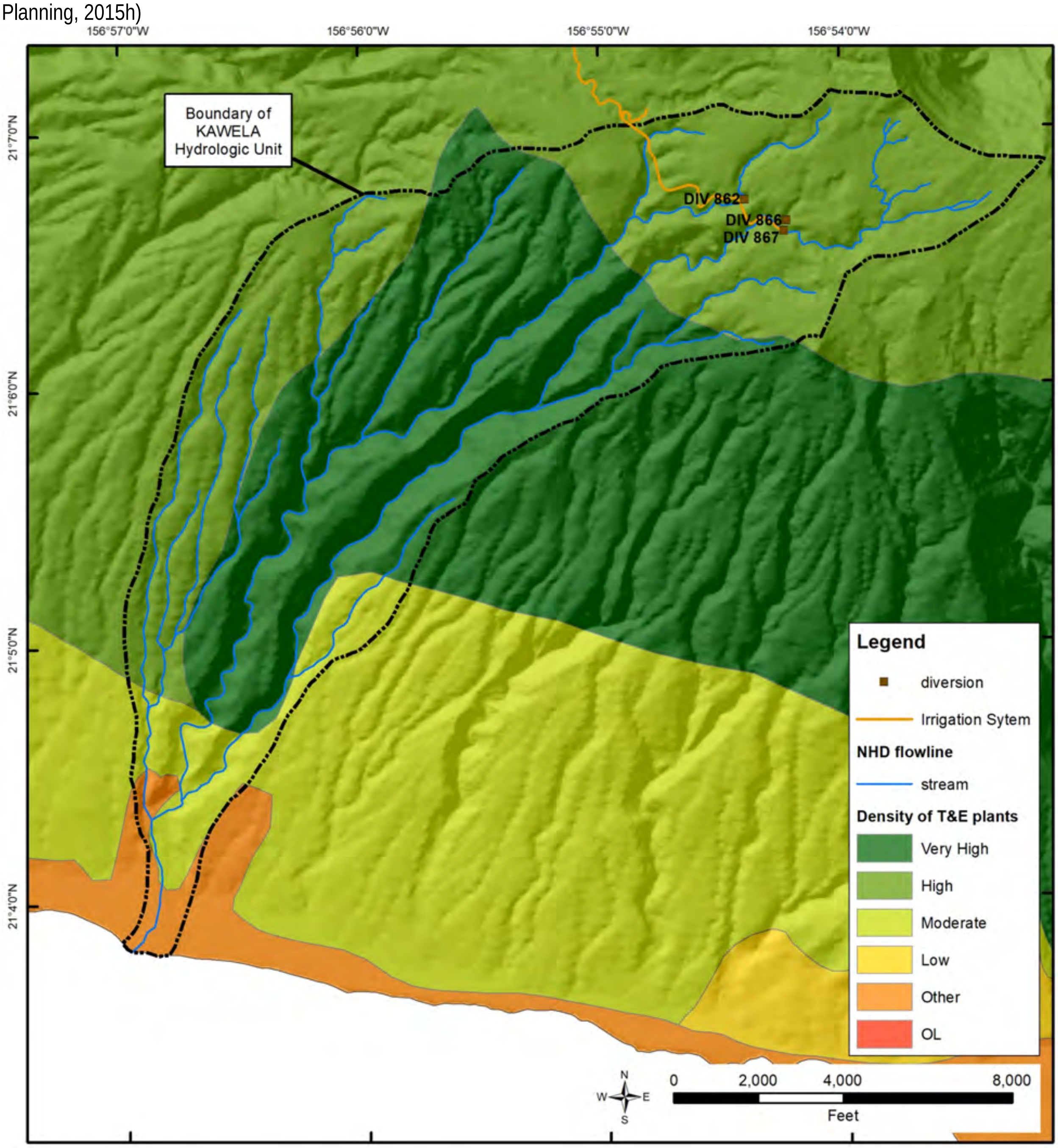


Figure 6-6. Catchment regions that are hydrologically connected to coastal areas of high biological significance for the island of Molokai. (Source: Tsang et al. 2019)

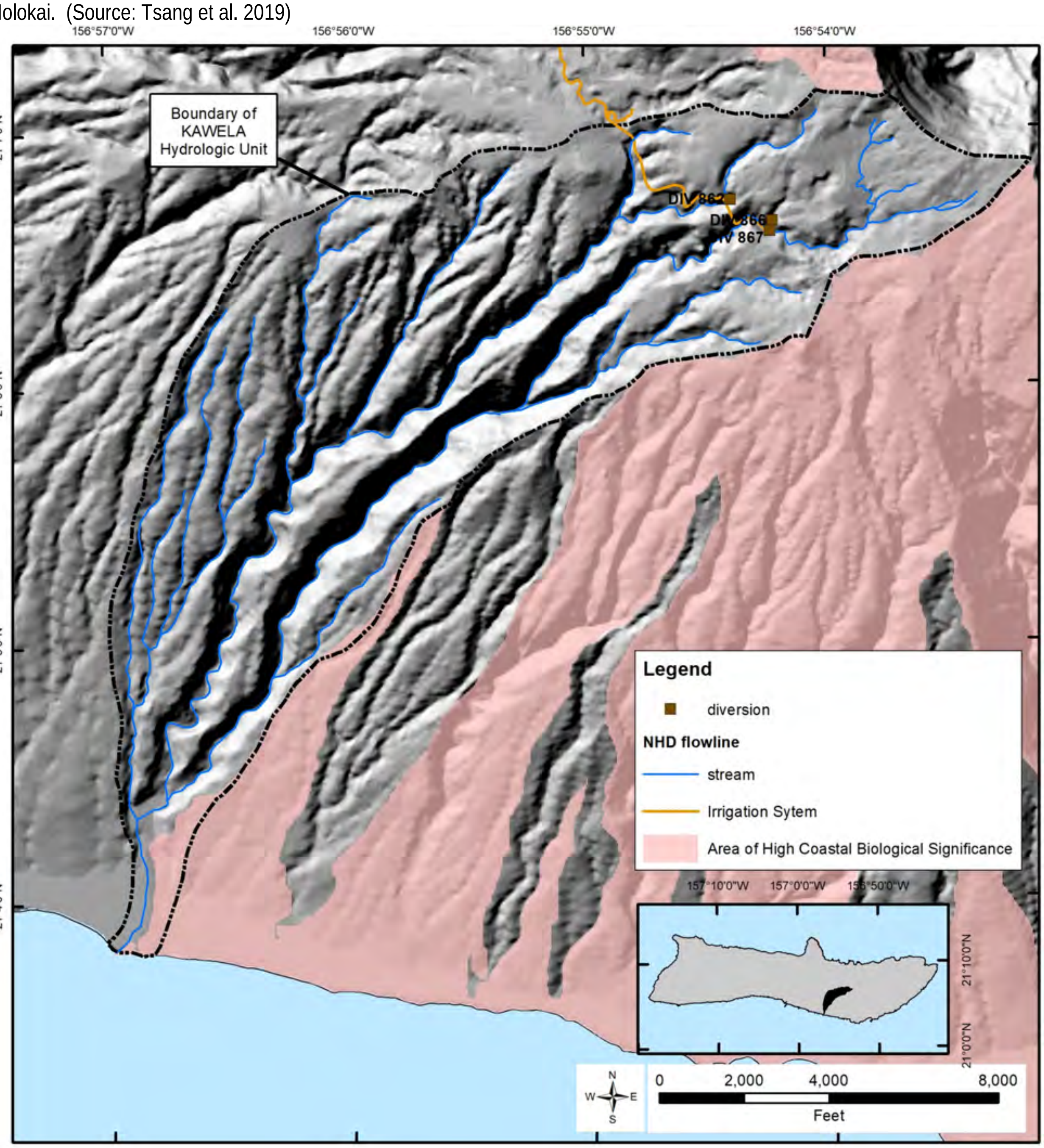
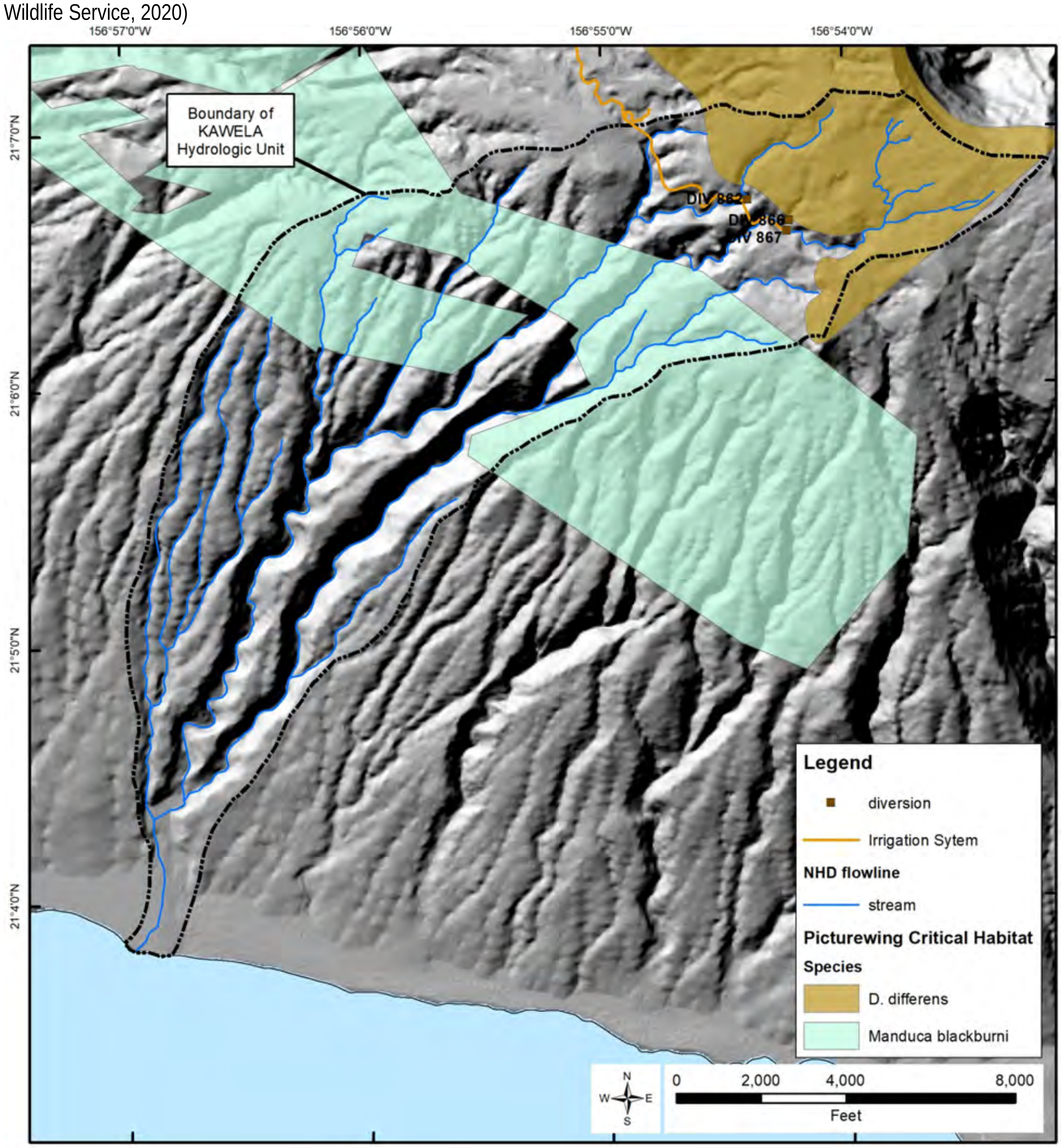


Figure 6-7. Critical habitat listing for picturewing species in relation to the Kawela hydrologic unit. (Source: U.S. Fish and Wildlife Service, 2020)



7.0 Aesthetic Values

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

The Kawela hydrologic unit supports few opportunities for aesthetic value to the general public as the watershed is entirely privately owned, although access can be made at the highway and from a 4-wheel drive jeep road.

In a 2007 Hawaii State Parks Survey, released by the Hawaii Tourism Authority (OmniTrak Group Inc., 2007), scenic views accounted for 21 percent of the park visits statewide, though that was a decrease from 25 percent in a 2003 survey. Other aesthetic-related motivations include viewing famous landmarks (9 percent), hiking trails and walks (7 percent), guided tour stops (6 percent), and viewing of flora and fauna (2 percent). On the island of Maui, visitors' preference to visit state parks for scenic views (26 percent) was second only to uses for outings with family and friends (29 percent). In comparison, residents primarily used state parks for ocean/water activities (30 percent), followed by outings with friends and family (28 percent), and then scenic views (9 percent). Overall, Maui residents were very satisfied with scenic views giving a score of 9.7 (on a scale of 1 to 10, with 10 being outstanding), with out-of-state visitors giving a score of 9.3. Though there are no state parks or recreational opportunities located in the hydrologic unit which would provide aesthetic value.

8.0 Navigation

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

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

The Kawela hydrologic unit does not provide any navigation opportunities.

9.0 Instream Hydropower Generation

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

There is no instream hydropower in the Kawela hydrologic units.

10.0 Maintenance of Water Quality

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

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

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

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

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

Fresh waters are classified for regulatory purposes, according to the adjacent land's conservation zoning. There are two classes for the inland fresh waters. Class 1 inland waters are protected to "remain in their natural state as nearly as possible with an absolute minimum of pollution from any human-caused source." These waters are used for a number of purposes including domestic water supply, protection of native breeding stock, and baseline references from which human-caused changes can be measured.

Class 2 inland waters are protected for uses such as recreational purposes, support of aquatic life, and agricultural water supplies.

Class 1 waters are further separated into Classes 1a and 1b. Class 1a waters are protected for the following uses: scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other non-degrading uses which are compatible with the protection of the ecosystems associated with waters of this class. Streams that run through natural reserves, preserves, sanctuaries, refuges, national and state parks, and state or federal fish and wildlife refuges are Class 1a. Streams adjacent to the most environmentally sensitive conservation subzone, "protective," are Class 1b, and are protected for the same uses as Class 1a waters, with the addition of domestic water supplies, food processing, and the support and propagation of aquatic life (HAR 11-54-3). These classifications are used for regulatory purposes, restricting what is permitted on the land around receiving waters. For example, public access to Class 1b waters may be restricted to protect drinking water supplies.

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

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

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

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

State of Hawaii WQS define: 1) the classification system for State surface waters, which assigns different protected uses to different water classes; 2) the specific numeric or narrative water quality criteria needed to protect that use; and 3) a general antidegradation policy, which maintains and protects water quality for the uses defined for a class. Quantitative and qualitative data are utilized. Numeric water quality criteria have specific concentrations (levels of pollutants) that must be attained based on water body type, e.g. fresh water stream. Qualitative standards are general narrative statements that are applicable to all State waters, such as "all waters shall be free of substances attributable to domestic, industrial, or other controllable sources of pollutants (State of Hawaii, Department of Health, 2004)." Conventional pollutants include nutrients and sediments. Existing water quality survailance data are provided in table 10-1. 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 2012 Integrated Report are Hawaii's 2010 §303(d) list, plus readily-available data collected from any State water bodies over the preceding 6 years (State of Hawaii, Department of Health, 2007). Per §303(d), impaired waters are listed after review of "'all existing and readily available water quality-related data and information' from a broad set of data sources" (State of Hawaii, Department of Health, 2004, p.57). However, available data are not comprehensive of all the streams in the State. According to the Hawaii Administrative Rules Title 11 Chapter 54 (HAR 11-54) all State waters are subject to monitoring; however, in the most recent list published (from the 2010 list that was published in 2012), only 88 streams statewide had sufficient data for evaluation of whether exceedance of WQS occurred. Kawela Stream did not appear on the 2018 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 presence of on-site sewage disposal systems (OSSDS) is commonly linked to increased nutrient and bacterial contamination of nearby waters. Figure 10-1 identifies the location of OSSDS in and nearby the Kawela hydrologic unit. There are 7 OSSDS in the Kawela hydrologic unit, mostly in the lower elevations near the coast where there are rural developments (Figure 10-1). The large concentration of OSSDS near the coastline in adjoining hydrologic units may also impact nearshore water quality in Kawela.

Kawela Stream is classified as Class 1 inland waters from its headwaters to approximately the 700 ft elevation as the surrounding land is in the conservation subzone "protective," although it is not contiguous and some of the upper elevations are classified as Class 2 inland waters. It should be noted that the conservation subzone map utilized for this interpretation is general and elevations are not exact. It should also be noted that there is no direct relationship between elevation and attainment of water quality standards.

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

Table 10-1. Mean and standard deviation (SD) water quality parameters measured at USGS 16415000 in the Kawela hydrologic unit, Molokai. (Source: EPA, 2020)

station name		**elevation (ft)**		**sample date range**							
USGS 16415000		3,625		8/26/69 - 1/18/72							
temperature		Alkalinity		Chloride		Hardness (Ca,Mg)		Magnesium (Mg)		Silica	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
6	15 (1.64)	6	2.83 (1.17)	12	10.17 (2.06)	6	6 (1.10)	6	0.92 (0.204)	6	6.00 (2.69)
Nitrate as N		Specific Cond.		pH		Floride		Sodium (Na)		TDS	
n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
7	0.14 (0.10)	6	41.7 (5.96)	6	5.65 (0.51)	5	0.08 (0.04)	6	5.4 (0.71)	15	9.16 (13.41)

Figure 10-1. On-site sewage disposal systems in or near the Kawela hydrologic unit, Molokai. (Source: State of Hawaii Department of Health, 2020)

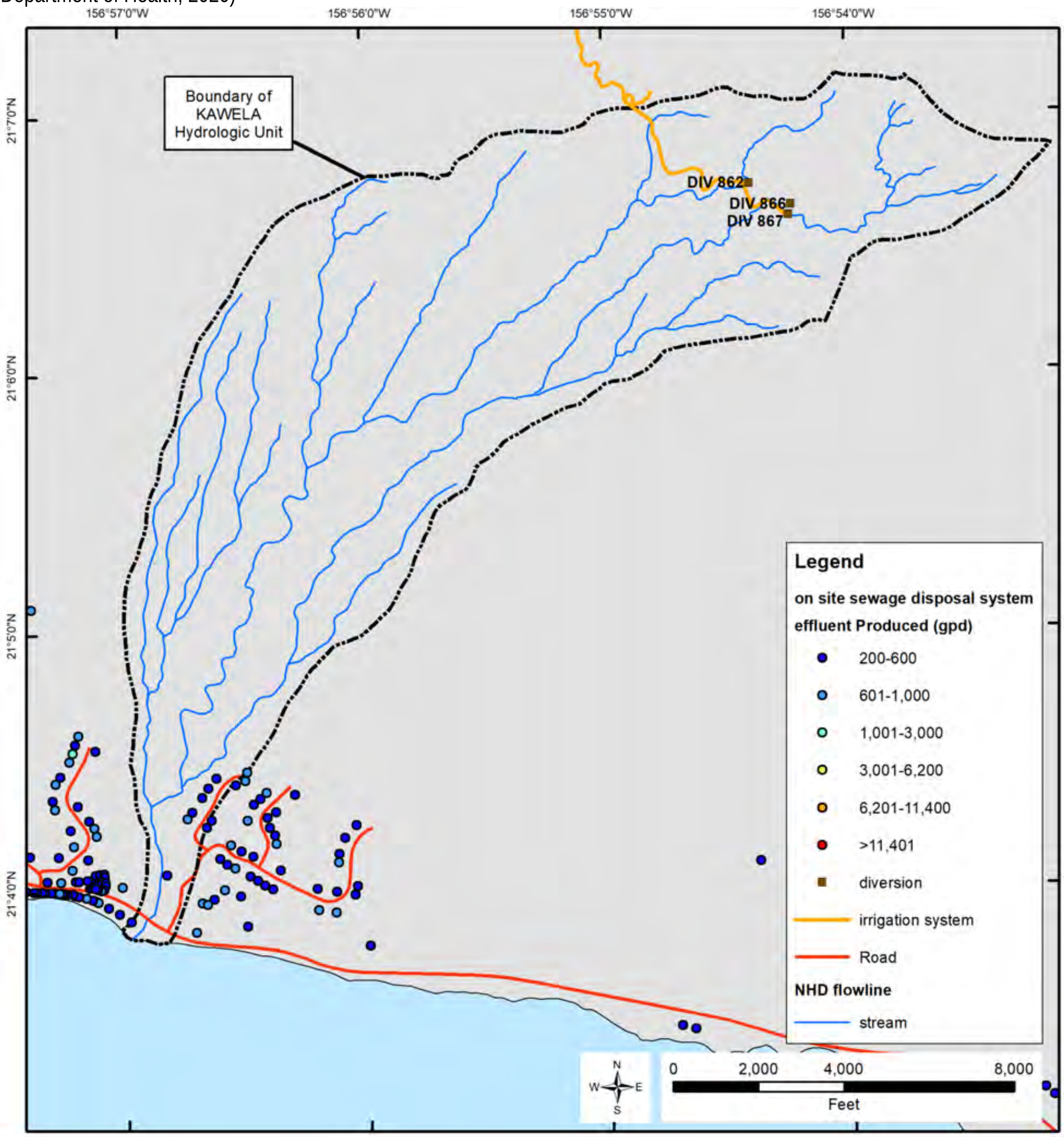
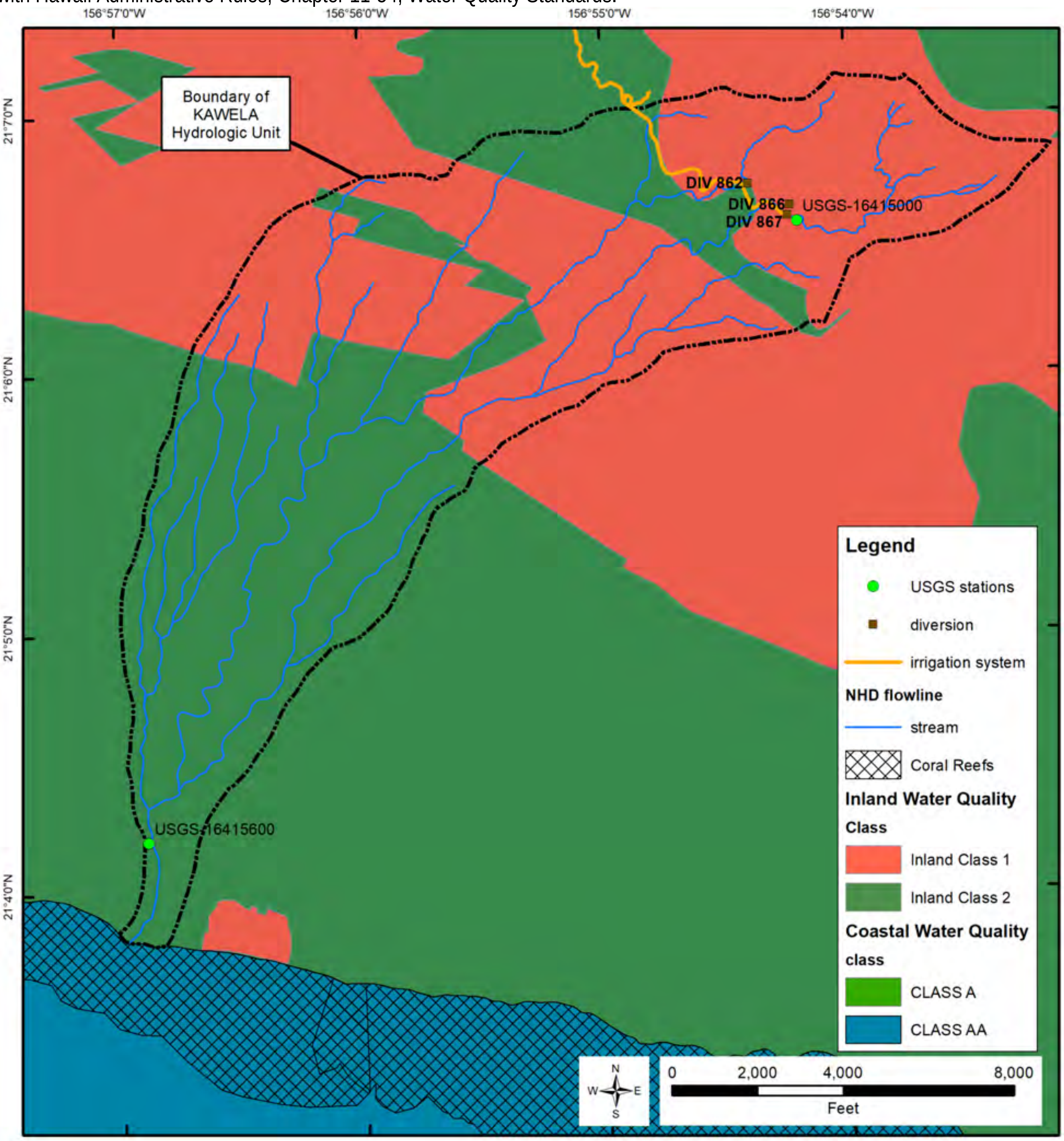


Figure 10-2. Water quality standards and water quality sample sites for the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2015e; USEPA, 2020). The classifications are general in nature and should be used in conjunction with Hawaii Administrative Rules, Chapter 11-54, Water Quality Standards.



11.0 Conveyance of Irrigation and Domestic Water Supplies

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

Neither the State nor the County keeps a comprehensive database of households whose domestic water supply is not part of a municipal system (i.e. who use stream and / or catchment water). The City and County of Honolulu Board of Water Supply does not have data for water users who are not on the county system and may be using catchment or surface water for domestic use. The State of Hawaii Department of Health Safe Drinking Water Branch administers Federal and State safe drinking water regulations to public water systems in the State of Hawaii to assure that the water served by these systems meets State and Federal standards. Any system which services 25 or more people for a minimum of 60 days per year or has at least 15 service connections is subject to these standards and regulations. Once a system is regulated by the Safe Drinking Water Branch, the water must undergo an approved filtration and disinfection process when it has been removed from the stream. It would also be subject to regulatory monitoring. There are two private water systems in the Kawela hydrologic unit regulated by the Public Utility Commission (Molokai Ranch Mountain Water System and Kawela Water System), with the DOH Safe Drinking Water branch regulating the Kawela Water System as a domestic water system that serves more than 23 people. This system is dependent on groundwater as a source for both potable and non-potable water. The Molokai Ranch Mountain Water System is a non-potable water system that supplies water to customers in Hoolehua, Kualapuu, west Molokai, and the Manawainui Industrial Area, as well as meeting its own agricultural needs.

12.0 Protection of Traditional and Customary Hawaiian Rights

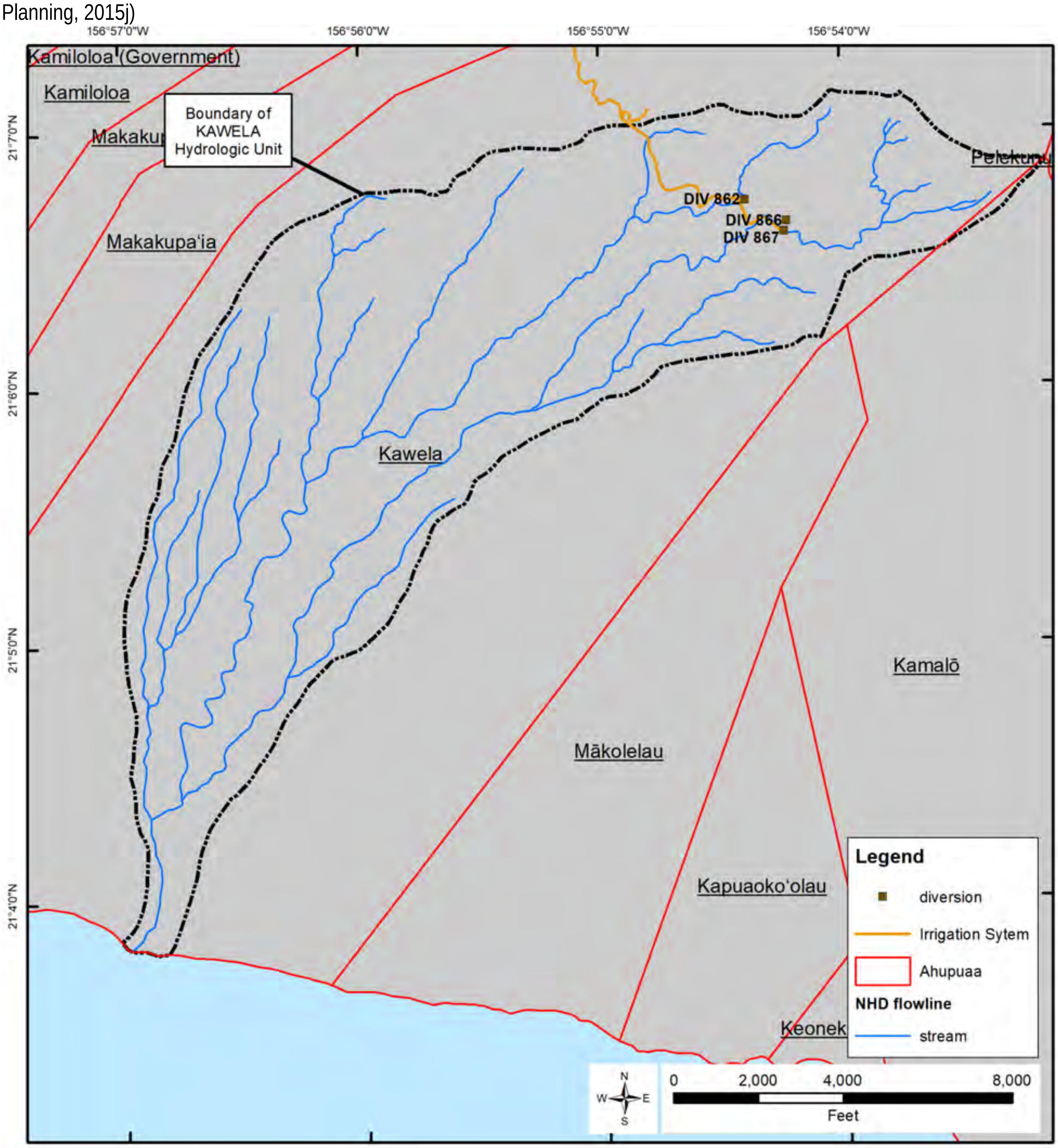
The maintenance of instream flows is important to the protection of traditional and customary Hawaiian rights, as they relate to the maintenance of stream resources (e.g., hihiwai, opae, oopu) for gathering, recreation, and the cultivation of taro. Article XII, Section 7 of the State Constitution addresses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

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

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

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

Figure 12-1. Traditional ahupuaa boundaries in the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2015j)



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

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

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

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

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

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

In August 2000, the 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

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

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

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

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

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

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

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

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

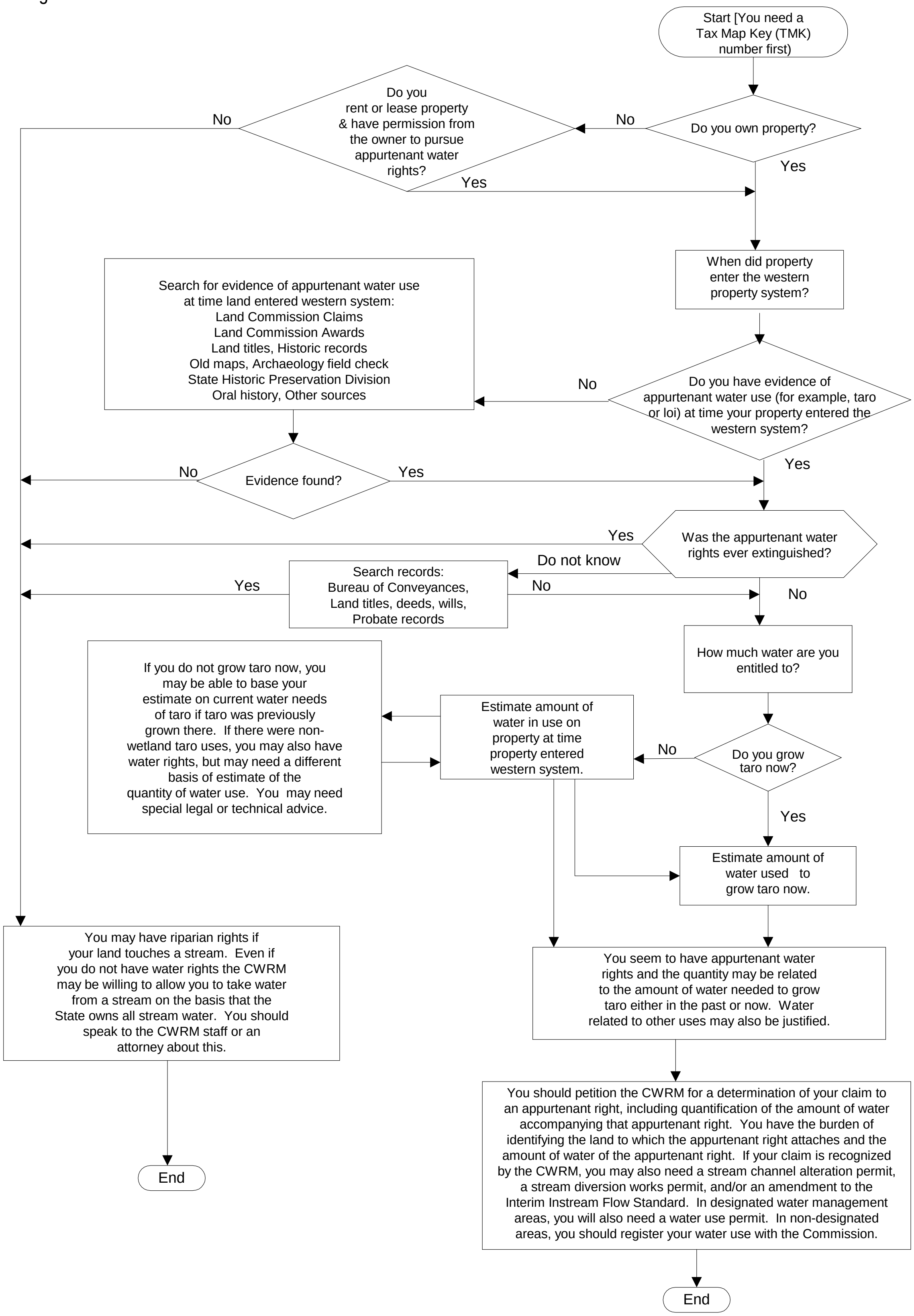


Table 12-1. Land Awards, claimants, associated tax map key (TMK) parcels, and landowners for the Kawela hydrologic unit, Molokai. [LCA is Land Commission Award; Gr. is Grant; por. is portion; and G.L. is Government Lease; BOE is Board of Education]

Land Award	TMK	Landowner	Claimant
LCA 8559 B:28	various	various	Lunalilo, William C
LCA 10107:1	254001029	Napoleon-Grambusch, Pilialoha	Maunaloa
LCA 10107:2	254001029	Napoleon-Grambusch, Pilialoha	Maunaloa
LCA 160 B:1	254001023	Molokai Properties	Kapuahalio
LCA 3910:1	254001023	Molokai Properties	Nalalau
BOE Grant 23:3	254001023	Molokai Properties	Board of Education

Taro Production

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

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

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

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

The average and median inflows from all 10 cultivation areas studied are listed in Table 12-4 below. The study indicated that the "values are consistent with previously reported inflow and are significantly higher than values generally estimated for consumption during kalo cultivation." It should also be noted that farmers were interviewed during field visits; most "believed that their supply of irrigation water was insufficient for proper kalo cultivation."

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

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

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

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

> The southern coast [of Molokai] is one of gently sloping *kula* lands with a shallow shore, for the most part bordered by a good fringing reef. This configuration enabled the people of Molokai to build the largest number of salt-water fishponds to be found on any single stretch of coast in the islands.
>
> (p. 515)

In *Hawaiian Fishponds* (1964), Summers clarified that two "fishponds" near Kawela were squarish in form and served for evaporating sea water to make salt. More recently, several ponds have been or were being cleared for fish farming. Handy and Handy (1972) stated that it was probably its fishponds which gave Molokai its reputation as the "land of plenty":

> Before the days of ranching, forests covered much of the uplands around Mauna Loa on western Molokai. Probably some dry taro was planted here. Dry taro is known to have been planted on the southern *kula* lands of eastern Molokai, from Kamalo to the eastern end of the island. On the western half of the island evidence of wet-taro cultivation were found only in the swampy lands below Manawainui Gulch, about three miles northwest of Kaunakakai. Probably there were small terraced areas upstream.
>
> (p. 515)

Continuing on:

> Formerly the small streams on the southeastern coast carried more water than they do now, and it is certain that in many of the interior valleys there are small sections of terraces. Wet taro was seen at Keawanui, Puko‘o, Kawaikapu, Waialua, Honouliwai, and Pohakupuli. It is quite certain that formerly taro was cultivated on flats and in gulches all the way from Kamalo eastward. In ancient times Waialua, with its two streams and extensive flats, was the largest terraced area on Molokai’s south coast.

An archeological survey of Molokai in 1937 conducted by Southwhich Phelps (1941) reported the following wet-taro areas: Halawa, Halawa uplands, Wailau, Pelekunu, Waikolu, Honouliwai, Moanui, Waialua, Kamalo, Mapulehu, and Kahananui.

Additionally, the *Au Okoa* Hawaiian newspaper on September 26, 1867, provided a detailed account of the taro localities on Molokai which included: Waialua, Poniuahua and Puelelu, Honomuni and Kamanoni, Kuliula, ‘Ualapue, and Kaamalo.

In 1931, Handy and Handy (1972) observed potato patches at various places near the road along the south coast, and Hawaiians reported that many parts of the kula land used to be planted with both sweet potato and dry taro. Handy and Handy (1972) assumed that potatoes were grown all along this coastal plain fringed with fishponds from Waialua to Punakou. Between Kaunakakai and Kalamaula on the slopes of Kakalahale and Luahine hills there were potato plantations. There were many flourishing Hawaiian homesteads at Hoolehua and Kualapuu refers to sweet potato hill. Much of western Molokai was formerly covered with trees, which likely influenced local climate patterns, soil erosion, and suitability for agriculture.

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]

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

Archaeological Evidence for Hawaiian Agriculture

Individual cultural resources of Kawela hydrologic unit was not classified by the Hawaii Stream Assessment (HSA), but generally classified based on the Historic Preservation Division database. Data were collected in three general areas of: 1) archaeological; 2) historical; and 3) modern practices. Archaeological data were originally compiled by the State Historic Preservation Division and are only current to 1990, the date of the HSA (Table 12-5). There are seven identified archaeological sites in the Kawela hydrological unit (Table 12-4). Evidence suggests that Kawela was a dryland agricultural region with substantial population pre-contact that relied mostly on marine resources. This is further supported by the minimal wetland or dryland pre-contact agriculture associated with the Kawela hydrologic unit as modeled by Ladefoged et al. (2009), who modeled the extent of pre-contact agriculture across the Hawaiian Islands (Figure 12-3).

Table 12-4. Archaeological sites in and near the Kawela hydrologic unit, Molokai. (Source: Kipuka Database, 2021)
[LCA is Land Commission Award; Gr. is Grant;

Historic Site #	State Site #	SHPD Library	Land Award	Description
00714	50-60-03-00714	Mo-00025	8559 B:28	Numerous residential features interspread with dryland agricultural features; organic remains, midden, artifacts found; a platform with coral & upright slab was probably a shrine
00715	50-60-03-00715	Mo-00025	8559 B:28	Circular enclosure 5.5 x 4.5m; no midden or artifacts present; 3 coral fragments observed; isolated from other features
00716	50-60-03-00716	Mo-00025	8559 B:28	45 x 125m area of numerous stone-faced earthen terraces & stone mounds & modified outcrops representing stone clearance
00717	50-60-03-00717	Mo-00016	8559 B:28	Consists of 27 residential, agricultural, religious & burial features; also 3 petroglyph sites; dense concentrations of shell midden & artifacts; probably residence of high status persons; excavated
00718	50-60-03-00718	Mo-00025	8559 B:28	2 residential shelters; 2 lithic/midden scatters & 3 burial platforms; probably prehistoric & early historic use
00719	50-60-03-00719	Mo-00025	8559 B:28	A boundary wall & permanent habitation structure; 2 adjoining terraces w/scatter of shellfish & basalt flakes
00700	50-60-04-00700	Mo-00016	8559 B:28	12 Structures w/midden & lithic scatters; a large (9x6m) structure, possibly Hale Mua, temporary shelters & 2 platforms, probably burials

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.

While according to a 1990 Hawaii Coastal Zone Management Program *Hawaiian Fishpond Study for the Islands of Hawaii, Maui, Lanai, and Kauai,* there were no existing or historic fishponds present directly in the Kawela hydrologic unit, there were multiple fish ponds along the coast within the vicinity of the Kawela hydrologic unit, as identified in Figure 12-3 (DHM, Inc., 1990).

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

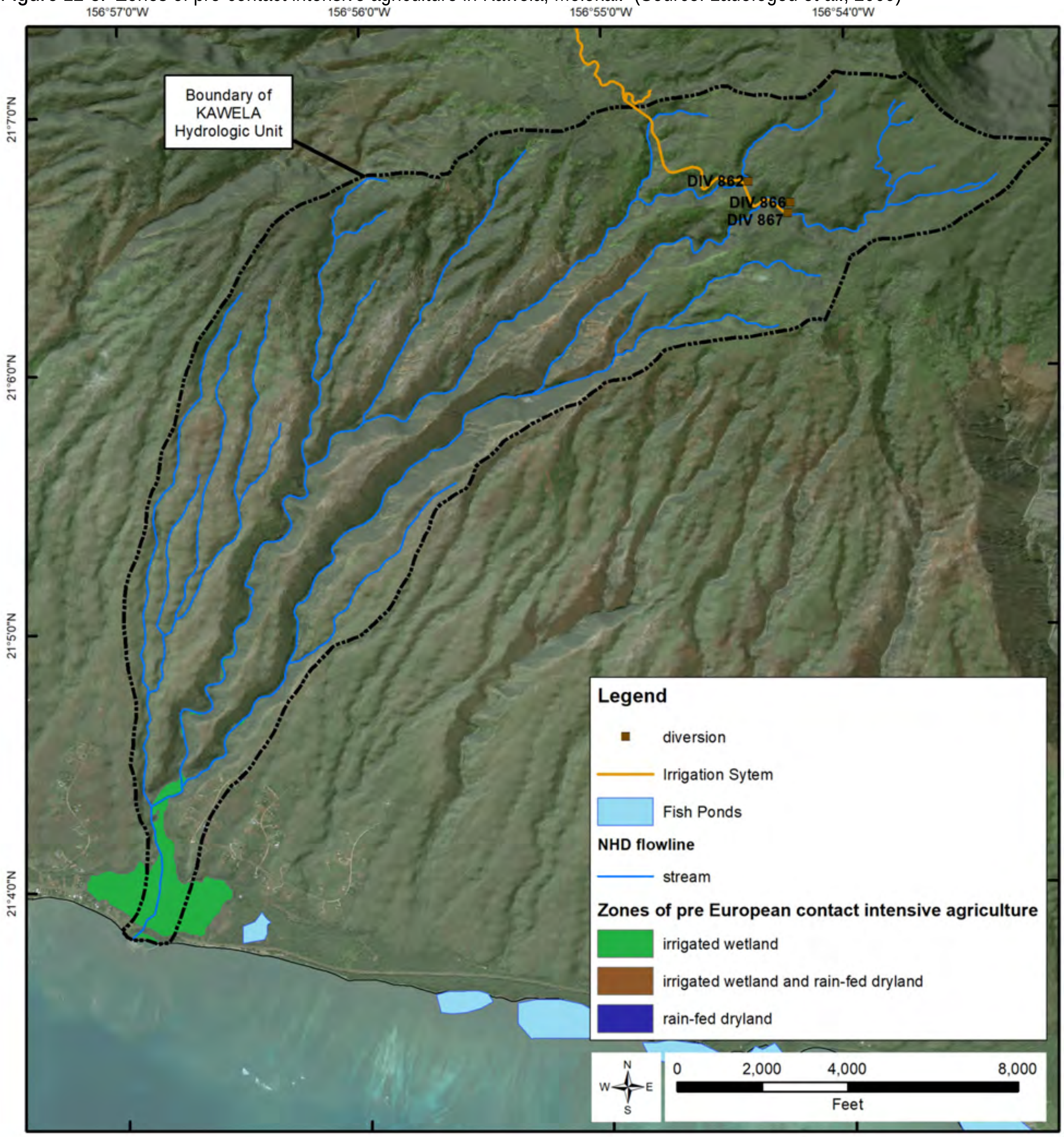


Table 12-5. Cultural resource elements evaluated as part of the Hawaii Stream Assessment for Kawela stream, Molokai. (Source: Smithsonian, 1990)

Category	Value
Survey coverage: The extent of archaeological survey coverage was analyzed and recorded as complete, partial, very limited, and none. Few valleys are completely surveyed. Many have little or no survey coverage.	partial
Predictability: The ability to predict what historic sites might be in unsurveyed areas was scored as high, medium, or low predictability or unable to predict. A high score was assigned if archaeologists were able to predict likely site patterns in a valley given historic documents, extensive archaeological surveys in nearby or similar valleys, and/or partial survey coverage. A low score was assigned if archaeologists were unable to predict site patterns in a valley because of a lack of historical or archaeological information. A medium score was assigned to all other cases.	Substantial information available
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.	15
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.	A C D E
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.	continuous sites
Overall Sensitivity: The overall sensitivity of a valley was ranked very high, high, moderate, low, or unknown. Very high sensitivity areas have moderate or high densities of sites with little or no land alteration. They are extremely important archaeological and/or cultural areas. High sensitivity areas have moderate or high densities of sites with little or no land alteration. Moderate sensitivity areas have very few sites with the sites meriting preservation consideration due to multiple criteria or moderate densities of sites with moderate land alteration. Low sensitivity areas have very few sites due to normal site patterning or due to extensive land alteration. The sites present are significant solely for their informational content, which enable mitigation through data recovery. Those valleys where no surveying had been undertaken and the ability to predict what might be found was low were ranked unknown.	very high
Historic Resources: 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.	No
Taro Cultivation: Streams and stream water have been and continue to be an integral part of the Hawaiian lifestyle. The committee identified a number of factors important to current Hawaiian practices. These include current taro cultivation, the potential for taro cultivation, appurtenant rights, subsistence gathering areas, and stream-related mythology. The committee felt that a complete assessment of the cultural resources of Hawaii's streams should include these items but, due to limits of information, only the current cultivation of taro was included.	No

13.0 Public Trust Uses of Water

The State Water Code (Hawaii Revised Statutes 174C-2) states that:

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

Article 11, Section 1 of the Hawaii State Constitution maintains that the:

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

This solidified the Public Trust Doctrine as constitutional law. Further, Article 11, Section 7, states that the "State has an obligation to protect, control, and regulate the use of Hawaii's water resources for the benefit of its people." The Public Trust Doctrine now identifies four priority uses of water as: (1) water for traditional and customary practices, including the growing of taro; (2) reservations of water for Hawaiian Home Land allotments; (3) water for domestic use of the general public; (4) maintenance of waters in its natural state. In the Kawela hydrologic unit, the use of water for traditional and customary practices was covered in Chapter 12 and water in its natural state is covered in Chapters 3-7. The following is an analysis of Maui County Department of Water Supply (DWS) Molokai system and the reservations of water for Hawaiian Home Lands.

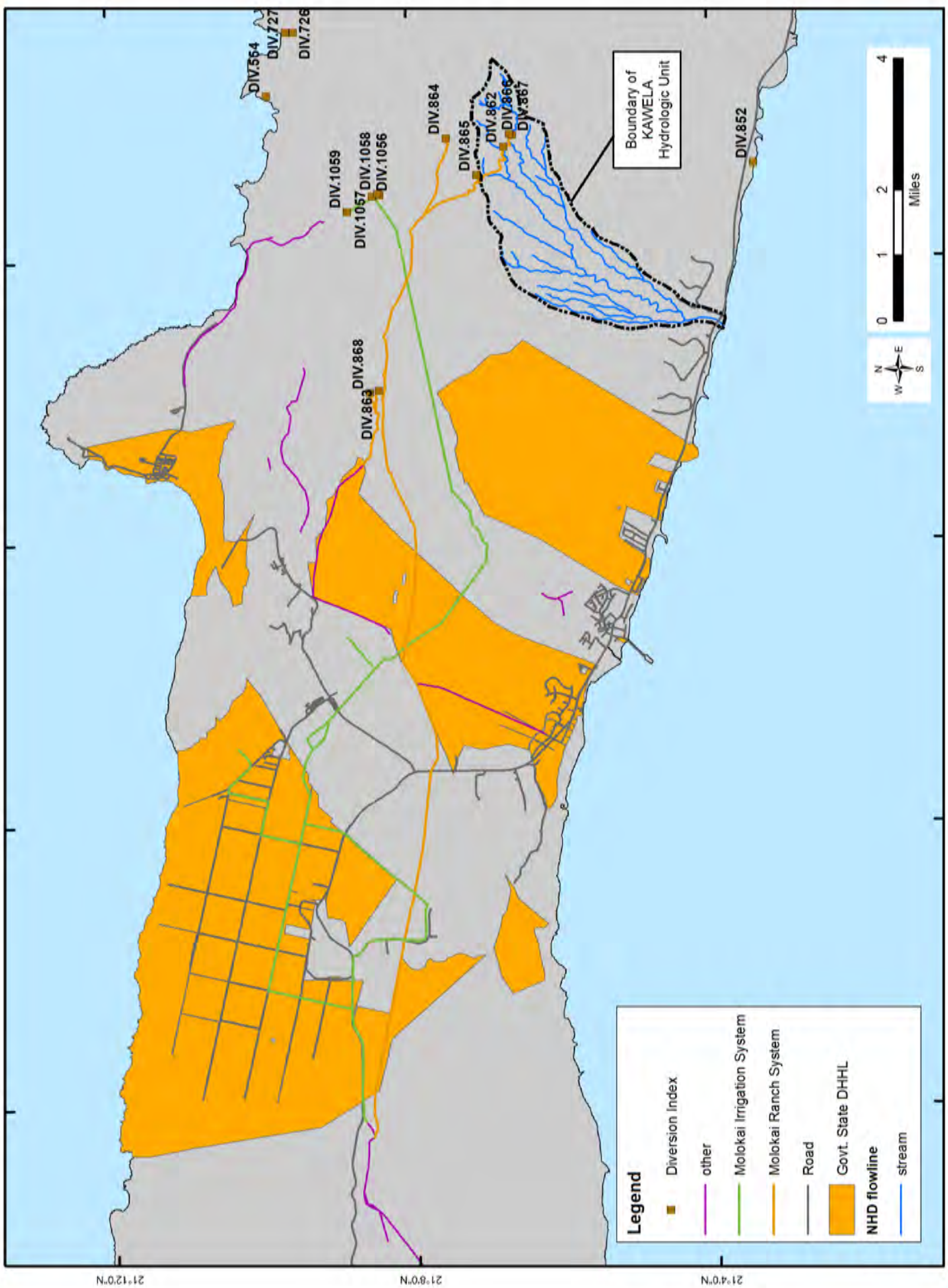
Maui County Municipal System

The Maui County DWS municipal water system relies on water pumped from the Kawela aquifer system in the Kawela hydrologic unit to support domestic and agricultural water uses in the Kaunakakai region. Maui County DWS operates a municipal water system that relies upon groundwater from one well in the Kawela hydrologic unit. In 1966, the county operated a drinking water source that supplied demand all the way to the Kaunakakai region via a gravity-fed pipeline (State of Hawaii DLNR, 1966). This source was dependent on surface runoff captured at Makaeleele Dam, located at the 2,365 feet elevation above Kalae. Approximately 55,000 gpd was supplied by this system while the remainder of water demand was met via a Maui-type well in Kawela constructed by the American Sugar Company in 1920 (Kawela Shaft).

Hawaiian Home Lands

A component in the assessment of water use includes an analysis of the presence of Department of Hawaiian Home Lands (DHHL) parcels within or near the surface water hydrologic unit. The mission of DHHL is to effectively manage the Hawaiian Home Lands trust and to develop and deliver land to native Hawaiians (PBR Hawaii, 2004). In June 2005, DHHL published the Molokai Island Plan update, which serves to examine infrastructure needs, provide development cost estimates, and identify priority areas for homestead development. Of the more than 31,000 acres of DHHL land on the island of Molokai, there are none in the Kawela hydrologic unit. Most of DHHL's land holdings are in the central plateau region of Hoolehua, which is serviced by the Molokai Irrigation System (Figure 13-3). There was a non-potable DHHL water system which diverted water from Waihanau Stream through a tunnel to Kalae and the Kualapuu operational as recently as 1982, although that system is not currently being used. Water was diverted from the stream at 2,264 feet in elevation through 2,800 feet of tunnel to an intake structure in Kahapaakai Gulch. From there, it is delivered through an 8-inch and 6-inch pipeline to one 2-million gallon steet tank and two 80,000-gallon redwood storage tanks at Kauluwai. Two 6-inch lines to two 3.5-million gallon concrete reservoirs in Hoolehua for homesteads. In 1966, the DHHL groundwater source (USGS Well 16) was used only as a supplemental source since energy costs to pump the well were great. The system averaged 285,000 gpd with 65,000 gpd for Kalanianaole colony on the southern coastal area and 220,000 gpd used in the Hoolehua area, not including water delivered by the MIS (State of Hawaii DLNR, 1966).

Figure 13-1. Hawaiian Home Lands parcels in western Molokai. (Source: State of Hawaii, Department of Hawaiian Home Lands, 2011)



14.0 Noninstream Uses

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

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

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

Water Leaving the Kawela Hydrologic Unit in Ditch Systems

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

The Commission has conducted field investigations to verify and inventory surface water uses and stream diversions and update existing surface water information. The information collected from these site investigations and the original registration files are included in Table 14-2.

In the Kawela hydrologic unit, Molokai Properties operates one surface water system (called the Mountain Water System) that has historically doubled as an irrigation system for non-potable agricultural and industrial uses as well as a potable drinking water system in West Molokai. The original system, called the Ranch line, operates from east to west, as part of the Mountain Water System. Molokai Properties (under its previous operating name Molokai Ranch) registered all of its diversions as identified in Table 14-2. The locations of these diversions are depicted in Figure 14-1. The Dole line diverts water from two locations in the Manawainui hydrologic unit (Kuhuaawi Stream tributaries). The locations of diversions that are part of the Dole line are depicted in Figure 14-2.

Since the enactment of HAR Title 13 Chapter 168, stream diversion works permits are required for the construction of new diversions or alteration of existing diversions, with the exception of routine maintenance. These permitted (as opposed to "registered") diversion works are not part of the Commission's verification effort, nor have any diversions been permitted in the Kawela hydrologic unit.

Continuous record data are available for the individual Molokai Ranch diversions for the Honolilolilo Stream intake, Lualohi intake, and Kalihi intake, which have their own meters, although it the period of record is limited. There is monitoring of the combined contribution of all the Kawela, Kamoku, and Honolilolilo intakes immediately before the pipeline discharges into the first mountain reservoir. The Kamoku intake has not been connected to the pipeline for many decades and therefore, the combined flow minus the Honolilolilo meter (when available) represents the flow of water diverted from the three Kawela intakes. Further, the East Kawela Tributary intake has not been operational since at least 2005, and therefore the calculated Kawela metered flow represents only the main East Fork Kawela and West Fork Kawela intakes. The flows at 50 (Q_{50}) and 90 (Q_{90}) percent exceedence probability are common indices of median total flow and low flow, respectively. When a flow duration curve is plotted for measurements made at a ditch, it shows the variability in the amount of water diverted for agricultural or domestic uses. Diverted flow statistics are provided for each of the metering stations available (Table 14-1).

Table 14-1. Selected off-stream water use statistics for each portion of the Molokai Ranch Mountain System based on monthly reported diverted totals, Molokai. (Source: CWRM, 2021) [Flows are in cubic feet per second (million gallons per day)]

Station ID	location	period of record	mean daily flow	Q_{50}	Q_{70}	Q_{90}
4-26	Honolilolilo Stream Pipeline abv Kawela Pipeline	2000-02, 2004-05, 2019-Present	0.189 (0.122)	0.147 (0.095)	0.078 (0.050)	0.0015 (0.001)
	Kawela Pipeline abv Honolilolilo inflow[1]	2000-02, 2004-05, 2019-Present	0.346 (0.224)	0.345 (0.223)	0.206 (0.133)	0.033 (0.021)
4-28	Kalihi Pipeline[2]	2000-02, 2004-05	0.082 (0.053)	0.0185 (0.012)	0.0124 (0.008)	0.0015 (0.001)
4-29	Lualohi Pipeline[2]	2001-02, 2004-05	0.215 (0.139)	0.183 (0.118)	0.091 (0.059)	0.040 (0.026)
	Total	2000-02, 2004-2005	1.068 (0.690)	0.930 (0.601)	0.712 (0.460)	0.541 (0.350)
	Total	2019-Present[3]	0.575 (0.372)	0.577 (0.373)	0.292 (0.189)	0.036 (0.023)

[1]values obtained by subtracting monthly totals from gage 4-26
[2]intakes have been inactive since 2005; data reflect only flows diverted when active
[3]represents only Honolilolilo, West Kawela, and East Kawels intakes

Figure 14-1. Registered diversions (ID) and ditches/pipelines identified in and nearby the Kawela hydrologic unit as part of the Ranch line of the Molokai Ranch mountain water System, Molokai. (Source: State of Hawaii, Commission on Water Resource Management, 2015g)

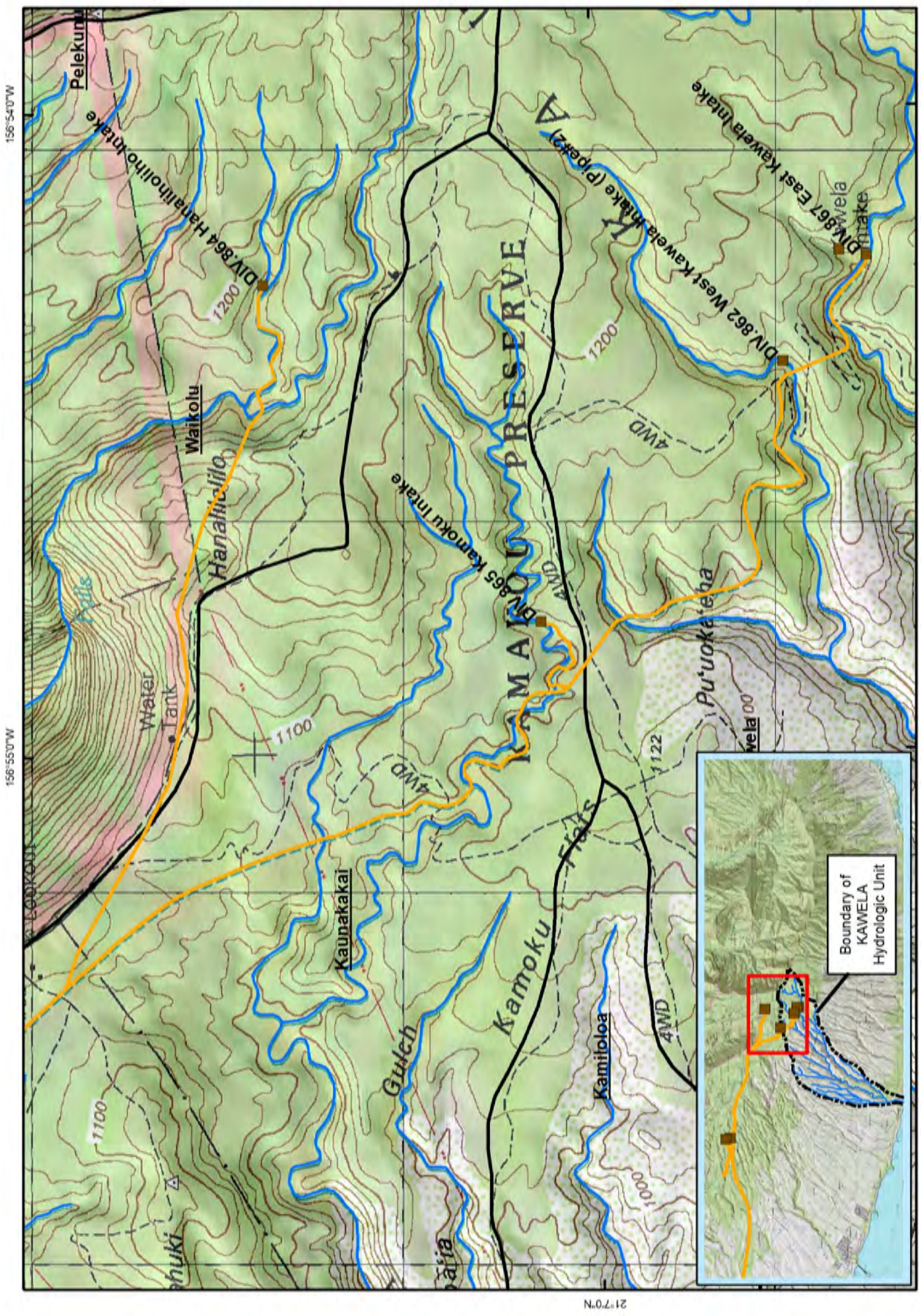


Figure 14-2. Registered diversions (ID) and ditches/pipelines identified in and nearby the Kawela hydrologic unit as part of the Dole Water Line Section of the Molokai Ranch mountain water system, Molokai. (Source: State of Hawaii, Commission on Water Resource Management, 2015g)

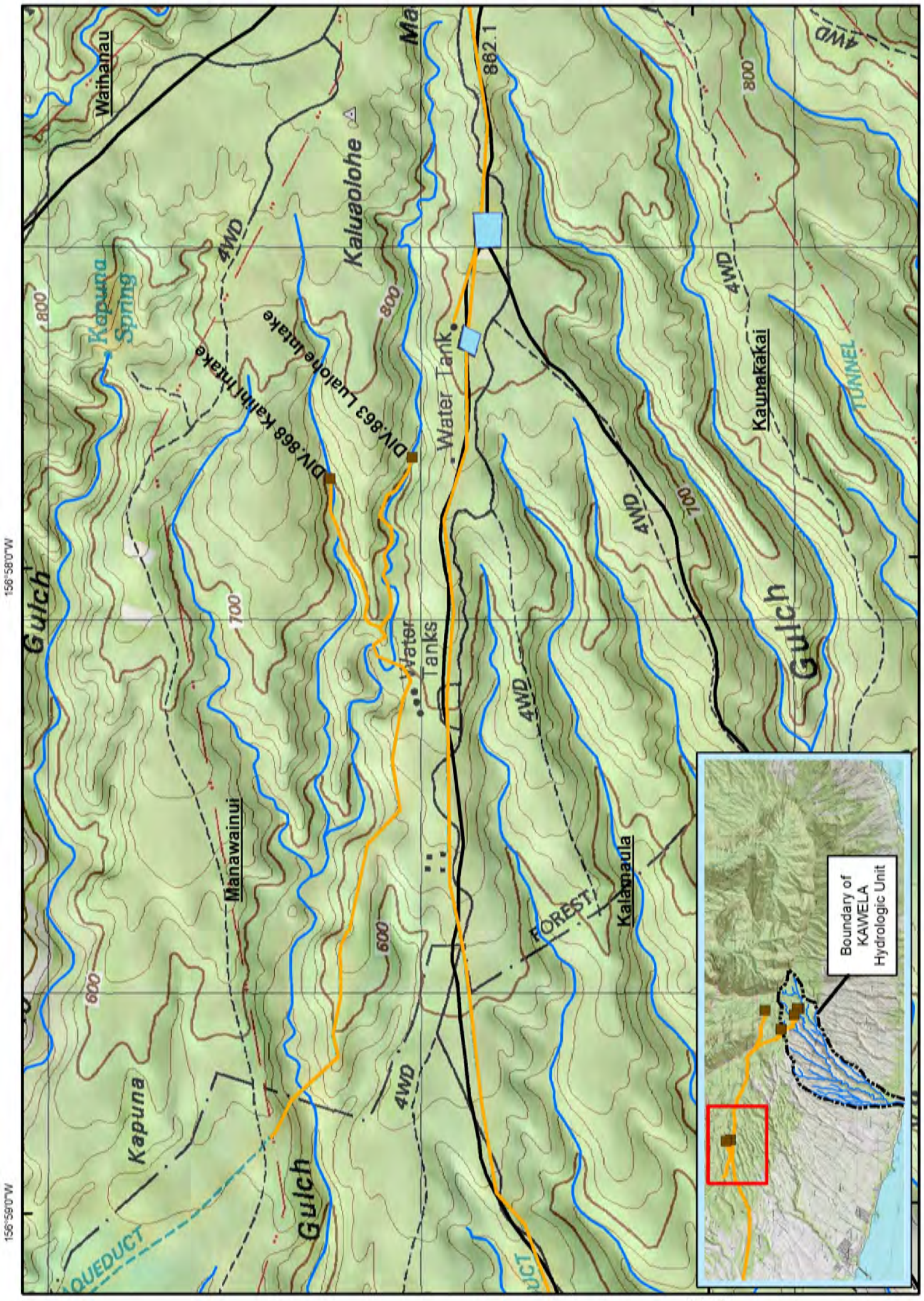


Table 14-2. Registered diversions in and near the Kawela hydrologic unit, Molokai.
[Source of photos are denoted at the end of each description; CWRM, Commission on Water Resource Management; Chevrons ( ) indicate general direction of natural water flow to and out of diversions; Arrows ( ) indicate direction of diverted surface water flow]

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.867.4	MOLOKAI RANCH	5-4-003:026	n/a	Yes	Yes	Yes	

East Kawela Diversion to Molokai Ranch System
Photos. a) Upstream view of concrete diversion dam across East Kawela Stream (CWRM, 2016); b) flush valve from gravel trap at diversion (CWRM, 2016); c) upstream view of East Kawela Stream from diversion (CWRM, 2016); d) Diversion dam from left bank (CWRM, 2016); e) intake box on left bank (CWRM, 2016); f) upstream view of HDPE pipeline along left bank (CWRM, 2016)

a)

b)

c)

d)

e)

f)


Table 14-2. Continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.866.4	MOLOKAI RANCH	5-4-003:026	n/a	Yes	Yes	Yes	

East Kawela Tributary Diversion to Molokai Mountain System

Photos. a) PVC pipeline leading from CRM intake supported by concrete piers (CWRM, 2016); b) PVC pipeline disconnected from CRM intake (CWRM, 2020); c) Upstream view of East Kawela Tributary below intake (CWRM, 2016); d) upstream view of East Kawela Tributary above intake (CWRM, 2016); e) Downstream view of East Kawela Tributary from intake (CWRM, 2016)

a)

b)

c)

d)

e)

f)

Table 14-2. Continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.862.4	MOLOKAI RANCH	5-4-003:026	n/a	Yes	Yes	Yes	

West Kawela Stream Diversion to Molokai Mountain System

Photos. a) Upsteram view of CRM dam across stream with active pipeline (right side) and inactive former pipelines (left side) (CWRM, 2016); b) diversion from right bank with pipeline intake (CWRM, 2016); c) intake pool behind diversion (CWRM, 2016); d) inactive pipelines from diversion (CWRM, 2016); e) upstream view of West Kawela Stream from diversion (CWRM, 2016); downstream view of West Kawela Stream from diversion (CWRM, 2016)

a)

b)

c)

d)

e)

f)

Table 14-2. Continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.865.4	MOLOKAI RANCH	5-4-003:026	n/a	Yes	Yes	Yes	

Kamoku Diversion on SF Kaunakakai Stream to Molokai Mountain System

Photos. a) diversion dam across stream with disconnected pipeline along left bank (CWRM, 2016); b) water flowing through disconnected pipeline (CWRM, 2016); c) water spilling over right bank dam wall (CWRM, 2016); d) left bank view from diversion (CWRM, 2016); e) pipeline transmission tunnel to main pipeline (CWRM, 2016); f) upstream view of SF Kaunakakai from diversion (CWRM, 2016)

a)

b)

c)

d)

e)

f)

Table 14-2. Continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.864.4	MOLOKAI RANCH	5-4-003:026		Yes	Yes	Yes	

Honolilolilo Diversion on Waikolu Stream to Molokai Mountain System

Photos. a) diversion dam across stream with pipeline along left bank (CWRM, 2016); b) water flowing over dam (CWRM, 2016); c) pipeline intake above dam (CWRM, 2016); d) upstream view from diversion (CWRM, 2016); e) downstream view of pipeline supported along left bank (CWRM, 2016);

a)

b)

c)

d)

e)

f)

Table 14-2. Continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.864.4	MOLOKAI RANCH	5-3-003:005		Yes	Yes	Yes	

Lualohe Diversion on SF Kuhuaawi Stream to Molokai Mountain System
Photos. a) concrete and bedrock diversion dam across stream at top of waterfall with pipeline along left bank (CWRM, 2016); b) water flowing over dam and pipelines (CWRM, 2016); c) downstream view of intake above waterfall (CWRM, 2016); d) downstream view of intake above waterfall (CWRM, 2016); e) upstream view of South Fork Kuhuaawi Stream (CWRM, 2016)

a)

b)

c)

d)

e)

f)

Table 14-2. Continued.

Event ID	File Reference	Tax Map Key	Diversion Amount (cfs)	Active (Yes/No)	Verified (Yes/No)	Riparian (Yes/No)	Rights Claim (Yes/No)
REG.868.4	MOLOKAI RANCH	5-3-003:005		Yes	Yes	Yes	

Kalihi Diversion on NF Kuhuaawi Stream to Molokai Mountain System

Photos. a) concrete and bedrock diversion dam across stream at top of bedrock cascade with pipeline along left bank (CWRM, 2016); b) clogged pipeline intake on right bank (CWRM, 2016); c) view from left bank of water flowing over dam (CWRM, 2016); d) upstream view of intake above waterfall (CWRM, 2016); e) upstream view of North Fork Kuhuaawi Stream below diversion (CWRM, 2016); f) downstream view of intake above cascade (CWRM, 2016)

a)


b)


c)


d)


e)


f)


Current Agricultural Demands

A large portion of the Kawela hydrologic unit (59.6 percent) is designated as conservation land by the State Land Use Commission, and 40.3 percent is designated as agriculture. However, using the 2015 Department of Agriculture Baseline Agriculture Survey (Perroy et al., 2015), no agriculture currently takes place. Water from the Molokai Ranch mountain water system was used historically for sugarcane and pineapple cultivation, domestic water supply, livestock water, and small diversified agriculture outside of Kawela hydrologic unit in Hoolehua and west Molokai. Recently, Molokai Ranch was sold and renamed Molokai Properties Ltd. Like many ranches in Hawaii, under new ownership, the ranching operation transitioned to became more dependent on a cow-calf operation rather than a beef production operation. Molokai Properties currently owns approximately 28.7 square miles (18,346 acres) in agriculturally zoned lands. In 2015, these lands were occupied with seed production, diversified crop, pasture, and flowers/landscaping (Table 14-3, Figure 14-3). Some of the agricultural lessees of Molokai Properties are served by the Molokai Irrigation System to meet their non-potable water needs.

Table 14-3. Crop category, acerage, estimated irrigation demand, and water demand by category based on the 2015 Agricultural Baseline assessment for Molokai Property-owned lands in agriculture. (Perroy et al., 2015)

Crop Category	Acrage	Irrigation Demand (gad)	Crop Water Demand (gpd)
Diversified crop	19.84	3400	67,456
Flowers/Foliage/Landscape	3.84	3700	14,208
Pasture[1]	17,342.7	--	--
Seed Production	979.8	4660	4,566,054
Total	18,346		

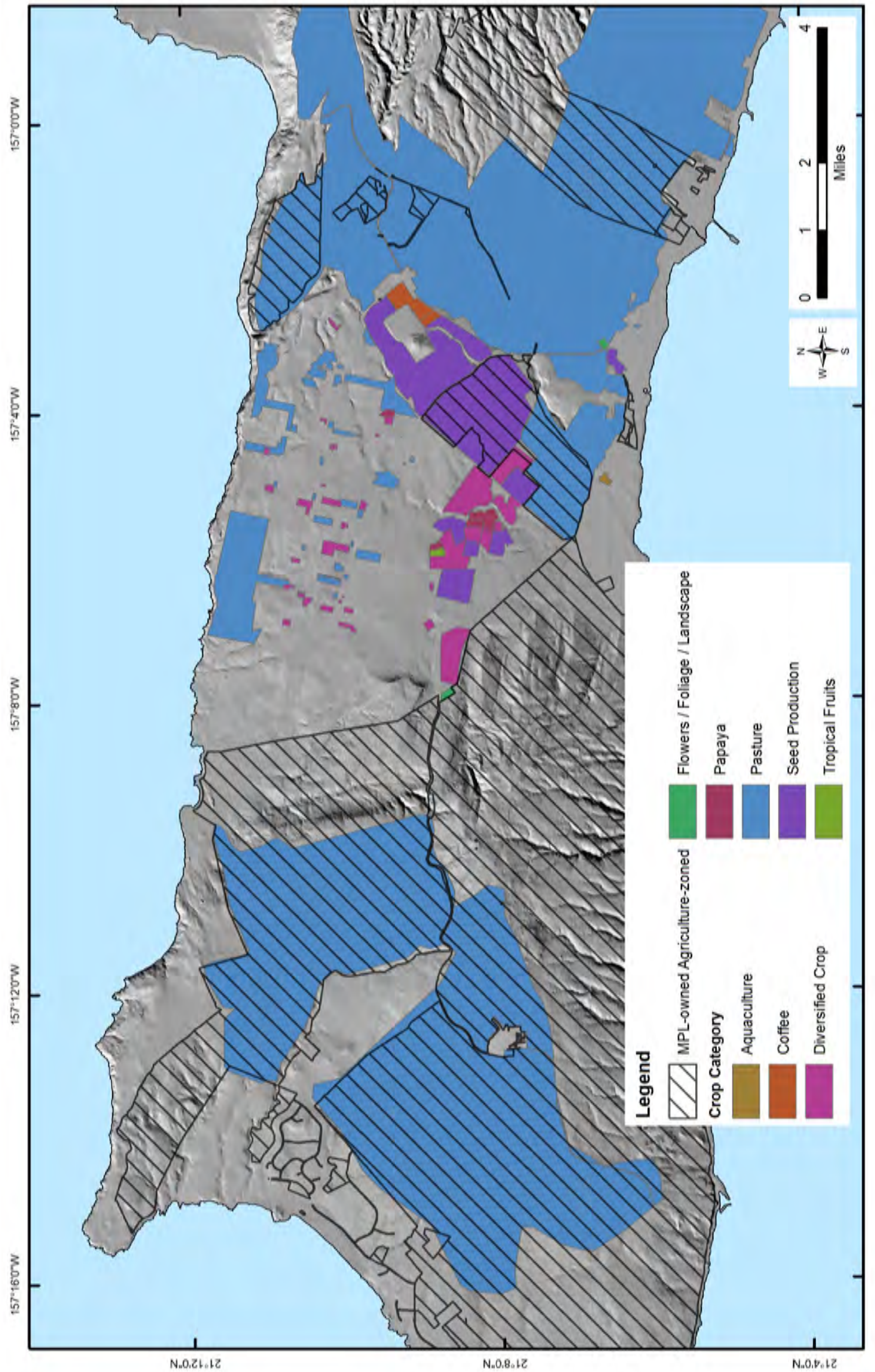
[1]assumed unirrigated pasture; livestock water demand calculated separately

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 groundwater 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[5]. 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 (Figure 14-3). 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 (Figure 14-4). 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).

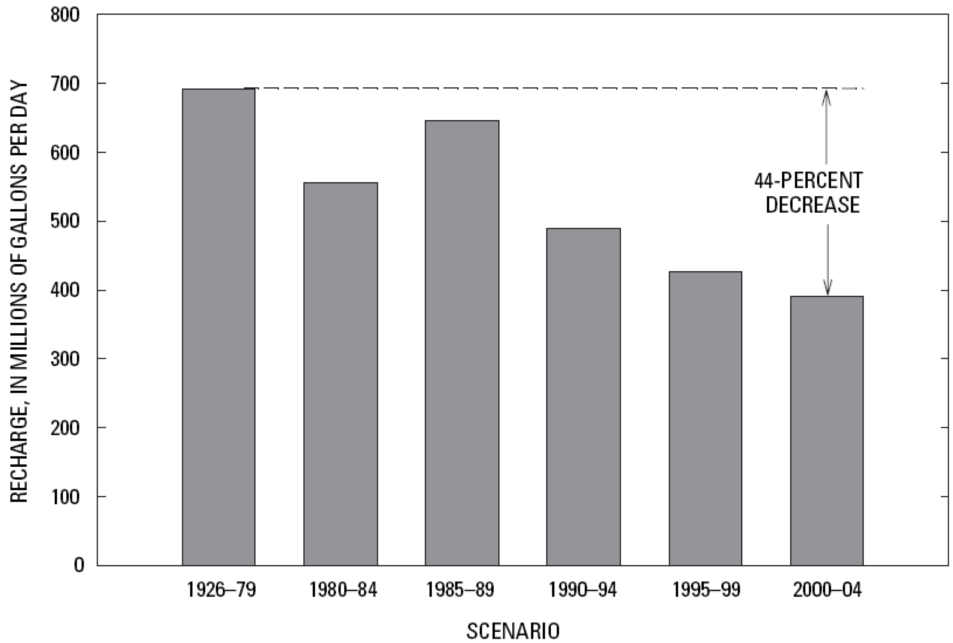
[5] Water-budget is a balance between the amount of water leaving, entering, and being stored in the plant-soil system. The water budget method/equation is often used to estimate ground water recharge.

Figure 14-3. 2015 Baseline Agricultural Land Use map for central Molokai with various Molokai Properties land highlighted. (Source: Perroy et al. 2016)



Similarly, restoring streamflow in Kawela Stream will improve groundwater recharge as the stream loses flow in the lower member of the East Molokai Volcanic Series, recharging the Kawela Aquifer System. While large-scale agricultural irrigation has been shown to increase groundwater recharge by increasing water inputs from high rainfall areas (surface water sources) to low rainfall areas (irrigation uses), small scale landscape irrigation is unlikely to substantially increase groundwater recharge.

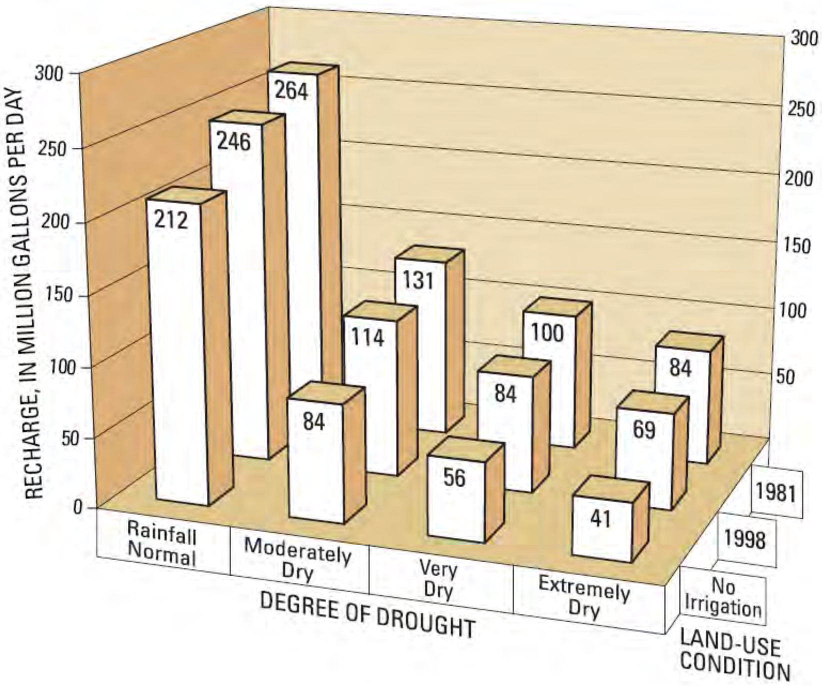
Figure 14-4. Estimated recharge for six historical periods between 1926 and 2004, central and west Maui, Hawaii. (Source: Engott and Vana, 2007)



Utilization of Important Agricultural Lands

In 1977, the Agricultural Lands of Importance to the State of Hawaii (ALISH) were completed by the State Department of Agriculture (HDOA), with the assistance of the Soil Conservation Service (SCS), U.S. Department of Agriculture, and the University of Hawaii College of Tropical Agriculture and Human Resources. Three classes of agriculturally important lands were established for Hawaii in conjunction with the SCS in an effort to inventory prime agricultural lands nationwide (Figure 14-5). Hawaii's effort resulted in the classification system of lands as: 1) Prime agricultural land; 2) Unique agricultural land; and 3) Other important agricultural land. Each classification was based on specific criteria such as soil characteristics, slope, flood frequency, and water supply. The ALISH was intended to serve as a long-term planning guidance for land use decisions related to important agricultural lands. As agricultural commodities changed substantially with the closure of large-scale pineapple and sugarcane in the 1980s-2000s, the HDOA funded an updated baseline study of agricultural land use (ALUM) for 2015. The HDOA is currently in the process of developing agricultural incentives based on classifications of Important Agricultural Lands. The burden of maintaining a non-potable water system can be more easily supported by large private landowners which have divested interests across their assets. The Molokai Ranch mountain system is completely owned by Molokai Properties, although some portions of it exist on land owned by the State of Hawaii (Figure 14-9).

Figure 14-5. Summary of estimated recharge, in million gallons per day, for various land-use and rainfall conditions in the Lihue Basin, Kauai, Hawaii. (Source: Izuka et al., 2005)



Though both ALISH and ALUM datasets are somewhat outdated, many of the same agricultural assumptions may still hold true. The information is presented here to provide the Commission with present or potential noninstream use information. The Kawela hydrologic unit has 0.092 square miles of land designated as "other" in the classification of ALISH (Figure 14-6). The ALISH designation also provides some context for the water used out of the hydrologic unit. The Molokai Ranch Mountain Water System supports the water needs of agriculture in portions of the Hoolehua plain and west Molokai (Figure 14-7, Table 14-4).

Table 14-4. Agricultural Lands of Importance to the State of Hawaii owned by Molokai Properties on Molokai. (Source: State of Hawaii, Office of Planning, 2015g)

Type	Square miles	Acres
Prime land	1.498	958.72
Unique land	0	0
Unclassified land	1.007	644.48
Other lands	24.190	15,481.60

Figure 14-6. Agricultural Lands of Importance to the State of Hawaii (ALISH) for the Kawela hydrologic unit, Molokai. (Source: State of Hawaii, Office of Planning, 2020j)

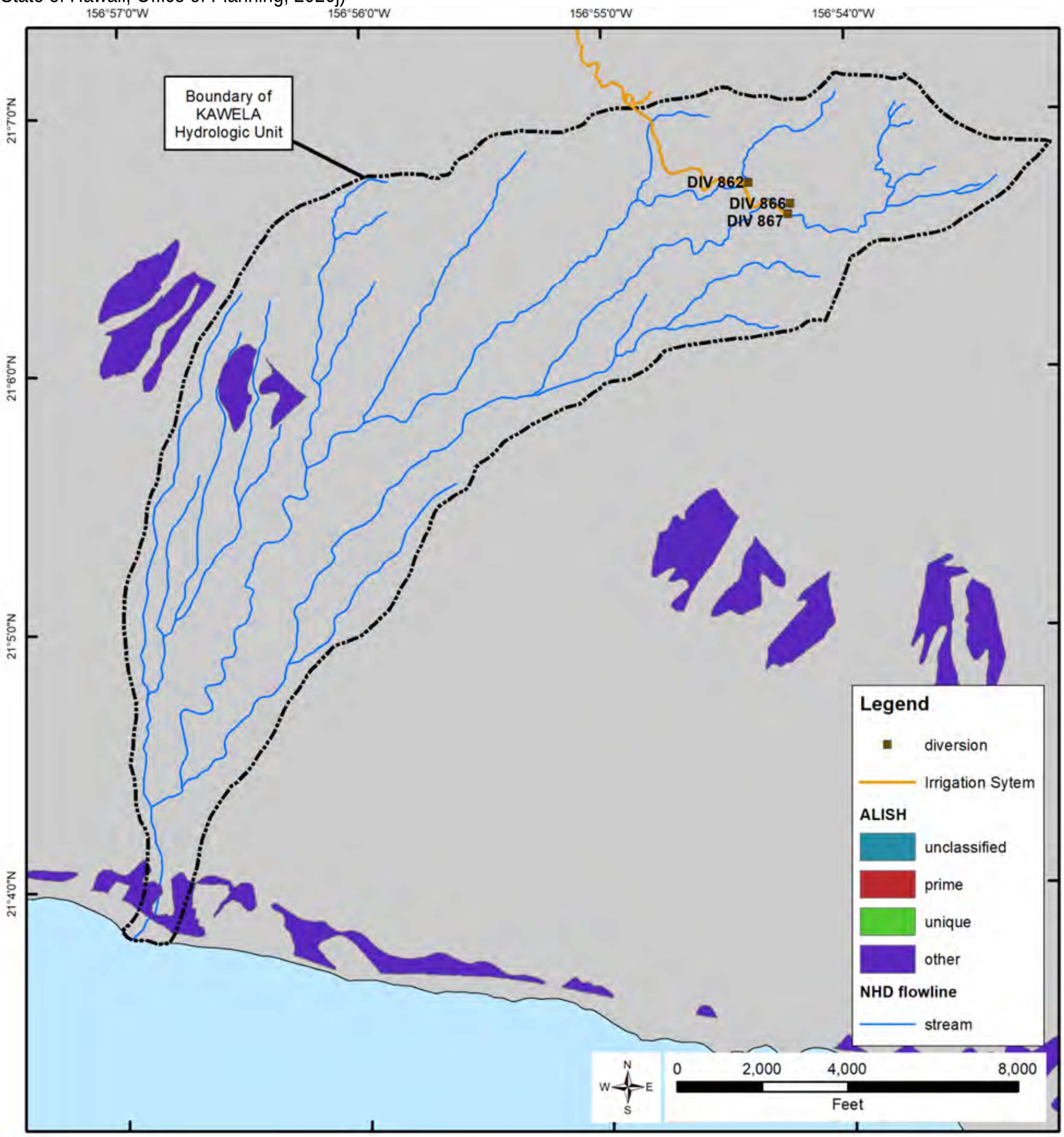
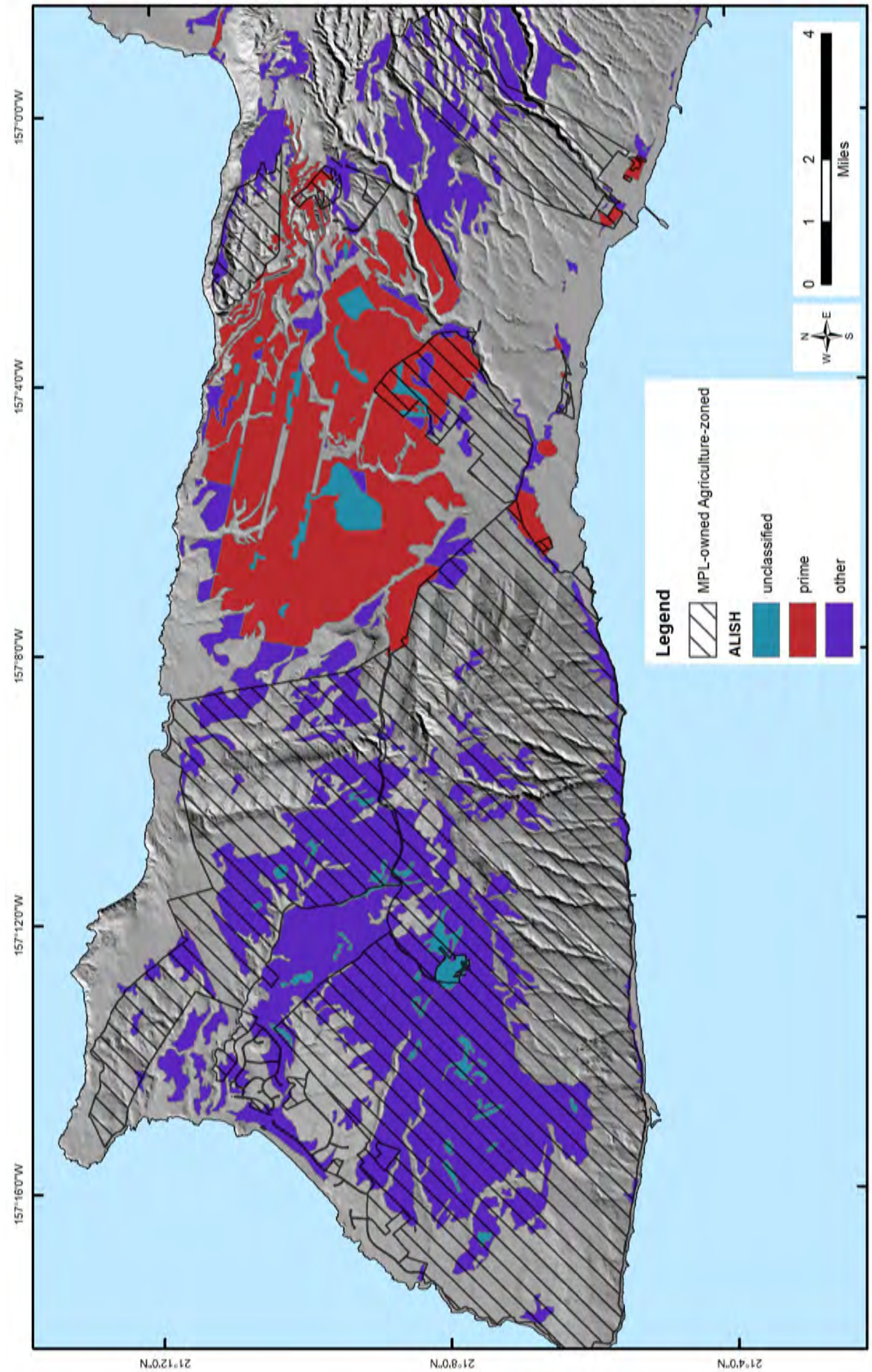


Figure 14-7. Agricultural Lands of Importance to the State of Hawaii (ALISH) owned by Molokai Properties, Molokai. (Source: State of Hawaii, Office of Planning, 2020j)



Molokai Ranch Mountain Water System

In 1897, Charles M. Cooke and other Honolulu businessmen purchased 70,000 acres of land from the trustees of Princess Pauahi's estate. Molokai Ranch was formed in 1908 when Charles M. Cooke bought out his partners and his son, Geoge P. Cooke, began raising cattle and farming sweet potato. The current Molokai Ranch system is composed of many different water systems that have been integrated together over the years. The original ranch system started with five stream diversions (called the "ranch line") in the upper Kawela, Kaunakakai, and Waikolu watersheds, the principal sources being East and West Kawela at 3,600 ft in elevation, to bring water to Hoolehua. In 1912, a 2.5-inch pipeline was constructed to bring water to Mauna Loa. In 1923, the Libby, McNeil & Libby Company leased land from Molokai Ranch in the Maunaloa area to plant pineapple. Del Monte operated a pineapple plantation in Hoolehua for many decades, leasing land from the State of Hawaii and primarily relying on surface water. However, due to the limited availability during drought, Del Monte drilled a well (now called well 17) in 1951 to meet the potable water needs of its plantation and to provide backup irrigation water when insufficient surface water was available. In 1946, Libby, McNeil & Libby built a domestic water system to serve the pineapple plantation community in Maunaloa, sourcing water from one tunnel and two stream diversions from the Lualohi (now called the Manawainui) watershed called the "Dole line" via the 3-in steel and galvanized iron Dole line which feeds three tanks with a total storage of 1.3 million gallons. In 1959, a 6-in and 8-in pipeline were constructed from Poholua tank to Puunana in order to pump water up to Maunaloa town. When the pineapple plantation ceased operation, the system reverted to Molokai Ranch. The MIS was completed in 1967 through fundng from the Federal Small Reclamation Projects Act to bring water from Waikolu valley to Hoolehua. The Dole line was interconnected with the Molokai Irrigation System (MIS) and water was metered into the MIS and distributed at Puunana from the MIS. In 1960, a 5-million gallon asphalt fiber-lined reservoir was constructed in Puunana and a 5-million gallon asphalt fiber-lined reservoir at Lualohi was built in the late 1960s. While not metered, average usage from the mountain water system in 1982 was estimated at 75,000 gpd in Maunaloa, 15,000 gpd in Kipu, and 10,000 in Manawainui (0.100 mgd). At the time, Del Monte had a pineapple plantation that leased land from the state DOA, DHHL, Castle & Cooke, and Molokai Ranch. Del Monte received approximately 25% of the water from the mountain water system.

The Kaluakoi development began in 1976 and a water system that supplied water from Maunaloa to Kaluakoi became Molokai Public Utilities, Inc in 1981. The domestic and landscape irrigation needs were met with a single system that combined water from the mountain water system and Well 17 water (via the MIS) and was treated at Puunana. This system now exclusively utilizes water from Well 17. Originally, Kaluakoi utilized the MIS transmission system to deliver water to Mahana, where it was pumped up to the butyl-lined reservoirs at Puunana. An understanding of how the historic system has been integrated into Molokai Properties system is available in Figure 14-11.

A summary of the water sources as described in 1982 is provided in Table 14-5. No flow recording was ever done prior to the 1990s and no meters existed until the Ranch installed one above the first reservoir and on the pipeline from the Honolilolilo intake in the 1990s. The Libby system had its own transmission pipeline called the "Dole" line and water from the Ranch line could be sent to the Dole line. This was eventually interconnected, and the Dole line is currently discontinued.

The USGS has maintained a continuous monitoring station (USGS 16415000) above the EF Kawela intake (Diversion 867) since November 2018. With some exceptions for missing data, 15-minute data can be used to understand the temporal variability of low and high surface flows that are available for instream and off stream use at this location (the East Kawela tributary diversion and transmission pipeline that historically brought water to EF Kawela above the intake is not currently operational). The Molokai Ranch intake is a 10-inch pipeline with and maximum capacity of 0.77 cfs (~0.5 mgd) as identified by the Belt, Collins, & Associates report (1982) and confirmed with the closed channel flow equation. Based on this, the monthly mean daily flow currently diverted and currently remaining in the stream can be depicted in Figure 14-8. The mean amount diverted is 0.36 cfs (0.23 mgd) and the mean amount remaining in the stream is 0.33 cfs (0.21 mgd). Based on mean daily flow values from 11/7/2018 to 8/16/2021, 58% of days had zero flow remaining immediately below the diversion in EF Kawela. The minimum mean daily flow recorded at USGS 16415000 was 0.06 cfs (0.04 mgd).

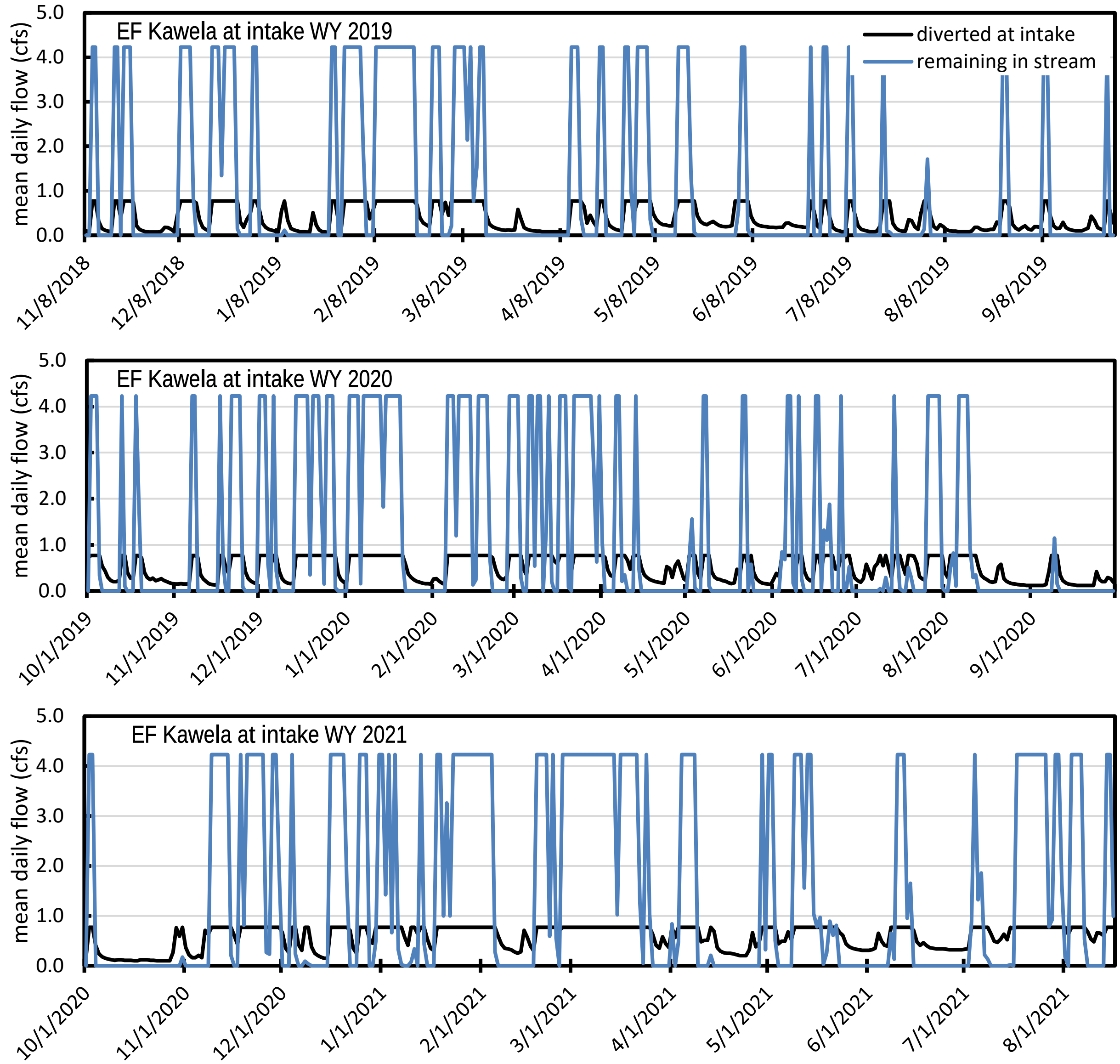
Table 14-5. Historic statistics of the Molokai Ranch mountain water system. (Source: Belt, Collins, & Associates, 1982).

	Elevation (ft)	Drainage Area (mi^2)	Minimum Flow (mgd)	Maximum divertable flow (mgd)
Sources above Libby Connection (Dole line)				
East Kawela + East Kawela Tributary	3625, 3775	0.52	0.52	0.50
West Kawela	3675	0.086	0.086	0.10
Kamoku Gulch	3675	0.13	0.015	0.15
Ohialele (Honolilolilo) Gulch	3775	0.11	0.015	0.15
Sources below Libby Connection (Dole line)				
Lualohi Tunnel	2550	1000-ft tunnel	0.03	0.05
Lualohi Gulch	2300	0.23	0.00	0.10
Kalihi Gulch	2320	0.10	0.00	0.07
			0.11	0.7-0.8

The presence of the Molokai Ranch mountain water system adds considerable complexity to the Commission's role in weighing instream and noninstream uses. While this is largely due to the transfer of water from one hydrologic unit to another, the importance of the system to both agriculture and industrial water supply in Hoolehua and west Molokai, and in the consideration of economic impacts. Further, the potable and non-potable systems that now fall under Molokai Ranch's usage (including the Del Monte Well 17 and Kalua Koi system) were historically interconnected, and included connectivity to the State's Molokai Irrigation System, although the later was disconnected in 2018. A new pipeline from Well 17 to west Molokai constructed in the last few years has eliminated the need to treat the combined flow of surface and groundwater at Puunana Water Treatment Facility. The complexity of the Molokai Ranch mountain water system is illustrated in Figures 14-9, 14-10, and 14-11.

In total, the Molokai Ranch mountain water system consists of 8 separate intakes, a couple of large and small reservoirs, booster pump stations. The system primarily captures surface water from Kawela and Waikolu watersheds, with smaller diversions from Kaunakakai and Manawainui watersheds. The total non-potable reservoir capacity is 49,450,000 gallons, split between the 5,000,000 and 4,000,000 gallon reservoirs at the top of the system, the two newly built and lined 15,000,000 gallon reservoirs immediately below these reservoirs, and three reservoirs in west Molokai: the 7,000,000 gallon Puunana Reservoir, the 250,000 gallon Puunana Agricultural tank, and the 3,200,000 gallon Maunoloa Reservoir. In 2004, Molokai Ranch estimated is December daily average usage of non-potable water as 70,000 gpd.

Figure 14-8. Mean daily flow (cubic feet per second) remaining in stream and diverted by the intake on the East Fork Kawela Stream at 3,650 ft for water year (WY) 2019 (top) 2020 (middle), and 2021 (bottom). (Source: USGS, 2021)



Other Water Systems Owned by Molokai Properties

Molokai Properties now owns Well 17 (purchased from Del Monte), which supplies potable water to the certain customers in the Kaualapuu, Kalae, Manawainui Industrial Park, Maunaloa town, and Kaluakoi development (Figure 14-11). At the end of 2017, a new pipeline was installed to directly deliver potable water from Well 17 to west Molokai, and the mountain water system was discontinued.

The estimated average potable water needs supplied by Well 17 (directly or via the Molokai Irrigation System or the Molokai Ranch mountain water system) in 1982, and projected need for 1990 and 2000 are provided in Table 14-6. While the Kaluakoi development has not grown as originally planned and the original hotel and golf course have closed down, there are long-term plans to rebuild the resort and additional home sites are already zoned.

Table 14-6. Metered average daily water use (in millions of gallons per day, mgd) in 1982 and projected 1990 and 2000 needs met by Well 17. [note: there was no metering of potable water for agricultural irrigation needs] (Source: Belt, Collins, and Associates, 1982)

	1982		1990		2000	
Potable Water Sub-system	average daily use	Installed supply capacity	Average daily use	Required supply capacity	average daily use	Required supply capacity
Kaluakoi	0.850	2.000[1]	1.230	2.030	1.850	3.050
Kalae-Kipu	0.015	0.230	0.055	0.091	0.095	0.157
Manawainui	0.010	0.230	0.200	0.330	0.400	0.660
Mauna Loa	0.075	0.230	0.122	0.202	0.211	0.348
total	0.950		1.607		2.556	

[1]limited by agreement with the MIS for interconnectivity and transmission

End uses of Molokai Properties Water Systems

The mountain water system and the well 17 water sources provide for the agricultural and domestic needs of Molokai Properties, but are also managed to provide for the delivery of water to lessees of Molokai Properties, developments of Molokai Properties, lessees of other neighboring landowners, and other users within the service area (including residences, businesses, non-profits, and the County of Maui) as defined by their Public Utility Commission accepted service area. These include locations in Maunaloa, Kualapuu, Kipu, Manawainui, and the Molokai Industrial Park. Molokai Properties has three subsidiary utilities: Waiola O Molokai (WOM), Molokai Public Utilities, Inc (MPU), and Mosco, Inc. Mosco is the wastewater utility, while WOM and MPU are water delivery utilities. The WOM utility operates a potable water system that services the Kalae, Kualapuu, Hoolehua, Mainawainui, Maunaloa, and Kaluakoi areas, now soley delivering water from Well 17. MPU has provided water service in the Kaluakoi area in west Molokai since 1981. When Molokai Properties ceased operations of its hotel and resort facilities in 2007, it could no longer afford to manage both utilities at a loss and tried to sell them. The PUC intervened and allowed a temporary rate increase until the utilities could apply for a permanent rate increase. Two reasons why these water utilities are so expensive to run is that: 1) the sources are very far from many of the end uses, necessitating the repair and maintence of many tens of miles of pipelines, some of which are very old; and 2) both systems require the use of costly booster pumps to distribute water to their end uses. For the year 2010, WOM had 4,580 service connections and billed 50,000,000 gallons, resulting in an average usage of 10,900 gallons per connection. the total revenue generated during 2010 was $288,660. Besides standard water utility business expenses, WOM also incurs direct expenses through the purchase of water delivery from Well 17 ($55,926 in 2010), from DHHL at Kalae ($42,000 in 2010), and the treatment of water at Puunana to produce potable water for west Molokai ($9,000 in 2010). Once the Maunaloa Lodge and Kaluakoi resorts were closed, the costs to treat water at Puunana declined precipitously (e.g., it was as high as $140,860 in 2004). Total expenses to operate WOM in 2010 was $543,203, resulting in a net loss of $254,543. Once their utility rate increase was approved by the PUC, the additional revenue brough the utility into sounder financial standing. Currently, their user charge (per 1,000 gallons) is $10.69, with meter costs ranging from $10 for a 5/8” meter to $517 for an 8” meter. Once the potable pipeline connecting Well 17 to Maunaloa was completed, there was no need to operate the Puunana WTF.

Figure 14-9. Schematic diagram of the Molokai Ranch Mountain Water System provided by Molokai Ranch (2002)

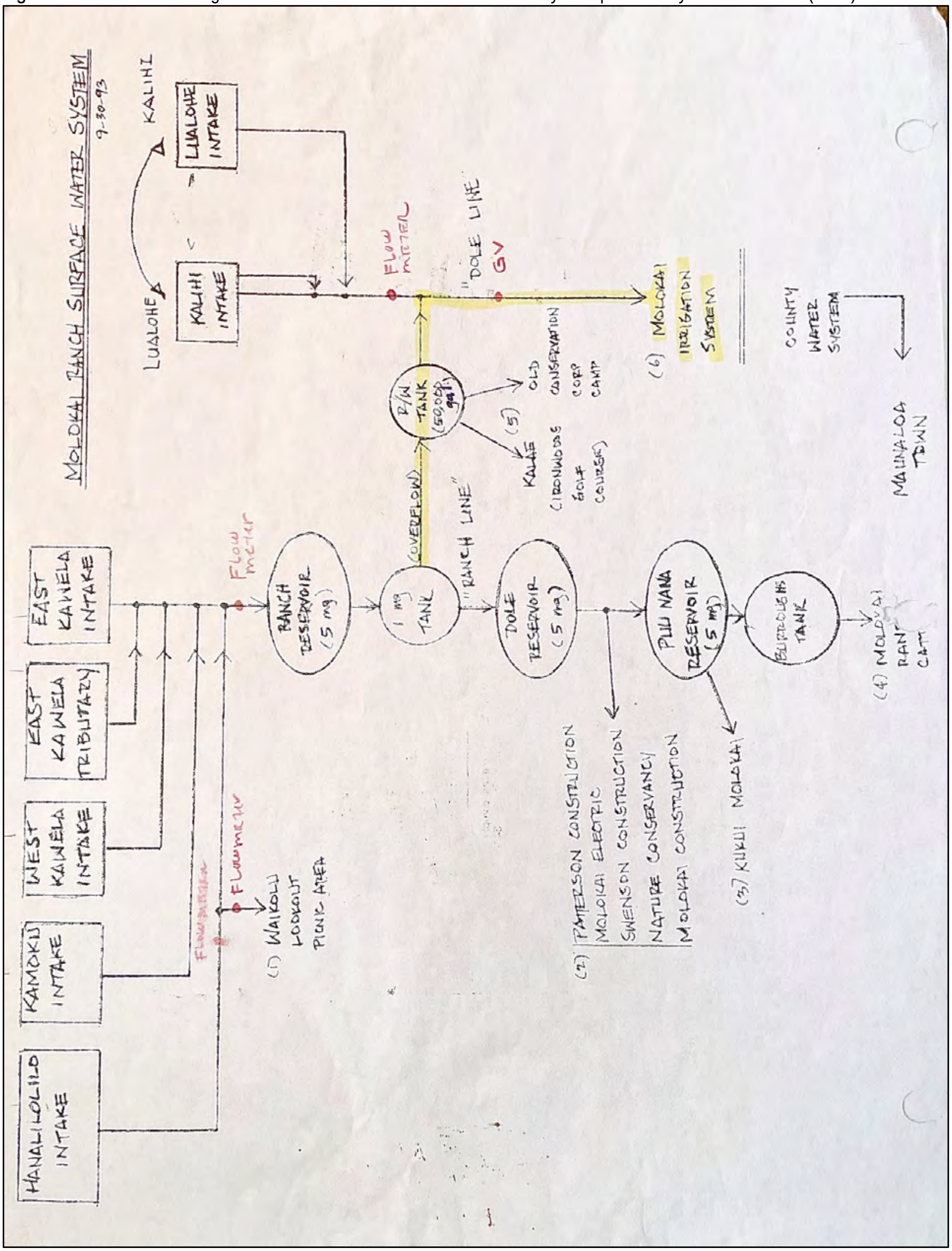


Figure 14-10. Elevational profile of the Molokai Ranch Mountain Water System intakes in relation to the reservoirs build in 2003 as provided by Molokai Ranch (2002)

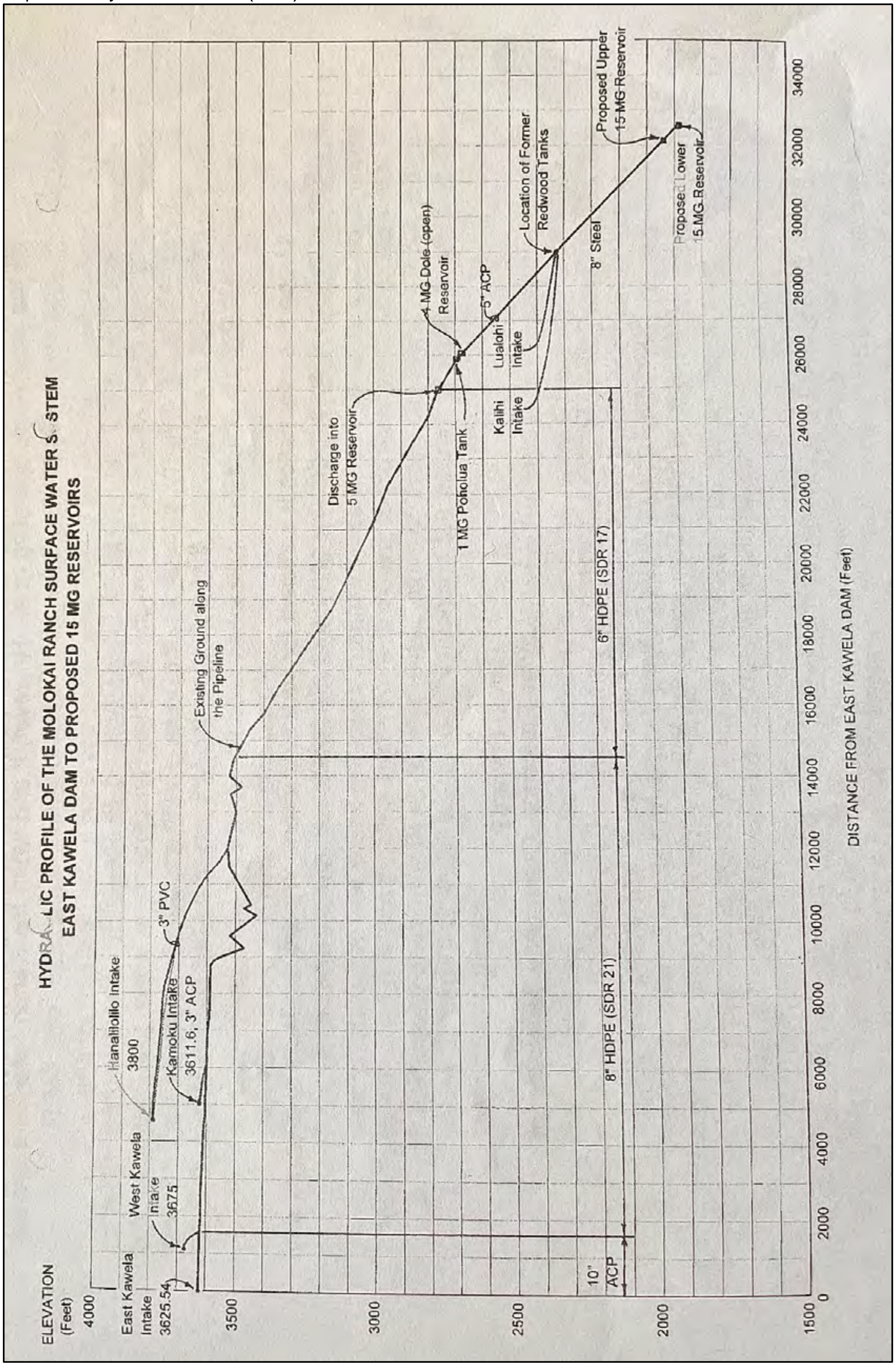
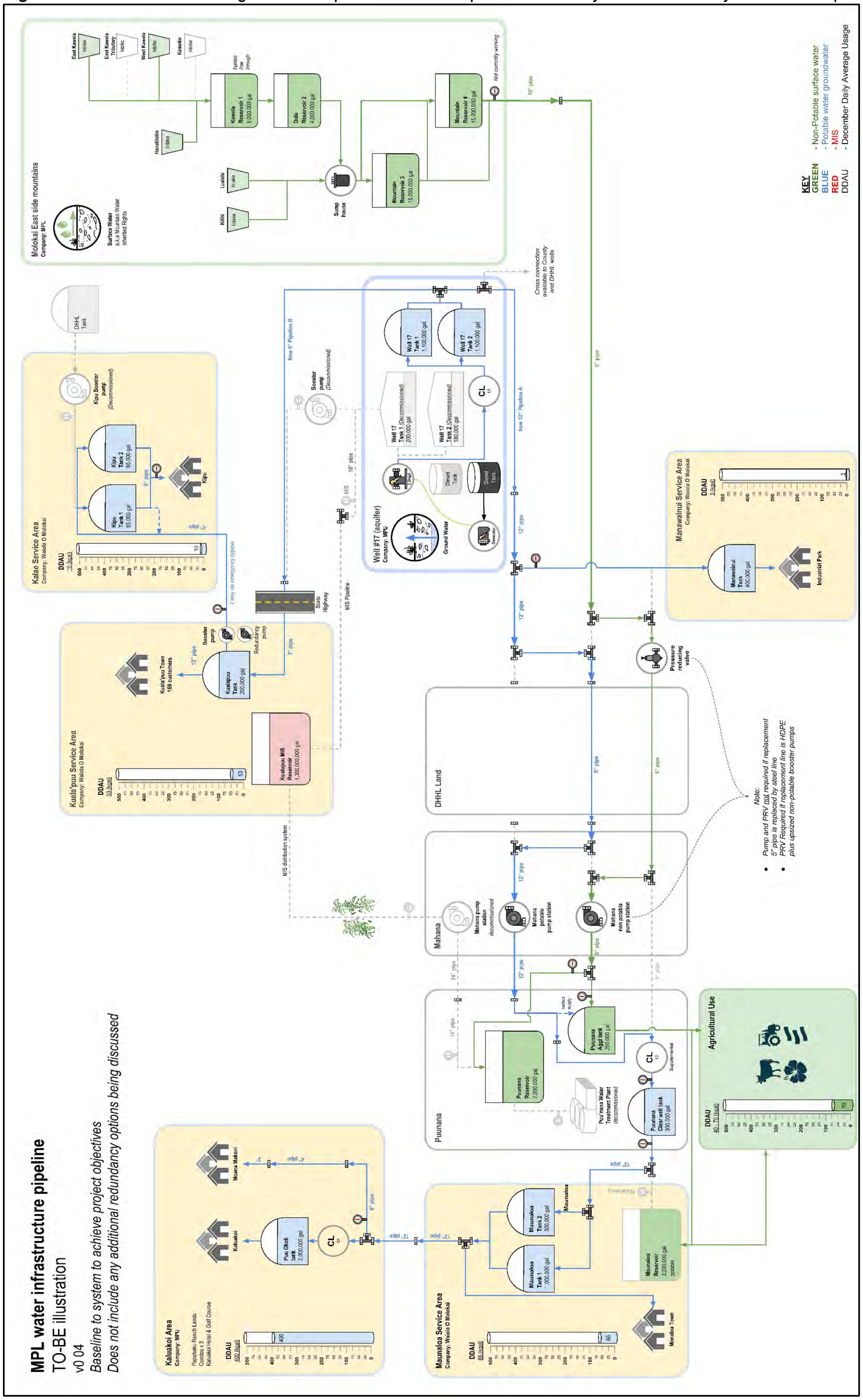
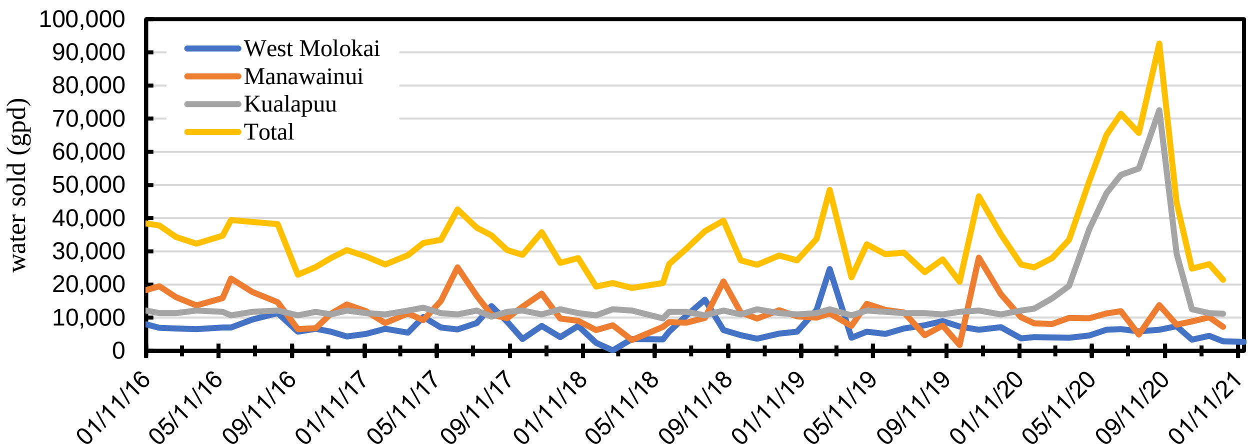


Figure 14-11. Schematic diagram of the potable and non-potable water systems owned by Molokai Properties as of 2021.



Water is delivered from the non-potable mountain water system to various customers in three distinct areas by Molokai Properties: West Molokai, Manawainui Industrial Area, and Kualapuu. The variability in water delivery is depicted in Figure 14-12. The West Molokai customers also includes the livestock water demands of Molokai Properties. The large increase in Kualapuu demand in 2020 is the result of deliveries to Kualapuu Ranch. In 2017, non-potable water stopped being treated at the Puunana WTF and only Well 17-sourced water has been delivered to Kaluakoi since then.

Figure 14-12. Monthly non-potable water sold in average gallons per day (gpd) from the mountain water system by system and total. (Source: Molokai Properties)



In the latest water use permit application (WUPA) for Well 17, Molokai Properties identified existing and planned potable water uses. While the application only specifies the water sourced from Well 17, there are non-potable water deliveries to these same uses within the service area. The total and per unit average daily need of existing and planned uses by service area for potable and non-potable water is identified in Table 14-7. Most of the existing metered uses are below Maui County water demand estimate standards with the exception of the Kaluakoi Resort Residences, which have an average of 1,288 gpd per unit. This use is described by Molokai Properties in their Well 17 WUPA as both domestic consumption and irrigation of landscaping and agriculture in agriculturally zoned parcels. It is noteworthy that while the state land use district for these parcels is indeed agriculture, this region receives little rainfall (<20 in per year), and truck crop agriculture could not be reasonably practiced.

There are multiple locations where potable water is being used to meet non-potable needs: Kipu Golf Course Office Area landscaping (area unknown); Kaluakoi Hotel landscaping (18.12 acres); Kaluakoi Resort Condo landscaping (35.448 acres); Kaluakoi Resort Residences (agriculturally zoned parcels using 2x the county residence rate). Further, the Manawainui Industrial Park was historically fed only by the mountain water system but was recently connected to the potable water system. The three current tenants in the Manawainui Industrial Park (Tri-L, Space Options, and Swenson Construction) have metered usage of both potable and non-potable water. Tri-L is a concrete manufacturer whose 5-year average usage of 13,338 gpd is described as 30% office (4,001 gpd) and 70% from surface water (9,337 pgd) but their non-potable metered usage is 7358 gpd. While the current total water use reflect the use with much of the existing Kaluakoi Resort closed, the estimated existing water demand reflects if the built resort infrastructure were restored as originally built and reopened. Overall, Molokai Properties estimated total existing potable water use is 447,878 gpd (0.448 mgd) and non-potable water use (excluding MPL's ranching operations) is 32,175 gpd (0.0322 mgd). The 5-year average water demand for MPL's ranching operation from 2014-2020 was approximately 13,181 gpd with a maximum of 21,397 gpd (Figure 14-15). However, the Kaluakoi Resort landscaping and Kaluakoi Hotel landscaping 90,518 gpd demand is provided by potable water. These uses, the resident landscaping and agricultural uses, and the currently closed Kaluakoi golf course could be met with non-potable water available from the Maunaloa Reservoir or the reused water provided by the wastewater treatment facility, or a combination of both.

Irrigation Needs of Diversified Agriculture

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

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

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

Understanding that water demand is highly site, weather, application, and crop dependent, IWREDSS can still provide a useful approximation of water needs. The simulation was used to estimate the IRR for four types of crops grown on Molokai in three different TMK parcels: 2-5-2-024:010 (a DHHL parcel in Hoolehua); 2-5-2-001:009 (a DOA parcel in Hoolehua); and 2-5-2-012:004 (a Molokai Properties parcel in Hoolehua). The 1:5 year drought IRR for dryland kalo, seed corn, and coffee are approximately 2100 gallons per acre per day (Table 14-8). The model calculates IRR based on long-term rainfall records available at the weather stations located nearest to the fields. Thus, the estimated IRR represents an average value for given drought scenarios as opposed to average or wet year conditions. However, the estimated IRR for the relative drought year frequencies could be extrapolated to represent the highest demand scenarios. Alternatively, water demand per tree can be used based on the number of trees planted.

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

Table 14-7. Estimated existing and planned potable and non-potable water uses sourced from Well 17 (potable) and the Molokai Ranch mountain water system (non-potable) for Molokai Properties utilities. All values in gallons per day (gpd) [note: WOM = Waiola O Molokai; MPU = Molokai Public Utilities]

		units		Water Use Rate[1]		Existing Total Water Use		Planned Total Water Use	
Service Area (Untility)	Use	Existing	Planned	Potable	Non-Potable	Potable	Non-Potable	Potable	Non-Potable
Kalae (WOM)									
	Kipu Residences	18	7	439		7,906		10,975	
	Kipu Golf Course Office Area	1	0	629		629		629	
Kualapuu (WOM)									
	Residences	122	42	196		23,877		32,144	
	Reed House	1			6,069		6,069		6,069
	Shafer House	1			6,069		6,069		6,069
	County Park	1	0	1,047		1,047		2,332	
	Aka‘ula School	1		236		236		529	
	Commercial businesses	5	1	1,010		5,052		6,060	
	Kualapuu Ranch (2020 data)				20,000				
Manawainui (WOM)									
	Manawainui Industrial Park	3	16	933		2,798	775	17,727	775
	Swenson (business)	1	0			480	768		768
	Space Options (business)	1	0			1,519	1,117		1,117
	Tri-L (concrete)	1	0			13,338	7,359		7,359
	The Gas Co.						3		3
	Maui Electric Co.						827		827
	Goodfellow Inc (office)						567		567
	Goodfellow Inc (crusher)						0		0
	Oliwai Pastures/Kamakana Farms						0		0
	Molokai Sea Farms						2,177		2,177
	County of Maui baseyard	0	1	*140/ft^2		0		14,967	
Maunaloa (WOM)									
	Neighborhood Residences	143	323	251		37,192		81,073	
	Molokai Land Trust						106		106
	Sakugawa & Sons (livestock)						6,257		6,257
	ARInc (lessee)						81		81
	Kaupoa Camp	80	0	112		8,950		8,950	
	Kolo Camp	20	0	38		761		761	
	Paniolo Camp	80	0	40		3,225		3,225	
	Lodge	22	0	359		7,903		7,903	
Kaluakoi (MPU)									
	Papohaku Beach Park	1	0	12,176		12,176		12,176	
	Papohaku Beach Access	5	1	377		1,883		2,262	
	Kaluakoi Resort Condos	124	350	*350		43,400		122,500	
	Kaluakoi Resort Landscaping	35.448 acres				62,140		62,140	
	Kaluakoi Hotel units	148	0	*350		51,800			
	Kaluakoi Hotel Landscaping	15.12	18.12	1,877		28,378		34,012	
	Kaluakoi GC Facilities	5	0	*600		3,000		3,000	
	Kaluakoi Resort Residences	106	325	1,228		130,188		399,100	
	Kaluakoi Condos	0	284	*350		0	0	113,750	
	Kaluakoi Hotel & Apartments	0	481	*350		0	0	168,350	

[1]based on 5-year average meter reading for potable (2013-2017) or non-potable (2016-2021)
*county of maui standard used

Availability of Suitable Grazing Lands

Range and pasture lands are diverse types of land where the primary vegetation produced is herbaceous plants and shrubs. The lands provide forage for beef and dairy cattle, sheep, goats, horses, and other domestic livestock. The primary economic outputs of rangelands are livestock production, but successful management can also play a major role in watershed health. Well managed range and pasture lands can provide environmental values including essential ecosystem services such as clean water, carbon sequestration, wildlife habitat, and recreational opportunities. Scenic, cultural, and historic values of these lands may also provide quality of life values. In Hawaii, approximately 25 percent of the total land mass is range or pastureland. Historic use and management of grazing lands occurred without the benefit of grazing land science. Further, many lands that were designated as rangeland due to a lack of sufficient rainfall to support cultivated agriculture (i.e., dry lands) have experienced a significant decline in seasonal and annual rainfall since the 1920s (see Figure 3-10; Frazier and Giambelluca, 2017).

Table 14-8. Mean drip irrigation demand estimates for various crops grown in central Molokai based on IWREDSS scenarios modeled using the trickle drip irrigation method given a 10 ft depth to water table. Irrigation Requirement (IRR) value in gallons per acre per day.

		1 in 5-year drought water demand		
crops	irrigation method	TMK 252012004	TMK 252001009	TMK 252024010
coffee	Trickle Drip	1951	2103	2026
seed corn	Trickle Drip	2025	2108	2076
dryland kalo	Trickle Drip	2039	2113	2101
papaya	Trickle Drip	709	774	750

Overgrazing pastures is a major global environmental hazard leading to the permenant loss of topsoil, reduction in vegetation quality, and long-term consequences for cattle health and the economic suitability of a ranching operation. Overgrazing is the practice of grazing livestock on vegetation before it has fully recovered from a former grazing state. Grazing by ungulates (e.g., cattle, goats, sheep, pigs) is caused by one or more factors including: 1) a lack of proper animal management; 2) socio-economic conditions of the farmer; 3) drought or decline in precipitation that affects vegetation recovery; 4) improper land use, such as mining, slash and burn agriculture, logging, and pollution; 5) overstocking of animals; 6) poor irrigation techniques. As a result, overgrazing can lead to soil erosion, land degradation, loss of valuable species, food shortage, livestock death, and deforestation.

Successful grazing operations often utilize an intensive-rotational plan, where the number of cattle and the length of grazing match the forage quality and quantity in a given paddock. The cattle are then rotated to a new paddock following the short-duration intensive grazing, allowing the first paddock to recover. The size of the herd that can be grazed is dependent on the growth and quality of forage and the size of the land available.

Grazing management is dependent on an evaluation of forage quality and quantity. Forage can be defined as the edible parts of plants, other than separated grain, that can provide standing feed for grazing animals or be harvested for feeding. Crops that are sometimes classified as grain crops are also forages, such as corn and sorghum grown for silage. Forage suitability groups (FSG's) are composed of one or more individual soil map units having similar potentials and limitations for forage production (USDA-NRCS, 2003). Soils within a forage production suitability group are sufficiently uniform to:

- Support the same adapted forage plants under the same management,
- Require similar conservation treatment and management to produce the forages selected in the quality and quantity desired, and
- Have comparable potential productivity

Pastureland condition is the status of the plant community and the soil in a pasture in relation to its highest possible condition under “ideal” management. The land user selects and establishes the desired plant community unless a preexisting one is acceptable or can be developed from the existing site. The desired plant community should be selected on the basis of the adaptability to the existing soils and climate at the site. Livestock production goals and livestock forage preferences should also be considered.

Where “ideal” pastureland management is applied, grazing pressure and agronomic inputs are managed in a manner that keeps the desired plant community reasonably stable at the species proportions desired for the livestock type and class. Over time, permanent pastures tend to naturalize. Other unintended plants invade and become part of the plant community. Some of these are acceptable forage species; others are not. Shifts in plant species composition, if allowed to proceed without intervention, usually result in a plant community that does not meet the goals of the land user. This plant community often produces lower quality forage than the established pasture plant community, sometimes yields less forage, and may not respond as well to agronomic inputs.

Rangeland is a kind of land on which the historic climax vegetation was predominantly grasses, grasslike plants, forbs, or shrubs. Rangeland includes land revegetated naturally or artificially to provide a plant cover that is managed like native vegetation. Rangelands include natural grasslands, savannas, most deserts, tundra, alpine plant communities, coastal and freshwater marshes, and wet meadows.

Rangelands provide numerous products and have many values and uses. Rangelands are a primary source of forage for domestic livestock and for wildlife. Rangelands provide water for urban, rural, domestic, industrial, and agricultural use. They provide wildlife habitat, areas for natural recycling, purification of the air, and carbon sequestration. Rangelands have aesthetic value, provide open space, and act as buffers for urban areas. They are a vital link in the enhancement of rural social stability and economic vigor (USDA-NRCS, 2003).

Soil Textures

Texture is given in the standard terms used by the U.S. Department of Agriculture. These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is less than 2 millimeters in diameter. "Loam," for example, is soil that is 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand. If the content of particles coarser than sand is 15 percent or more, an appropriate modifier is added, for example, "gravelly." The texture classification of agriculturally zoned soils on land owned by Molokai Properties is provided in Table 14-9 and Figure 14-14 and summarized in Table 14-10. Soil texture, combined with rainfall, are factors that influence the type of plant community that can be supported. These lands are predominantly silty clay (~40%) and silty clay loam (~20%), and extremely stony silty clay loam (~14%). Common grasses that can be supported on these soils and their average percent dry matter are: kikuyu grass (25%), pangola grass (22%), guinea grass (24%), signal grass (26%), and california grass (21%) (Thorne and Stevenson, 2007). Other grasses available include green panic, giant guinea, and buffalo grass. Due to a lack of rainfall, pasture grass does not grow well on Molokai and additional livestock feed is imported from the mainland during dry conditions. For example, in 2012, 662,000 pounds of cattle and horse feed was purchased through the farm supply cooperative (de Sa et al. 2013).

Fragile Soil Index

Soils can be rated based on their susceptibility to degradation in the "Fragile Soil Index" interpretation. Fragile soils are those that are most vulnerable to degradation. In other words, they can be easily degraded—they have a low resistance to degradation processes. They tend to be highly susceptible to erosion and can have a low capacity to recover after degradation has occurred (low resilience). Fragile soils are generally characterized by a low content of organic matter, low aggregate stability, and weak soil structure. They are generally located on sloping ground, have sparse plant cover, and tend to be in arid or semiarid regions. The index can be used for conservation and watershed planning to assist in identifying soils and areas highly vulnerable to degradation (USDA-NRCS, 2003).

Depending on inherent soil characteristics and the climate, soils can vary from highly resistant, or stable, to vulnerable and extremely sensitive to degradation. Under stress, fragile soils can degrade to a new altered state, which may be less favorable or unfavorable for plant growth and less capable of performing soil functions. To assess the fragility of the soil, indicators of vulnerability to degradation processes are used. They include organic matter, soil structure, rooting depth, vegetative cover, slope, and aridity.

Table 14-9. Area and percent of available land by soil texture classification for agriculturally zoned land owned by Molokai Properties. (Source: USDA-NRCS, 2003)

classification	Area (square miles)	Percent (%)
bedrock	0.825	1.09%
clay	1.289	1.70%
clay loam	0.041	0.05%
extremely stony silty clay	8.447	11.12%
extremely stony silty clay loam	10.925	14.38%
medial silt loam	0.835	1.10%
mucky peat	0.098	0.13%
sand	1.058	1.39%
silt loam	7.030	9.25%
silty clay	30.034	39.53%
silty clay loam	15.349	20.20%
stony sandy loam	0.014	0.02%
water	0.023	0.03%

The organic matter content indicates the capacity of the soil to resist and/or recover from degradation processes. Organic matter improves the soil pore structure, increases water infiltration, and reduces soil compaction and soil erosion. Soil structure indicates the capacity of the soil to resist degradation from accelerated water erosion (by increasing the amount of infiltration). Pore structure is the most important aspect of soil structure as pores provide habitat for organism. Shallow soils are more vulnerable to degradation processes because they have limited rooting depth and have a reduced amount of material from which to form new soil. As erosion removes the upper soil profile, productivity will decline if the subsoil is limiting for crop growth. Vegetative cover is very important as uncovered soil is most vulnerable to the processes of soil erosion, both by wind and water. Slope (a measure of the steepness or the degree of inclination) indicates the degree of vulnerability to erosion and mass movement. Aridity is defined by the shortage of moisture. Lack of water is a main factor limiting biological processes and the ability of the soil to resist and/or recover from degradation.

Soils are placed into interpretive classes based on their index rating, which ranges from 0 to 1. An index rating of 1 is the most fragile, while a rating of zero is the least fragile. Interpretative classes are as follows:

Not Fragile (index rating less than or equal to 0.009). These soils have a very high potential to resist degradation and be highly resilient. They are highly structured with an organic matter content greater than 5.7%, are nearly level, are deep or very deep, have greater than 85% vegetative cover, and are in a climate that is wet or very wet.

Slightly Fragile (index rating less than 0.009 and less than or equal to 0.209). These soils have a high potential to resist degradation and be resilient. They are: poorly structured to weakly structured soils that have an extremely low to moderate content of organic matter, are very deep, have high vegetative cover, occur on nearly level ground, and are in wet or very wet climates; highly structured soils that have a very high content of organic matter, are very shallow to moderately deep, have high vegetative cover, occur on nearly level ground, and are in wet or very wet climates; highly structured soils that have a very high content of organic matter, are very deep, have low to moderately high vegetative cover, occur on nearly level ground, and are in wet or very wet climates; highly structured soils that have a very high content of organic matter, are very deep, have high vegetative cover; are on slopes greater than 3%, and are in wet or very wet climates; or highly structured soils that have a very high content of organic matter, are very deep, have high vegetative cover; occur on nearly level ground, and in semi-dry to mildly wet climates;

Moderately Fragile (index rating greater than 0.209 and less than or equal to 0.409). These soils have a moderate potential to resist degradation and be moderately resilient. They are: highly structured soils that have a very high content of organic matter, are very shallow, have high vegetative cover, occur in nearly level to moderately sloping areas, and are in semi-dry climates; poorly structured soils that have an extremely low content of organic matter, are deep, have low vegetative cover, occur in nearly level areas, and are in wet or very wet climates; poorly structured soils that have an extremely low content of organic matter, occur on gentle to very steep slopes, have high vegetative cover, and are in wet or very wet climates; weakly structured soils that have a very low content of organic matter, are deep, occur in nearly level to gently sloping areas, have high vegetative cover, and are in semi-dry climates; or weakly structured soils that have a very low content of organic matter, are very shallow to very deep, occur in nearly level to strongly sloping areas, have high vegetative cover, and are in mildly wet climates.

Fragile (index rating greater than 0.409 and less than or equal to 0.609). These soils have a low potential to resist degradation and low resilience. They are: well structured soils that have a low content of organic matter, are shallow to very deep, have moderate to moderately high vegetative cover, occur on steep slopes, and are in dry climates; well structured soils that have a low content of organic matter, are shallow to very deep, have a low vegetative cover, occur in nearly level to gently sloping areas, and are in dry climates; well structured soils that have a low content of organic matter, are deep, have low vegetative cover, occur on nearly level to very steep slopes, and are in a semi-dry climate; moderately structured soils that have a very low content of organic matter, are deep, have moderately high vegetative cover, occur on moderately steep to very steep slopes, and are in semi-dry climates; or weakly structured soils that have a low content of organic matter, occur on moderately steep to very steep slopes, have low vegetative cover, and are in wet or very wet climates.

Very Fragile (index rating greater than 0.609 and less than or equal to 0.809). These soils have a very low potential to resist degradation and very low resilience. They are: weakly structured soils that have an extremely low content of organic matter, are deep, have low vegetative cover, occur on nearly level to very steep slopes, and are in dry climates; weakly structured soils that have an extremely low content of organic matter, are shallow to very deep, have low vegetative cover, occur on nearly level to very steep slopes, and are in very dry climates; or poorly structured soils that have an extremely low content of organic matter, are very shallow, have no vegetative cover, occur on steep slopes, and are in mildly wet to wet climates.

Extremely Fragile (index rating greater than 0.809 and less than or equal to 1.0). These soils can have no potential to resist degradation and no resilience. They are: poorly structured soils that have an extremely low content of organic matter, are very shallow, have low vegetative cover, occur on very steep slopes, and are in dry or very dry climates; weakly structured soils that have a very low content of organic matter, are nearly level to very deep, have low vegetative cover, occur on very steep slopes, and are in dry climates; or very shallow soils on steep slopes.

The interpretive rating is based on soils that occur in the dominant land use for the map unit component and may not represent soils that occur in site-specific land uses. The fragile soil classification for agriculturally zoned soils on land owned by Molokai Properties is provided in Table 14-9 and summarized in Table 14-11. The largest portion of the Molokai Properties land was not rated, and approximately 50% of the land was classified as fragile or moderately fragile. A moderate classification would imply that under low vegetative cover on gently sloping to very steep slopes, under very dry conditions on moderately steep slopes, or even low vegetative cover under wet conditions, there is poor soil quality resulting is less productivity. Fragile soils have poor quality with low vegetative cover under wet or dry conditions, especially on moderately steep or very steep slopes.

Table 14-10. Area and percent of available land by soil fragility index classification for agriculturally zoned land owned by Molokai Properties. (Source: USDA-NRCS, 2003)

classification	Area (square miles)	Percent (%)
slightly fragile	1.985	2.61%
moderately fragile	14.545	19.14%
fragile	23.951	31.52%
extremely fragile	0.614	0.81%
not rated	34.898	45.92%

Drought vulnerable Soils

Even in a year, having normal precipitation or slightly less than normal, some soils are prone to having drought stress occur in the plants growing on them. Several conditions can allow this to happen. Most influential may be a relative lack of effective precipitation, as is estimated by subtracting the mean annual precipitation from an estimate of the annual evapotranspiration. Soils west of the 100th meridian frequently fall into this situation, especially at low elevations. Also, a soil may have an inherently low ability to store water. This is typical of sandy or shallow soils or soils having a high content of rock fragments. In this case, even though there may be significant rainfall, the soil matrix does not retain sufficient water for crop growth.

Topographic and climatic characteristics can be present to mitigate a soil's droughty tendacies. Some soils exist on water-gathering portions of the landscape and can thus support more plant growth than their similar neighbors because of run on. Some soils have a water table present within the rooting zone during the growing season to supply plant water needs. Finally, some soils exist in a climate where precipitation is much higher than evapotranspiration and the soil is nearly always moist. This can occur in cool climates at high elevations.

The ratings are both verbal and numerical. Rating class terms indicate the extent to which the soils are vulnerable to drought. Numerical ratings indicate the degree of vulnerability associated with each soil or site feature. The ratings are shown in decimal fractions ranging from 0.01 to 1.00. They indicate gradations between the point at which a soil feature imparts the greatest degree of vulnerability (1.00) and the point at which the soil feature helps to mitigate drought vulnerability (0.00).

Figure 14-13. Agricultural and conservation zoned land owned by Molokai Properties on the island of Molokai (top) and the 1983-2012 mean annual rainfall for this land (bottom).

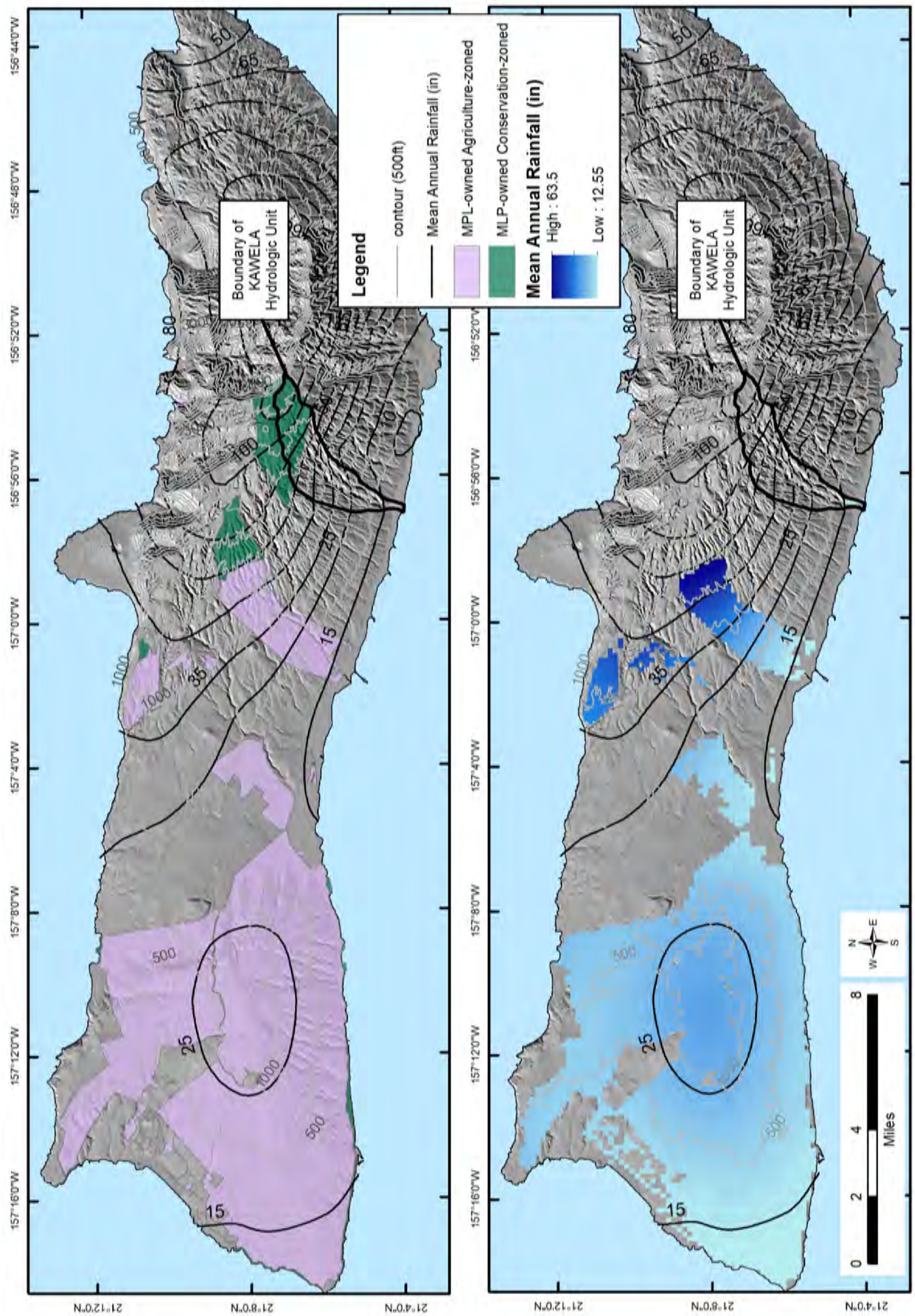


Figure 14-14. Soil series classification for Molokai and the agriculturally zoned land owned by Molokai Properties (USDA-NRCS, 2003)

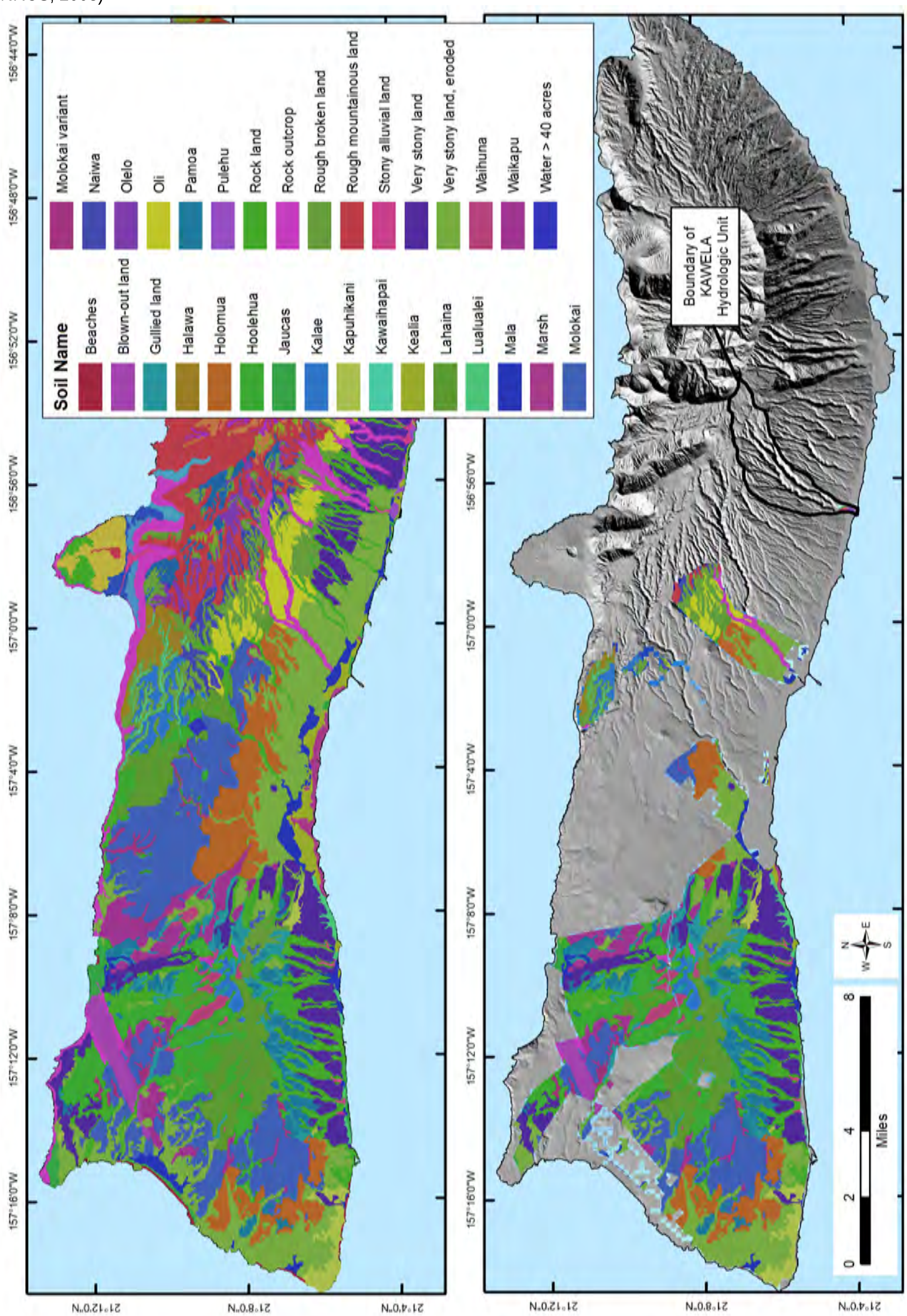


Table 14-11. Soil map unit name, soil texture, fragile soil index, and soil drought classification, area, percent of total for agriculturally zoned land owned by Molokai Properties for the island of Molokai (USDA-NRCS, 2003).

soil map unit	area (acre)	percent of total	soil texture	soil fragile index	drought vulnerability index
beaches	7.9	<0.01%	sand	not rated	drought vulnerable
gullied land	2004.3	4.10%	silty clay loam	not rated	severely drought vulnerable
Halawa silty clay 3-25% slope (MLRA 164)	160.1	0.30%	silty clay	slightly fragile	drought vulnerable
Halawa silty clay 3-25% slope (severely eroded)	25.7	0.10%	silty clay	not rated	drought vulnerable
Holomua silty loam 0-3% slope	461.8	0.90%	silt loam	fragile	severely drought vulnerable
Holomua silt loam, 3- 7% slope	1619.1	3.30%	silt loam	fragile	severely drought vulnerable
Holomua silt loam, 3- 7% slope (severely eroded)	707.9	1.50%	silt loam	fragile	severely drought vulnerable
Holomua silt loam, 7- 15% slope	163.7	0.30%	silt loam	fragile	severely drought vulnerable
Holomua silt loam, 7-15% slope (severely eroded)	392.8	0.80%	silt loam	highly fragile	severely drought vulnerable
Hoolehua silty clay loam, 3-10% slopes (severely eroded, MLRA 158)	1028.60	2.10%	silt loam	moderately fragile	severely drought vulnerable
Hoolehua silty clay, 0-3% slope	28.5	0.10%	silty clay loam	moderately fragile	drought vulnerable
Hoolehua silty clay, 3-7% slope	1228.70	2.50%	silty clay	moderately fragile	drought vulnerable
Hoolehua silty clay, 7-15% slope	2625.00	5.40%	silty clay	moderately fragile	drought vulnerable
Jaucas sand, 0-15% slope (MLRA 163)	139.6	0.30%	silty clay	moderately fragile	severely drought vulnerable
Jaucas-Dune land complex, 0-15% slope (MLRA 158)	602.7	1.20%	sand	moderately fragile	severely drought vulnerable
Kalae silty clay, 2-7% slopes (MLRA 165)	74.7	0.20%	sand	moderately fragile	drought vulnerable
Kalae silty clay, 7-15% slope (MLRA 165)	9.7	0.00%	silty clay	moderately fragile	drought vulnerable
Kalae silty clay, 5-15% slope (severely eroded)	430.4	0.90%	silty clay	fragile	drought vulnerable
Kalae silty clay, 15-25% slope (severely eroded, MLRA 165)	17.5	0.00%	silty clay	moderately fragile	drought vulnerable
Kalae silty clay, 25-40% slope (severely eroded)	168.1	0.30%	silty clay	moderately fragile	drought vulnerable
Kapuhikani extremely stony clay, 3-15% slope (MLRA 163)	1034.10	2.10%	silty clay	fragile	drought vulnerable
Kawaihapai silty clay loam, 2-7% slope	91.5	<0.01%	silty clay loam	not rated	drought vulnerable
Kealia silt loam, 0-1% slope (MLRA 163)	125.2	0.30%	silt loam	moderately fragile	slightly drought vulnerable
Lahaina silty clay, 0-3% slope (MLRA 158)	138.4	0.30%	silty clay	fragile	severely drought vulnerable
Lahaina silty clay, 3-7% slope (MLRA 158)	1,006.50	2.10%	silty clay	fragile	severely drought vulnerable
Lahaina silty clay, 7-15% slope (MLRA 158)	1,180.00	2.40%	silty clay	fragile	severely drought vulnerable
Lahaina silty clay, 7-15% slope (severely eroded, MLRA 158)	781.2	1.60%	silty clay	fragile	severely drought vulnerable
Lahaina silty clay, 15-25% slope (severely eroded, MLRA 158)	345.5	0.70%	silty clay	fragile	severely drought vulnerable
Lahaina silty clay, 25-40% slope (severely eroded, MLRA 158)	190.8	0.40%	silty clay	fragile	severely drought vulnerable
Lualualei clay, 0-2% slope (MLRA 163)	264.5	0.50%	clay	moderately fragile	drought vulnerable

Table 14-9. continued.

soil map unit	area (acre)	percent of total	soil texture	soil fragile index	drought vulnerability index
Lithic Eutrotorrox, 15-25% slope (severely eroded, MLRA 158)	449	0.90%	silty clay loam	fragile	severely drought vulnerable
Mala silty clay, 0-3% slope (MLRA 166)	567.5	1.20%	silty clay	fragile	severely drought vulnerable
Mala silty clay, 3-7% slope (MLRA 166)	127	0.30%	silty clay	fragile	severely drought vulnerable
Molokai silty clay loam, 0-3% slope (MLRA 158)	210.8	0.40%	silty clay loam	fragile	severely drought vulnerable
Molokai silty clay loam, 3-7% slope (MLRA 158)	2,485.20	5.10%	silty clay loam	fragile	severely drought vulnerable
Molokai silty clay loam, 3-7% slope (severely eroded)	91.5	0.20%	silty clay loam	not rated	severely drought vulnerable
Molokai silty clay loam, 7-15% slope (MLRA 158)	1,393.80	2.90%	silty clay loam	fragile	severely drought vulnerable
Molokai silty clay loam, 7-15% slope (severely eroded, MLRA 158)	1,123.10	2.30%	silty clay loam	fragile	severely drought vulnerable
Marsh	62.9	0.10%	mucky peat	slightly fragile	slightly drought vulnerable
Naiwa silty clay loam, 3-13% slopes (MLRA 165)	102	0.20%	silty clay loam	slightly fragile	moderately drought vulnerable
Naiwa silty clay loam, 7-15% slopes (severely eroded)	68.8	0.10%	silty clay loam	not rated	drought vulnerable
Olelo silty clay, 3-15% slope (MLRA 164)	0	0.00%	silty clay	slightly fragile	slightly drought vulnerable
Oli medial silt loam, 10-30% slope (MLRA 165)	526.6	1.10%	medial silt loam	slightly fragile	drought vulnerable
Oli medial silt loam, 30-70% slope (MLRA 165)	8.1	0.00%	medial silt loam	moderately fragile	drought vulnerable
Pamoa silty clay, 5-20% slopes (MLRA 158)	740.6	1.50%	silty clay	moderately fragile	drought vulnerable
Pamoa silty clay, 5-20% slope (eroded, MLRA 158)	1,122.70	2.30%	silty clay	moderately fragile	drought vulnerable
Pamoa stony silty clay, 5-20% slope (eroded, MLRA 158)	968.4	2.00%	silty clay	moderately fragile	drought vulnerable
Pulehu stony sandy loam, 0-7% slope (MLRA 166)	9.1	0.00%	stony sandy loam	fragile	drought vulnerable
Pulehu clay loam, 0-3% slope (MLRA 163)	26.5	0.10%	clay loam	fragile	drought vulnerable
Rock land	4,405.60	9.10%	silty clay	not rated	drought vulnerable
Rock outcrop	528.3	1.10%	bedrock	not rated	slightly drought vulnerable
Rough broken land	1,808.60	3.70%	silty clay	not rated	slightly drought vulnerable
Rough mountainous land	143.2	0.30%	silty clay loam	not rated	slightly drought vulnerable
Stony alluvial land	90.5	0.20%	extremely stony silty clay	not rated	drought vulnerable
Very stony land	5,315.40	10.90%	extremely stony silty clay	not rated	severely drought vulnerable
Very stony land, eroded	6,992.10	14.40%	extremely stony silty clay loam	not rated	severely drought vulnerable

Table 14-9. continued.

soil map unit	area (acre)	percent of total	soil texture	soil fragile index	drought vulnerability index
Water > 40 acres	14.9	0.00%		not rated	
Waihuna clay, 3-7% slope (MLRA 158)	125.2	0.30%	clay	slightly fragile	drought vulnerable
Waihuna clay, 7-15% slope (MLRA 158)	278.8	0.60%	clay	slightly fragile	drought vulnerable
Waihuna clay, 15- 25% slope (MLRA 158)	156.5	0.30%	clay	moderately fragile	drought vulnerable
Waikapu silty clay loam, 0-3% slope (MLRA 158)	92.2	0.20%	silty clay loam	fragile	drought vulnerable
Waikapu silty clay loam, 3-7% slope	674.4	1.40%	silty clay loam	not rated	drought vulnerable
Waikapu silty clay loam, 3-7% slope (severely eroded)	80.1	0.20%	silty clay loam	not rated	drought vulnerable
Waikapu silty clay loam, 7-15% slope (severely eroded, MLRA 158)	784.8	1.60%	silty clay loam	fragile	drought vulnerable

Severely drought vulnerable (rating index equals 1.0). The soil and site properties present are such that the plants growing on the soil must be very drought tolerant even in years with normal amounts of rainfall. The soil may have very low water storage capacity (below 5 cm) or may be in an area of low annual precipitation or high annual temperature or both.

Drought vulnerable (rating index is greater than 0.67 but less than 1.0). The soil and site properties are such that drought conditions generally occur every year. The soil may have low water storage capacity (5 to 15 cm) and the site may have low annual precipitation or high annual temperature or both.

Moderately drought vulnerable (rating index is greater than 0.33 but less than 0.67). The soil and site proerties are such that in an average year, some water stress may occur, but in a good year, plant available water is generally adequate. Water storage is in the range of 15 to 25 cm. Rainfall and estimated potential evapotranspiration are nearly equal.

Somewhat drought vulnerable (rating index is greater than 0 but less than 0.33). These soils have greater than 25 cm of water storage and annual precipitation is generally adequate for plant growth. In dry years some water stress may occur.

Slightly drought vulnerable (rating index equals 0). These soils are either in lowlying parts of the landscape where plant roots may exploit near-surface ground water or are in areas where precipitation is much higher than potential evapotranspitration. In an extremely dry year plants may be water stressed on these soils.

The drought vulnerability classification for agriculturally zoned soils on land owned by Molokai Properties is provided in Table 14-10 and summarized in Table 14-12. Approximately 61% of the land is classified as severely drought vulnerable and approximately 95% of their land is classified as at least drought vulnerable.

Table 14-12. Area and percent of available land by drought vulnerability classification for agriculturally zoned land owned by Molokai Properties. (Source: USDA-NRCS, 2003)

classification	Area (square miles)	Percent (%)
slightly drought vulnerable	4.169	5.49%
drought vulnerable	25.496	33.56%
moderately drought vulnerable	0.159	0.21%
severely drought vulnerable	46.122	60.71%
water	0.023	0.03%

USDA-NRCS Pasture Groups for Estimating Forage Production

Approximately 58,000 acres of land is used for grazing on Molokai, with most of this occurring in the arid western end of the island. Soils on the island were grouped by the Soil Conservation Service (precursor to the Natural Resources Conservation Service) into four pasture groups which produce similar amounts of vegetation and require similar management (Soil Conservation Service, 1972).

Pasture Group I consists of soils on alluvial fans that developed in material weathered from alluvium and coral sand in the drier parts of the island. They tend to be 20 to 60 inches deep and slope from 0 to 15%. These soils tend to be in low elevation (<200 feet elevation) regions with annual rainfall between 10 and 20 inches with good drainage. The vegetation in unimproved pasture produces anywhere from 400 to 1,300 pounds of dry forage per acre per year, with 75% or more produced during the wet season. If the pasture is improved with buffel grass, guinea grass, or haole koa, the pasture could produce 1,700 to 2,600 pounds of dry forage per acre per year.

Pasture Group II consists of soils on alluvial fans, terraces, and low uplands that developed in alluvium, volcanic ash, and weathered igneous rocks. They tend to be 20 to 60 inches deep and slope from 0 to 35%. These soils tend to be in mid elevation regions up to 1,600 feet and in regions with annual rainfall between 15 and 35 inches with good drainage. The vegetation in unimproved pasture produces anywhere from 700 to 1,700 pounds of dry forage per acre per year, with 75% or more produced during the wet season. If the pasture is improved with buffel grass, guinea grass, or haole koa, the pasture could produce 1,400 to 2,600 pounds of dry forage per acre per year.

Pasture Group III consists of soils on alluvial fans, terraces, and low uplands that developed in alluvium, volcanic ash, and weathered igneous rocks. They tend to be 24 to more than 60 inches deep and slope from 0 to 40%. These soils tend to be in mid elevation regions up to 3,250 feet and in regions with annual rainfall between 30 and 60 inches with good drainage. The vegetation in unimproved pasture produces anywhere from 2,400 to 3,200 pounds of dry forage per acre per year. If the pasture is improved with kikuyu grass, pangola grass, green panicgrass, intortum, or haole koa, the pasture could produce 2,400 to 3,200 pounds of dry forage per acre per year.

Pasture Group IV consists of soils of stony, rocky and steep land types on alluvial fans, terraces and uplands that developed from alluvium, colluvium, volcanic ash, and weathered igneous rocks. They tend to be widely ranging in depth from very shallow to more than 60 inches deep and slope from level to very steep. These soils tend to be in upper elevation regions up to 3,370 feet and in regions with annual rainfall between 15 to more than 100 inches with good drainage. Due to the variation in rainfall, the vegetation production is highly variable but similar to the first three groups.

The soils types in the properties used by Molokai Properties for cattle ranching almost exclusively fall into Pasture Group II, with the Molokai-Lahaina association soils and unimproved pasture. Since 2014, Molokai Properties has used 16,560 acres of land for cow-calf operations. Under the best of circumstances (1700 pounds of dry weight per acre per year), at a 25% harvest efficiency, this would produce approximately 7,038,000 pounds of forage per year, or 586,500 pounds per month. Based on the availability of forage, the cow-calf operation exceeded the available forage for ideal conditions six out of nine years from 2013 to 2021.

Rainfall Conditions for Estimating Carrying Capacity of Pasture

Livestock grazing is inefficient at removing available forage due to under utilization, damage to plants caused by trampling, loafing, and losses owing to other, non-livestock factors (e.g., insecs or wildlife). The USDA-NRCS (2003) recommends estimating harvest efficiency at 25%, although under high-intesity, short-duration grazing programs it may be as high as 40%. In controlled studies of similarly arid, semi-tropical regions, Fynn and O'Connor (2001) found that using a simple rotational grazing system with two differing starting conditions (good vs. poor), stocking rate had an influence on grass composition, with a significant interaction effect with rainfall. On poor condition rangeland, stocking rate determined of supplementary feeding was needed and influenced cow weight gain.

The agriculturally zoned land owned by Molokai Properties is identified in Figure 14-13. Using the zonal statistics package for ArcGIS, the mean annual rainfall was calculated for each soil class for these agriculturally zoned lands. The results are provided in Table 14-13. The estimated stocking rate of pasture is determined by the vegetation type found in the pasture and the soil condition. The estimated stock rate for the various soils and rainfall found on Molokai Properties pasture land are provided in Table 14-13 in animal unit equivalent months (AUM) (USDA-NRCS, 2003). The carrying capacity for a ranching operation is dependent on the available forage, expressed in AUM or the amount of forage needed to support one animal unit for one month. With the given annual rainfall conditions provided in Table 14-13, a total of 54,078.33 AUM of forage are available to Molokai Properties if all agriculturally zoned land were used for grazing. However, since 2014, only 16,560 acres have been used for cow-calf operations. Without knowing the exact the boundardies of the pastures used for livestock, we can estimate the productivity based on the most common soils found in the pasture lands: Lahaina soils (0.77 AUM per acre). This would support a maximum of 12,751.2 AUM. Hypothetically, assuming that forage is equally available all 12 months (i.e., there is no temporal variation in forage quality), a maximum of 1062.6 animal units could be supported. In some years, the number of animal unit equivalents that Molokai Properties raised exceeded this maximum. This likely resulted in the death or premature slaughter of hundreds of cows.

Bulls (x1.4 AUE) need 1,295 pounds per month forage, cows (x1.07 AUE) need 988 pounds per month forage, and weans (x0.7 AUE) need 547 pounds per month, animal unit equivalents (AUE). From 2013 to 2021, Molokai Properties ranching operation had a forage demand that averaged 855,520 pounds per month, ranging from 458,768 to 1,495,423 pounds per month, annually (Table 14-14). Molokai Properties ranching operation averaged 1016 AUE, ranging from 514 to 17301.

Alternatively, in interviews across a diversity of ranching operations on Hawaii, Asem-Hiablie et al. (2018) found that cow-calf stocking rates averaged 2.4 ha per head (5.93 acres per cow), with a range of 1.0 to 5.2 ha per head (2.47 to 12.85 acres per head). Molokai Properties lessee Sakugawa and Sons averages approximately 10 acres per head. Assuming a head is equal to an animal equivalent unit, with 16,560 acres, the maximum stocking rate under ideal conditions should range from approximately 1,300 to 1,656 animal units.

Water Demand of Cattle

Few studies have fully documented water use by beef cattle. Available data suggest that the water requirement of beef cattle is closely tied to the animal's size, the moisture content of their feed or forage, the external environmental conditions (e.g., air temperature, humidity), and if the animal is lactating (if female). Weight gains of pastured beef animals are greater if there is consistent water supply. Dry cows, bred heifers, and bulls need as little as 5.8 gallons per day (gpd) or as much as 14.3 gpd, but typically need around 10 gpd. The water requirement of lactating cows with calves ranges from 11.4 gpd to 17.7 gpd (National Research Council, 2000). When air temperature exceeds 80°F, a 400-pound growing beef calf requires 6.7 gpd compared to only 5.0 gpd when the temperature is at 60°F. When relative humidity increases, water requirements decrease. Mean annual temperature for Molokai Properties agriculturally zoned lands ranges from approximately 70 to 76°F. Thus, on an annual basis, a 400-pound growing beef calf requires approximately 5.8 gpd, a pregnant cow requires approximately 9.7 gpd, a lactating cow requires approximately 16.9 gpd, and a mature bull requires approximately 11.7 gpd (National Research Council, 2000). Assuming all cows are lactating (and thus require the greatest amount of water) estimated water requirements for the Molokai Properties cow-calf operation are provided in Table 14-14 and Figure 14-15. The average total annual water demand from 2014 to 2019 was 13,181 gallons per day or 0.0138 mgd and ranged from 7,077 to 21,397 gallons per day.

Figure 14-15. Annual number of bulls, cows, and weans and total annual water requirements for Molokai Properties cow-calf operation from 2013 to 2021.

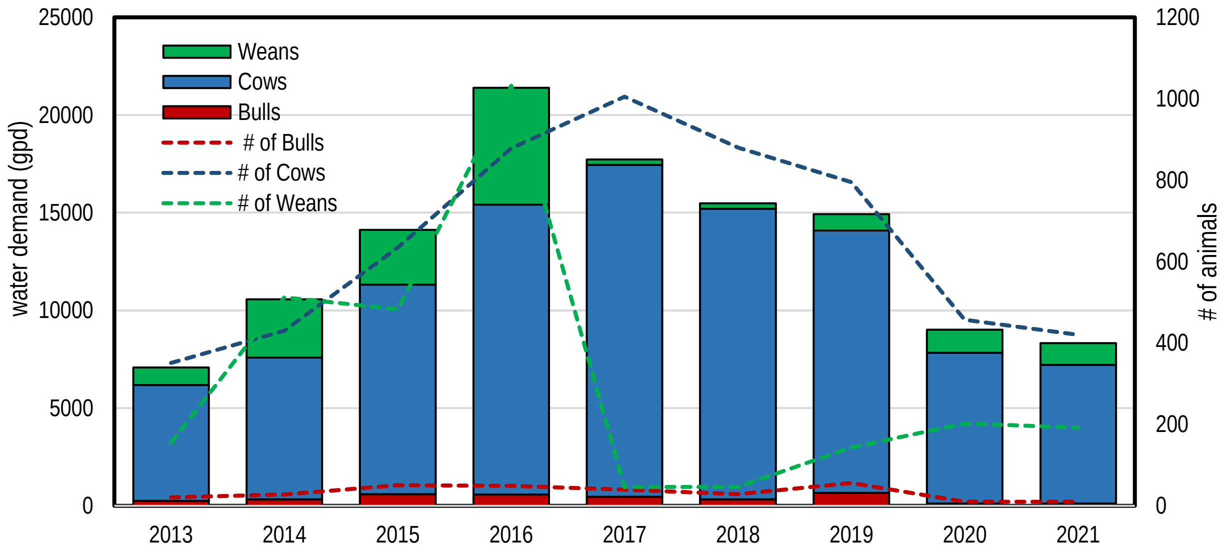


Table 14-13. Mean annual rainfall area by soil type, percent of agriculturally zoned land owned by Molokai Properties by soil type, estimated animal unit equivalent months (AUM) per acre and total AUM. (Source: USDA-NRCS, 2003)

Soil classification	Area (square miles)	Percent (%)	Mean Annual Rainfall (in)	Soil texture	Estimated AUM/acre	AUM*
Beaches	0.024	0.02%	14.11	sand	0.77	11.83
Blown-out land	1.884	1.24%	19.96		0.77	928.44
Gullied land	6.264	4.12%	24.52	silty clay loam	0.37	1483.32
Halawa	0.58	0.38%	41.73	silty clay	0.77	285.82
Holomua	10.45	6.88%	18.66	silty loam	0.71	4748.48
Hoolehua	15.346	10.10%	23.58	silty clay	0.77	7562.51
Jaucas	0.436	0.29%	22.46	sand	0.77	214.86
Kalae	2.19	1.44%	34.85	silty clay	0.77	1079.23
Kapuhikani	3.232	2.13%	15.60	extremely stony clay	0.66	1365.20
Kawaihapai	0.286	0.19%	39.63	silty clay loam	0.60	109.82
Kealia	0.394	0.26%	17.29	silty loam	0.71	179.03
Lahaina	11.386	7.49%	26.13	silty clay	0.77	5611.02
Lualualei	0.828	0.54%	18.92	clay	0.66	349.75
Mala	2.17	1.43%	17.97	silty clay	0.77	1069.38
Marsh	0.196	0.13%	18.01	mucky peat	0.60	75.26
Molokai	16.57	10.90%	19.87	silty clay loam	0.60	6362.88
Molokai variant	1.4	0.92%	21.00	silty clay loam	0.60	537.60
Naiwa	0.532	0.35%	54.02	silty clay loam	0.60	204.29
Oli	0.013	<0.01%	42.91	medial silt loam	0.71	5.91
Pamoa	1.672	1.10%	22.64	silty clay	0.77	823.96
Pulehu	8.854	5.83%	12.64	clay loam	0.71	4023.26
Rock land	0.11	0.07%	21.72	silty clay	0.77	54.21
Rock outcrop	13.772	9.06%	27.07	bedrock	0.00	0.00
Rough broken land	1.65	1.09%	41.39	silty clay	0.77	813.12
Rough mountainous land	5.652	3.72%	59.76	silty clay loam	0.60	2170.37
Stony alluvial land	0.446	0.29%	18.64	extremely stony silty clay	0.37	105.61
Very stony land	0.28	0.18%	20.56	extremely stony silty clay	0.37	66.30
Very stony land, eroded	16.616	10.93%	17.85	extremely stony silty clay loam	0.37	3934.67
Waihuna	21.85	14.38%	26.17	clay	0.66	9229.44
Waikapu	1.752	1.15%	21.53	silty clay loam	0.60	672.77
Water > 40 acres	5.1	3.36%	14.36	n/a	0.00	0.00

*under ideal conditions assuming an equal distribution of rainfall across the year

Table 14-14. Number of bulls (x1.4 AUE, 1295 pounds per month forage), cows (x1.07 AUE, 988 pounds per month forage), and weans (x0.7 AUE, 547 pounds per month), animal unit equivalents (AUE), forage needed (pounds per month) and their total daily water and forage demand by year for Molokai Properties cow-calf operation from 2013 to 2021.

	bulls				cows				weans						
year	number	AUE	forage needed	water demand (gpd)	number	AUE	forage needed	water demand (gpd)	number	AUE	forage needed	water demand (gpd)	total AUE	total daily water demand (gpd)	total monthly forage needed
2013	21	29.4	27195	245.7	351	375.6	346788	5931.9	155	108.5	84785	899	513.5	7076.6	458,768
2014	28	39.2	36260	327.6	430	460.1	424840	7267	512	358.4	280064	2969.6	857.7	10,564.2	741,164
2015	51	71.4	66045	596.7	635	679.5	627380	10731.5	483	338.1	264201	2801.4	1089.0	14,129.6	957,626
2016	49	68.6	63455	573.3	878	939.5	867464	14838.2	1032	722.4	564504	5985.6	1730.5	21,397.1	1,495,423
2017	40	56	51800	468	1005	1075.4	992940	16984.5	46	32.2	25162	266.8	1163.6	17,719.3	1,069,902
2018	29	40.6	37555	339.3	880	941.6	869440	14872	47	32.9	25709	272.6	1015.1	15,483.9	932,704
2019	56	78.4	72520	655.2	795	850.7	785460	13435.5	143	100.1	78221	829.4	1029.2	14,920.1	936,201
2020	10	14	12950	117	457	489.0	451516	7723.3	202	141.4	110494	1171.6	644.4	9011.9	574,960
2021	10	14	12950	117	420	449.4	414960	7098	192	134.4	105024	1113.6	597.8	8328.6	532,934

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16.0 Appendices

Appendix A Kawela, Maui, Hawaii. June 2008. DAR Watershed Code: 42015
State of Hawaii, Department of Land and Natural Resources, Division of Aquatic Resources.

APPENDIX A

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

Atlas of Hawaiian Watersheds & Their Aquatic Resources Kawela, Molokai