Watershed Management Plan for Hanalei Bay Watershed

Volume 1:
Watershed Characterization

October 2012

Prepared for:

Hanalei Watershed Hui
5299C Kuhio Hwy
P. O. Box 1285
Hanalei, Kauaʻi, HI 96714
www.hanaleiwatershedhui.org

Prepared by:

SUSTAINABLE RESOURCES GROUP INTN'L, INC.
111 Hekili Street, Ste A373
Kailua, HI 96734
www.srgii.com

This Project has been jointly funded by the U.S. Environmental Protection Agency ("Agency") or ("EPA") under Section 319(h) of the Clean Water Act, and the Hawai'i State Department of Health, Clean Water Branch. Although the information in this document has been funded wholly or in part by a Federal grant to the Hawai'i State Department of Health, it may not necessarily reflect the views of the Agency and the Hawai'i State Department of Health and no official endorsement should be inferred.

The Watershed Management Plan for Hanalei Bay Watershed has been developed as a two volume document: *Volume 1: Watershed Characterization* (this document), and *Volume 2: Strategies and Implementation*. The complete plan characterizes the project watersheds (Volume 1); recommends pollution control strategies, outlines implementation strategies, provides evaluation and monitoring protocols, and describes education and outreach approaches (Volume 2).

Executive Summary

Healthy waterbodies and coral reefs are vital to our culture, way of life, and economy. The Hanalei Bay Region suffers from water quality problems and coral reef degradation that are caused in part by land-based pollutants. Land use in this area over the past century has resulted in export of these pollutants, which adversely impact fresh and ocean water quality and the coral reef ecosystem, and diminish habitat for plants and animals and resource use by people. Land-based pollutants generated across large areas from diffuse sources are commonly referred to as non-point source (NPS) pollutants. NPS pollutants are transported off the watersheds in both surface water and groundwater and delivered into the ocean at various locations and rates.

The Hanalei Bay Region is currently targeted by Federal, State, and private efforts for watershed planning efforts with the goals of reducing stressors to and improving the overall health of coral reefs, nearshore waters, and watersheds. Established to promote sustainability and stewardship of the watersheds of Hanalei Bay (Hanalei, Waiʻoli, Waipā, and Waikoko), the Hanalei Watershed Hui plays an essential role in this effort. The *Hawaiʻi State Department of Health* funded the Hanalei Watershed Hui to develop this Watershed Management Plan (WMP) as a component of on-going efforts to identify and reduce stressors to, and improve the overall health of coral reefs, nearshore waters, and watersheds. The *Hanalei Bay Watershed Management Plan* (HBWMP) is composed of two volumes: *Volume 1: Watershed Characterization*, and *Volume 2: Strategies and Implementation*. It adheres to the Environmental Protection Agency (EPA) Clean Water Act (CWA) Section 319 guidelines for watershed plan development. These guidelines require use of a holistic, watershed based approach to identify sources and sinks of NPS pollutants, and the remedial actions necessary to reduce their loads to receiving waters.

Volume 1: Watershed Characterization summarizes the current environmental conditions of Hanalei Bay Watershed, with an emphasis on identifying water quality pollutant sources and types. It was developed using existing data and information, field investigations, interviews with a cross-section of people with historic and current knowledge of land uses and activities, and geospatial data analysis using geographic information system (GIS) software. The characterization provides a mechanism to evaluate watershed processes and determine if land uses and activities are generating NPS pollutants, altering the hydrologic regime and ecological processes, and causing adverse impacts to the watershed's ecosystem.

Major NPS pollutant sources within the watersheds are those land uses, activities, and inputs that have the greatest overall adverse impact to water quality and coral reef ecosystem health. The pollutants of primary concern within the Hanalei Bay Watershed, and the main focus of remediation efforts are, in order of priority, (1) sediment and plant detritus and other particulates that comprise Total Suspended Solids (TSS), (2) bacteria, and (3) nutrients. The main pollutant sources are wastewater disposal systems, grazing operations, and taro cultivation. Secondary pollutant sources are disturbed upland areas, overgrown and eroding streambanks, and managed wetlands used for waterbird habitat. The HBWMP is focused on water quality issues and does not specifically address: flooding, irrigation water supply, instream flows, or irrigation diversion works. While germane to water quality, these issues were not scoped to be assessed under this plan.

Volume 2: Strategies and Implementation discusses strategies for management of sources and NPS pollutants in the Hanalei Bay Watershed as identified in *Volume 1*. To refine the discussion of pollutants and their control strategies, the watersheds were delineated into six management units (Built Environment, Forested Upland, Grazing, Stream, Taro *Lo'i*, and USFWS Wetlands), three of which are high priority for immediate action (Built Environment, Taro *Lo'i*, and Grazing). Key water quality issues and recommendations by management unit are presented in Table ES-1.

Table ES-1. Major NPS Pollutant Sources and Recommended Management Practices

Pollutants/ Key Issues	Sources	Critical Areas	Management Practices
Built Environment			
Stormwater runoff, nutrients, bacteria, sediment, metals	Individual wastewater systems (cesspools, batch plants, septic tanks), impervious surfaces, land use and drainage systems	Hanalei Town	Baffle Box, Bioretention Cell, Curb Inlet Basket, Good Housekeeping Practices, Grass Swale, Gutter Downspout Disconnection, Permeable Surfaces, Storm Sewer Disconnection, Commercial WWTP Upgrades, Aerobic Treatment Unit, High Efficiency Toilets
Forested Upland			
Erosion/sediment, nutrients, bacteria	Naturally occurring and accelerated due to alien vegetation and feral animals,	All lands within Conservation Zone	Erosion Control Mats and Vegetative Plantings, Feral Ungulate Fencing
Grazing			
Bacteria, nutrients, sediment	Animal waste, trampling	Pastures used for buffalo and cattle	Grazing Management System (*prescribed grazing, travel ways to facilitate animal movement, livestock fencing, livestock watering*)
Stream			
Sediment	Streambanks, *hau* bush	Dense stands of *hau* bush	Channel Maintenance and Restoration
Taro *Lo'i*			
Nutrients, sediment, bacteria	Fertilizers, suspension of sediments, animal waste	Taro pondfields	Lo'i Management (*'auwai outlet gate closure protocol, dry tilling of taro ponds, taro resting period, 'auwai and ditch cleaning, constructed wetlands*), Fertilizer Management Plan, Pesticide Management Plan
USFWS Wetlands/Hanalei Refuge			
Nutrients, bacteria, sediments	Birds	Wetlands	Erosion Control Mats and Vegetative Plantings, Wetland Pollution Reduction Practices

Major sources of NPS pollution can be remediated through the implementation of management practices. Targeting priority areas and sites, and applying appropriate strategies is expected to decrease generation and transport of NPS pollutants that reach the ocean. Reduction of pollutant loads is a function of both the types and number of management practices installed. The HBWMP identifies a set of management practices for implementation based on the targeted pollutant locations and land use activities. They were chosen based on their expected performance to reduce sediment, nutrient, bacteria, and other NPS pollutants that currently impact water in streams, estuaries and the bay. Selection of practices was also based on practical considerations such as cost to install and maintain, past history on successes and failures of practices installed, and likelihood that land owners and managers would be willing to install and maintain practices.

Replacement of or upgrades to out-dated and failing wastewater treatment systems, both at the individual homeowner level (e.g. cesspools and septic tanks) and for the two commercial properties in Hanalei will likely have the most significant positive impact on water quality (primarily nutrients and bacteria). Management practices designed to reduce sediment and nutrient contributions from grazing areas and taro cultivation are also recommended as high priority.

The WMP also discusses elements required for implementation, including responsible entities, legal requirements, and financial resources. In addition, it details resources needed for implementing management practices, including data and analysis requirements, technical resources, and cost. Milestones should be set to track implementation on a programmatic level as well as the pollutant reductions being achieved and the affected change in the health of the ecosystem. It is highly recommended that all solutions be implemented as soon as possible, however it is recognized that this is likely not feasible due to financial and labor constraints. The priorities for implementation should not be considered rigid. If a landowner or entity responsible for a particular parcel has resources to implement a solution that is lower priority, the opportunity should be taken. Any installation of a management practice is a positive gain towards reducing NPS pollution. Adaptive management is necessary to improve management by learning from the outcomes of past activities.

Four types of monitoring are necessary to track management practices: trend, implementation, baseline, and effectiveness. Qualitative and quantitative information about the management practices, water quality, and coral reef ecosystem condition helps determine their effectiveness. The HBWMP identifies site-based effectiveness monitoring for recommended management practices. Long-term trend monitoring of water quality and coral reef ecosystem health will also provide information that can be correlated to implementing solutions to reduce NPS pollutants.

Success of the HBWMP is dependent on stakeholder awareness and involvement. The Hanalei Watershed Hui and other organizations must continue and expand activities to engage the local community in efforts to reduce NPS pollution. Implementation of the solutions recommended in the HBWMP, per the identified priorities, is crucial to reducing the generation and transport of sediments and other NPS pollutants. This will result in improved water quality and ecosystem health within the watersheds and the nearshore coastal waters.

This page intentionally left blank.

Table of Contents

List of Tables

List of Figures (Appendix A)

List of Photos (Appendix B)

Acronyms

AnnAGNPS	Annualized Agricultural Non-Point Source Pollution
BMP	Best Management Practice
BOD	Biological Oxygen Demand
CFS	Cubic Feet per Second
CRAMP	Coral Reef Assessment and Monitoring Program
CRCP	Coral Reef Conservation Program
CRWG	Coral Reef Working Group
CWA	Clean Water Act
CWB	Clean Water Branch
CZARA	Coastal Zone Act Reauthorization Amendments
CZM	Coastal Zone Management
CZMA	Coastal Zone Management Act
CZO	Comprehensive Zoning Ordinance
DAR	Division of Aquatic Resources
DBEDT	Department of Business, Economic Development and Tourism
DLNR	Department of Land and Natural Resources
DO	Dissolved Oxygen
DOFAW	Division of Forestry and Wildlife
DOH	Department of Health
DOT	Department of Transportation
DPW	Department of Public Works
EPA	Environmental Protection Agency
FIRM	Flood Insurance Rate Maps
HAR	Hawai‘i Administrative Rules
HBWMP	Hanalei Bay Watershed Management Plan
HRS	Hawai‘i Revised Statutes
HWH	Hanalei Watershed Hui
IWS	Individual Wastewater System
LAS	Local Action Strategy
LCC	Large Capacity Cesspools
MPN	Most Probable Number
MS4	Municipal Separate Storm Sewer System
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Non-Point Source
NRCS	Natural Resources Conservation Service
NSDPO	North Shore Development Plan Ordinance
NTU	Nephelometric Turbidity Units
NWR	National Wildlife Refuge
S4	Separate Storm Sewer System
SDWA	Safe Drinking Water Act
TMDL	Total Maximum Daily Load
TMK	Tax Map Key
TSS	Total Suspended Solids
TWIG	Targeted Watershed Initiative Grant
UIC	Underground Injection Control
USACE	U.S. Army Corps of Engineers
USCRTF	U.S. Coral Reef Task Force
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WMP	Watershed Management Plan
WWTP	Wastewater Treatment Plant

1. Introduction

The Hanalei region is ecologically, culturally and economically valuable to the island of Kaua‘i, the state of Hawai‘i, the U.S., and the world. Hanalei Bay attracts many recreational users that take advantage of snorkeling, surfing, and other beach activities. However, it suffers from coral reef degradation and water quality problems that are caused by land-based pollutants from the region’s four watersheds whose streams carry excessive amounts of pollutants into the bay.

1.1 Project Drivers

The Hanalei Bay Region is currently targeted by Federal, State, and private efforts for watershed planning efforts with the goals of reducing stressors to and improving the overall health of coral reefs, near shore waters, and watersheds. Land use in this area over the past century has resulted in export of land-based pollutants, which have impaired the water quality of near shore ocean waters and resulted in adverse impacts to the marine ecosystem. The most problematic land-based pollutants are sediment, nutrients, and microbial pathogens.[1] Detailed information on the occurrence and impacts of toxic chemicals in the Hanalei marine environment is currently lacking.

The Federal Clean Water Act (CWA) regulates surface waters of the United States and Section 303(d) requires all States to identify waterbodies that exceed certain water quality parameters. The Hanalei River and the streams in surrounding watersheds have been identified as “impaired” for various pollutants as not meeting state water quality standards. Total Maximum Daily Loads (TMDLs) were calculated for some of them in 2008 and the implementation of these loads are driven by Hawai‘i’s Polluted Runoff Control Program (Section 2.4.2).[2] In addition, Hanalei Bay was targeted by the Hawai‘i Coral Reef Strategy under the Land Based Pollution Local Action Strategy (LAS).[3] This Watershed Management Plan (WMP) builds off of some of those activities (i.e. monitoring, small-scale implementation).

1.2 Planning Process

1.2.1 Watershed Management Planning

This WMP supports the Hawai‘i Polluted Runoff Control Program’s efforts to protect and restore water quality and is in accordance with the U.S. Environmental Protection Agency’s (EPA) Nine Key Components for Watershed-Based Plans (Box C1). The watershed approach, which has been adopted and is supported by the EPA’s National Water Program, is a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically-defined geographic areas, taking into consideration both ground and surface water flow.[4] This WMP identifies measures to improve water quality and

[1] Unless otherwise stated, the use of the word sediment pertains to soil or rock particles that are transported in suspension in runoff water. Total sediment load includes both suspended sediments, and particles and rocks that are transported as bed load (bounced along and pushed).

[2] A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards (Section 2.4.2).

[3] http://hawaiicoralreefstrategy.com/index.php/local-action-strategies/land-based-sources-of-pollution

[4] Details can be found at http://water.epa.gov/resource_performance/planning/.

restore uses of these waters adversely affected by the pollutants. The management practices recommended in this plan will be eligible for Federal funding under CWA Section 319.

The *Watershed Characterization* summarizes the general watershed conditions with an emphasis on the sources, transmission, and fate of land based pollutants of four watersheds that drain into Hanalei Bay (Hanalei, Waiʻoli, Waipā, and Waikoko). A watershed is a unit of land that drains runoff to a common outlet. The characterization forms the basis for identifying management practices to remediate pollutants. Characterizing a watershed from ridge to reef (including lands *mauka* to *makai*) involves gathering and processing existing data and information to document existing watershed conditions. The characterization provides a mechanism to evaluate watershed processes and determine if land uses and activities are generating non-point source (NPS) pollutants, altering the hydrologic regime and ecological processes, and causing adverse impacts to the watershed's ecosystem.

A complete watershed characterization utilizes a multi-disciplinary scientific approach to collect information about the ecosystem processes, resource conditions, and historical changes due to cumulative effects of management practices. A series of concepts and categories, as presented in EPA's *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*, are used to document the watersheds of the Hanalei Bay Region: population and land use; physical and natural features; waterbody monitoring data; waterbody conditions; and pollutant sources (EPA 2008).[5] Gaps in data and knowledge bases are identified and suggestions included for additional information needs and future priorities.

1.2.2 Data Compilation

Analyzing existing data and information to characterize the watershed and pollutant sources provides the basis for developing effective management strategies to meet watershed goals (EPA 2008). Data collection was performed using a combination of information review of published and grey literature in digital and hard copy formats, GIS data from various sources, and on the ground inspections and assessments of existing conditions. The information is used to describe the watershed condition, the uses and activities that take place in the watersheds, and how these uses and activities may or may not impact the generation and transport of NPS pollutants from the land to streams, rivers, and ultimately Hanalei Bay.

1.2.3 GIS

When describing the physiographic characteristics of watersheds, GIS is a useful tool for analyzing and showing spatial relationships between various features of a watershed. GIS helps to graphically present spatial data to depict distances and discern relationships between various land uses and land cover types, possible pollutant sources and water quality measurements, among other things. Non-geographic data can be associated with GIS data to qualify and further explain these relationships and interactions. The resulting maps give a visual overview of watershed characteristics.

[5] See http://www.epa.gov/nps/watershed_handbook/

SRGII compiled a large geodatabase of GIS data for the project area. Data layers were obtained from various available public sites and project partners including National Oceanic and Atmospheric Administration (NOAA), Hawai'i Department of Business, Economic Development and Tourism (DBEDT), Hawai'i Department of Health (DOH), Kaua'i County, and Hanalei Watershed Hui (HWH). SRGII used the watershed boundaries defined in a data layer obtained from the DBEDT website. Other GIS layers and maps were then clipped to the project watersheds' area for further analysis. The high resolution satellite image was used as the visible background for analysis and figures depicting features on the watersheds. GIS was used to further analyze spatial relationships and create maps showing land uses, land cover, soils, landowners, water quality sampling areas and other relevant features of the project watersheds. This data was also used to compute areas/sizes of various features for the watershed characterization.

For all layers used, datum is North American Datum of 1983 and projection is Universal Transmercator Zone 4 North (NAD83 UTM4N). Unless specified all calculations are based on GIS data available from the State of Hawai'i GIS Data Repository, hosted by the Office of Planning.[6]

1.2.4 Field Work

Field work involved site visits to various locations in the four watersheds to become familiar with the locations where data and information had been collected previously by others.

1.2.5 Stakeholder Participation

Development of the Watershed Characterization (this document) involved meetings, interviews, field visits, and data exchange with project partners, stakeholders, scientists, and government agency personnel. The HWH was a key facilitator in identifying stakeholders and associated issues. Key findings will be presented to the community to provide a comprehensive picture of the pollutant sources in the project watersheds, confirm information, and solicit input for management practices to address pollution issues.

2. Watershed Planning: Setting the Context

The Hanalei Bay Watershed has been the subject of numerous water quality and watershed planning efforts. The watershed, stream, and bay's resources have been studied by a range of public and private entities including University of Hawai'i researchers, researchers from mainland universities, State and Federal agencies (e.g. DOH, Department of Land and Natural Resources (DLNR), EPA, NOAA, U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS), U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS)), and community organizations (e.g. HWH, Waipā Foundation). The types of scientific studies range from classification of vegetation communities, to use of genetic markers to identify sources of bacteria, to hydrodynamic modeling of the Bay's currents. Information regarding the current overall health of the Hanalei Bay Region, including watersheds, streams, and the bay, and their designated uses to be supported were acquired from several sources including water quality standards, the TMDL reports, and State water quality reports.

[6] http://www.state.hi.us/dbedt/gis/

2.1 Hanalei Watershed Hui

In 1998 the Hanalei community came together through the designation of the Hanalei River as an American Heritage River, and formed the Hanalei Heritage River Hui. A series of community meetings were held and the Hui developed a Watershed Action Plan for the Hanalei Watershed. The community was concerned that the waters of Hanalei River and Hanalei Bay were polluted and believed that something needed to be done to make the waters clean. They asked if the waters in the river and bay were fishable and swimmable. NPS pollution was identified as a primary problem. Presumptions were that high levels of turbidity came from eroding landscapes in the upper reaches of the watershed, streambank collapse, landslides, and agricultural runoff. Causes of high *enterococci* levels were presumed to be feral and domestic animals, and groundwater contamination from wastewater facilities. Causes of high nutrient levels were presumed to be wastewater facilities and agricultural fertilizers.

The Hui coordinated a series of actions to begin volunteer monitoring of the streams, river and bay. Federal partners were brought together as part of the American Heritage Rivers Initiative to assess pollution in these waters, its causes, and its effect on the stream, estuarine, and coral reef biological communities. NRCS undertook development of the Annualized Agricultural Non-Point Source Pollution (AnnAGNPS) computer model to quantify rates of erosion and sedimentation in the upper watershed.[7]

The Hanalei Heritage River Hui incorporated as the non-profit Hanalei Watershed Hui in 2003, with the mission to care for the *ahupuaʻa* of Hanalei, Waiʻoli, Waipā, and Waikoko guided by Hawaiian principles to *mālama ʻāina* and to promote sustainability and stewardship, integrity and balance, cooperation and aloha, cultural equity and mutual respect.[8] HWH was awarded and received funding under an EPA Targeted Watershed Initiative Grant (TWIG) in 2003. With this, and additional funding, the HWH partnered with Federal and university scientists in research and mitigation programs to address the pollution concerns of Hanalei residents in the bay and the surrounding rivers and streams. The grant, and collaboration with community partners including the County of Kauaʻi, Waipā Foundation, USFWS, Land Based Pollution LAS Steering Committee, and Hawaiʻi SeaGrant among others, allowed multiple action and study components to be carried out to address the water quality issues in Hanalei. Limitations were under-staffing, lack of funding, lack of time, problems prioritizing, lack of public interest, and adhering to timetables. Many lessons were learned from this TWIG and some of the proposed actions may still be options for the future. Activities that benefited from funding and/or collaborative efforts under the TWIG include:

- *Individual Wastewater Systems* (*IWS*): Assess cesspools, both public and private, and replace several private family cesspools. Work with County on replacement of three Beach Park cesspools as well as an IWS upgrade at Black Pot Park.
- *Wastewater Collection Strategic Planning*: Conduct community strategic planning and feasibility assessment for building a centralized wastewater treatment facility for the area (as of 2012, no suitable location has been identified).

[7] Information on AnnAGNPS can be found at http://go.usa.gov/KFO
[8] http://www.hanaleiwatershedhui.org/

- *Facilitate Installation of Checkgates*: Work with USFWS and taro farmers to get checkgates installed on ditches draining taro *lo'i* in order to retain soil being washed out of the pond fields. Several taro farmers put in their own checkgates and six were installed on the USFWS refuge at the lower end of the ditches.
- *Ungulate Fencing Demonstration Project*: Supply materials to the Waipā Foundation for a demonstration project that encloses cattle away from Waipā Stream.
- *Biological Resources Survey and Assessment*: Determine if non-native species in the watershed are causing degradation of surface water quality through comparison of non-native species distribution to areas of impaired water quality.
- *Water Quality Monitoring*: Conduct regular water quality monitoring for nutrients, Total Suspended Solids (TSS), Turbidity, *Enterococci* bacteria, pH, temperature and salinity. Provided baseline data used for the 2004 and 2006 303(d) lists.
- *Coral Reefs*: Support ongoing and facilitate new studies on coral reef health, including coral recruitment, benthic habitat and fish population.
- Various biological, ecological and water quality monitoring projects.
- Community meetings and outreach via demonstration projects.

2.2 Overview of Project Area

2.2.1 Geographic Scope

The Hanalei Bay Watershed is comprised of four subwatersheds that drain into Hanalei Bay and include, from east to west: Hanalei, Wai'oli, Waipā and Waikoko Watersheds (Figure 1).[9] The Hanalei Bay Watershed is located on the north shore of the Island of Kaua'i, Hawai'i, and is part of the Halele'a *moku* (district). The watershed drains approximately 32 mi^2 (83 km^2) and ranges in elevation from sea level along the coast to 5,147 ft (1,569 m). Hanalei Bay is lined with seven miles of shoreline, contains two fringing reefs, and has an open water body surface area of 16.8 mi^2 (2.6 km^2).

A fifth subwatershed, Waileia, not included in the HBWMP, is also located within the Hanalei Bay Watershed.[10] This 0.8 mi^2 (2.1 km^2) subwatershed drains a portion of the larger Princeville area and is part of the Hanalei *ahupua'a*. The Waileia Watershed was excluded since it was not included in past watershed management studies, plans, and efforts in the Hanalei Bay Watershed, including the 2008 TMDL. Most notably water quality sampling that has occurred in the four project area subwatersheds has not occurred in Waileia and the data and information needed to assess its condition is not available. It is recommended that water quality data be collected for Pu'u Poa Stream and the ocean waters fronting the watershed and a TMDL be developed for this watershed. Hawai'i DOH Clean Water Branch, the funding agency of this WMP, may consider funding a separate watershed planning effort for Waileia in the future.

2.2.2 Watershed Characteristics

The Hanalei Watershed is the largest of the four subwatersheds, making up approximately 73% of the Hanalei Bay drainage area [15,125 ac (6,121 ha)]. The Wai'oli Watershed is the second largest drainage area with nearly 3,483 ac (1,410 ha), followed by the 1,592 ac (644 ha) Waipā Watershed,

[9] Throughout this plan the term "Hanalei Bay Watershed" will be used to collectively refer to all four subwatersheds.
[10]

and the 458 ac (185 ha) Waikoko Watershed. The Hanalei River is one of Hawaiʻi's largest rivers in terms of length and flow volumes, and was designated as an American Heritage River in 1998. It drains into the Hanalei River Estuary, before terminating at Hanalei Bay, which is also fed by the Waiʻoli, Waipā, and Waikoko Stream estuaries.

Each of the four subwatersheds is drained by a network of surface water channels that combine to form a primary stream with the same name as the subwatershed. A portion of each subwatershed's stream water is diverted and used for irrigation of crops, watering animals, and waterbird habitat. A common physical feature of the subwatersheds is the presence of undeveloped, steeply sloped, forested headwater lands covered predominantly in non-native vegetation that transitions to moderately to gently sloping coastal plains. The coastal plain is used for agriculture, bird habitat, and residential and commercial uses.

The Hanalei Bay Watershed provides habitat for all five of the native goby (*ʻoʻopu*) fish species, and four federally listed rare and endangered native Hawaiian water birds. The estuary at the mouth of Hanalei River is a flourishing nursery for native fish and other species. Hanalei Bay is within the Hawaiian Islands Humpback Whale National Marine Sanctuary and its six distinct coral reef habitats are home to a variety of different fish species.

2.2.3 Issues of Concern

The subwatersheds are identified as State priority watersheds (i.e. Land-based Pollution LAS priority watersheds), where water quality and watershed planning activities have taken place.[11] The HWH has spearheaded local efforts to address water quality concerns by monitoring, developing, and implementing practices to reduce pollutants (Section 0). Ongoing water quality monitoring and assessment efforts identify TSS (sediments and plant detritus), bacteria, and nutrients as the pollutants of concern in the Hanalei Bay Watershed. Each of these occur both as part of natural watershed processes and in response to human uses and introduced animals.

These water quality issues have been identified for nearly two decades by community members, government agencies, and scientists as problematic to the health of the Hanalei Bay Watershed. Previous discussion has centered on decoupling how much pollution is naturally occurring versus the amount increased above natural due to human actions. As the body of knowledge pertaining to water quality and hydrologic process increases, both specifically for the Hanalei area and the larger Hawaiian Islands region, these relative contributions are becoming refined and better understood. These advances provide a foundation for better identifying sources of pollutants that are generated and transported off the subwatersheds in amounts greater than natural background levels, and for developing strategies to reduce them.

2.3 Regulatory Environment

Understanding the regulatory environment is essential for establishing a clear picture of water quality issues and ultimately solutions. There are numerous Federal, State and county agencies that have responsibility related to implementing activities related to controlling polluted runoff and maintaining water quality (Appendix C). Some of these entities have a role in promoting both

[11] http://www.hawaiicoralreefstrategy.com/index.php/local-action-strategies/land-based-sources-of-pollution

regulatory and voluntary approaches. Implementation of management measures is most effectively done through economic incentives or by regulatory drivers. Regulatory approaches work best when adequate mechanisms are in place to provide oversight and enforcement.

2.4 Meeting Water Quality Standards

2.4.1 Impaired Waterways

Under CWA Section 303(d), the EPA requires that each state develop a list of waters that fail to meet established water quality standards and are considered impaired. Water quality standards are composed of three elements: designated uses, numeric and narrative criteria, and anti-degradation policies and procedures. The existing Water Quality Management Plan for the State of Hawaiʻi (Hawaiʻi Administrative Rules (HAR) §11-54) defines State standards for particular parameters for Hawaiʻi waters by both narrative and numerical criteria (Appendix D.2).[12] Standards for inland fresh water systems follow the regulations listed in the Water Quality Management Plan that assesses for basic criteria of which elevated levels above numeric toxic pollutant standards would be cause for listing as an impaired waterbody. Intermittent and perennial streams as well as marine waters are considered for the following specific water quality criteria: basic criteria (narrative 'free of' and numeric standards for toxic pollutants; HAR §11-54-4), criteria for inland recreational waters (HAR §11-54-8.a), water column criteria for streams (HAR §11-54-5.2.b), bottom criteria for streams (HAR §11-54-5.2.b.2), specific criteria for estuaries (HAR §11-54-5.2.d.1) criteria for marine waters (HAR §11-54-6), criteria for marine recreational waters (HAR §11-54-8.b) and uses and specific criteria applicable to marine bottom types (HAR §11-54-7). Waterbodies in the Hanalei Bay Watershed have been included on the State's 303(d) list of impaired waters due to continuous exceedance of State water quality standards and impairment to their beneficial uses (Table 1; Figure 2).

Table 1. Waterbodies in the Integrated 303(d) List/305(b) Report[13]

Waterbody	Pollutants Impaired For (On 303(d) List)
Stream Waters	
Hanalei Stream	*Enterococcus*, Turbidity
Waipā Stream	Turbidity
Marine Waters	
Hanalei Bay: Landing (Pier)	*Enterococcus*, Turbidity
Hanalei Bay: Pavilion	Turbidity
Hanalei Bay: (Waiʻoli Beach)	Turbidity
Hanalei Bay: Mooring Station	*Enterococcus*
Hanalei Bay: Upstream of Dolphin	Turbidity
Hanalei River Estuary	*Enterococcus*, Turbidity
Waikoko Stream Estuary	Turbidity
Waiʻoli Stream Estuary	Turbidity
Waipā Stream Estuary	Turbidity

[12] See http://gen.doh.hawaii.gov/sites/har/AdmRules1/11-54.pdf.

[13] Impaired constituents per 2008/2010 State of Hawaii Water Quality Monitoring and Assessment Report: http://hawaii.gov/health/environmental/water/cleanwater/integrated/index.html

2.4.2 Total Maximum Daily Load

Total maximum daily loads or TMDLs are the amount of each impairing pollutant, as allocated on a daily basis, which can be delivered to a water body without impairing it. Load allocations for NPS pollutants are the product of the concentration of a pollutant times the volume of water. TMDLs have been calculated for NPS pollutants for the subwatershed streams and their estuaries as well as Hanalei Bay (Tetra Tech and DOH 2008; 2011).[14] TMDLs are quantitative limits calculated for the limiting pollutants in each water body, based on their respective capacity to assimilate pollutant loadings.[15] Management practices identified as part of the TMDL process, which are also part of a WMP or comprehensive implementation strategy that meets EPA's nine elements (Box C1), are eligible for Federal funding through CWA Section 319(h), administered by DOH.

DOH proposed establishing eight TMDLs for streams and estuaries in the Hanalei Bay Watershed. Phase 1 TMDLs (streams and estuaries) were established for turbidity for six waterbodies in the Hanalei Bay Watershed (Hanalei Stream, Hanalei Estuary, Waiʻoli Estuary, Waipā Stream, Waipā Estuary, and Waikoko Estuary); and for *Enterococcus* in Hanalei Stream and Hanalei Estuary (Tetra Tech and DOH 2008). Phase 2 TMDLs were established for the Hanalei embayment (marine waters) (Tetra Tech and DOH 2011). The water quality limited segments addressed in the Phase 1 and Phase 2 TMDLs are shown in Table 2.

Table 2. Water Quality Limited Segments Addressed in Phase 1 and Phase 2 TMDLs

Waterbody	Pollutants Impaired For	Standard
Phase 1		
Waipā Stream – Entire Network	Turbidity	Dry season
Hanalei Stream – Entire Network	Turbidity *Enterococcus*	Dry season
Hanalei Bay Estuary (Upstream of Dolphin Restaurant)	Turbidity	Year round
Hanalei River Estuary	Turbidity *Enterococcus*	Year round
Waikoko Estuary	Turbidity	Year round
Waiʻoli Stream Estuary	Turbidity	Year round
Waipā Stream Estuary	Turbidity	Year round
Phase 2		
Hanalei Bay: Landing (Pier)	Turbidity *Enterococcus*	Wet season
Hanalei Bay: Pavilion	Turbidity *Enterococcus*	Wet season
Hanalei Bay: Mooring Station	*Enterococcus*	Wet season
Hanalei Bay: Waiʻoli Beach	Turbidity	Wet season

[14] TMDL waste load allocations have not been calculated for point sources since there are none in the Hanalei Bay Watershed as defined under CWA statutory definitions.

[15] For example, limiting nutrient refers to the substance that controls or regulates plants growth. When its natural limits are exceeded, accelerated plant growth can occur (e.g. algal blooms).

TMDL load allocations will be implemented through *Hawai'i's Implementation Plan for Polluted Runoff Control* (DOH), *Hawai'i's Coastal Nonpoint Pollution Control Program Management Plan* (DBEDT), and the *Clean Water State Revolving Fund Intended Use Plan* (DOH), all of which serve the State Water Quality Standards (HAR §11-54) (Appendix D.2).

A TMDL implementation matrix and timeline is provided in the Phase 1 TMDL suggesting a phased approach in prioritizing and mobilizing implementation activities. The implementation timeline requests and recognizes the need for development of a WMP, including implementation priorities. Previous and ongoing efforts by local residents (e.g. taro *lo'i* restoration), groups (e.g. HWH), public entities (e.g. USGS), and landowners (e.g. Kamehameha Schools) have provided valuable experience in management practices and data collections to be utilized during the phased implementation approach. However, prior to this document, a WMP that addresses the EPA requirements for watershed plans has not been developed. This WMP assimilates existing information, including planning, data collection, monitoring efforts, watershed condition, and information on the primary pollutants, to develop a WMP that meets EPA guidelines. This plan provides guidance and prioritization for implementation efforts targeted at improving water quality. This WMP will help facilitate a coordinated and targeted effort to fund and implement pollution control strategies, including securing funding for implementation under CWA Section 319(h).

3. Population and Land Use Characteristics

Describing past, present, and future population and land use characteristics assists in identifying and quantifying the types and amounts of land-based pollutants from the region that enter the off-shore waters.

3.1 Anthropogenic Impacts

The first humans to settle the Hawaiian Islands, including the Hanalei Bay Region, engaged in fishing, gathering, and subsistence agriculture. Initial anthropogenic impacts to the region likely resulted from these Polynesian settlers who diverted a portion of water out of the streams and into taro and fish *lo'i*. Extraction of resources, including plants and animals, likely occurred from the upland forests, low-lying coastal areas, and the ocean. Archaeological evidence shows that Hawaiians began cultivating taro by the 13^{th} century in Hanalei Valley and on the slopes of the valley floor. Some unconfirmed research suggests a much earlier onset of taro cultivation, during the 7^{th} century. An extensive irrigation system was developed in the valley to irrigate taro. A second wave of human contact to the islands began in the 1800s by peoples of European and Asian ancestry. These groups brought animals, plants, and resource extraction techniques that significantly altered vegetation communities in the coastal zones and inland forests. They also brought diseases to the Hawaiian Islands that resulted in at least nine plagues that caused the death of many thousands of Polynesians (K. Maly, pers. comm.). Various attempts at growing crops such as mulberry trees (for silk production), oranges, coffee, tobacco, sugarcane and cattle, failed during this time due to the rainy conditions. With the influx of immigrants from China and Japan to work in agriculture, there was a high demand for rice, which is easier to grow in the conditions present in Hanalei (although the wet conditions only allowed for one crop per year). Thus, in the 1860s, the rice era began and many of the historic buildings in Hanalei today are reminders of that period. The

Haraguchi Rice Mill, originally built in 1930, is still standing and is Hawaiʻi's only surviving rice mill from this era. During the peak of the rice era in 1930, over 2,000 acres (809 ha) were under rice cultivation. However, a decline in rice production occurred in the 1930s due to heavy competition from California rice growers. The rice industry collapsed in 1960. The farmers who had been growing rice then started growing vegetables and taro.

The Hanalei Bay Region has retained its rural character through the present day. While the number of permanent residents in the four watersheds is relatively low, the Hanalei Bay Watershed, and the north shore of Kauaʻi in general, is frequented by tourists year round, peaking in the summer. Most of these visitors come by private vehicle. Tourists utilize the region's public services, including government and privately owned restrooms, which increases the daily volume of solid and sanitary waste.

3.2 Socio-Economics

The most recent census determined that in 2010 the total permanent resident population of Hanalei CDP was 450 people, which is nearly 6% less than it was in 2000. The total population of Kauaʻi was 67,091, which is an increase of 14.8% over the 2000 census. The median household income for Hanalei in 2010 was $48,085 and $64,147 for the State as a whole. The per capita income for Hanalei in 2010 was $28,657, and $27,880 for the State as a whole.

The visitor industry provides about 40% of all private sector jobs in Kauaʻi County (County of Kauaʻi 2000). The Hawaiʻi Tourism Authority reports that there were 1,042,633 visitor arrivals to the island of Kauaʻi in 2010, with each visitor spending an average of $148 per day. Tourism accounted for over $1 billion spent on Kauaʻi in 2010. The majority of visitors travel to Kauaʻi for pleasure and over 69% are repeat visitors.

The Hanalei area is popular for both its taro and for the beautiful beaches and parks. Although the Hanalei Valley produces 71% of Hawaiʻi's taro, the main source of income for the local government and residents is tourism (HWH 2012, County of Kauaʻi 2000). Hanalei has beautiful beaches, reefs for snorkeling and diving, and mountainous scenery. "A report prepared for the Hawaiʻi Tourism Authority states: Kauaʻi's extraordinary resources and the ability of visitors to participate in resource based activities, are considered the prime reasons for Kauaʻi's success as a resort destination" (County of Kauaʻi 2000). At least 30% of the housing in Hanalei is open for seasonal recreational or occasional use (145 out of 336 total housing units). Although some people stay in the tourist facilities available in the Hanalei area, many tourists staying at other parts of the island travel to the north shore to enjoy these scenic amenities.

One popular tourist activity, commercial boat trips from Hanalei to the Nā Pali Coast, has caused controversy since the mid 1980's when the number of permits issued for conducting operations swelled to 47. During its lucrative years, commercial boating brought an estimated $7.5 million a year of income to the Hanalei area and provided employment for around 200 people. Throughout the late 1980's and early 1990's the debate over environmental impacts to the Hanalei River, Hanalei Bay and the nearby Nā Pali Coast, as well as other concerns, caused the Kauaʻi Planning Commission to limit the number of commercial tour boats operating out of Hanalei. In the late 1990's DLNR became more involved in the dispute and all boats without county permits were moved out of Hanalei by 1998. In August of 2011 an amendment to HAR Chapter 13 to regulate commercial boating activities in Hanalei was adopted. Most of the commercial tours to the Nā Pali coast are now run out of Nāwiliwili and Port Allen, although a few still run out of Hanalei Bay.

3.3 Land Ownership and Use

Land use can be characterized by State-designated Land Use Districts and within each district by land owners and/or managers (Figure 3). Additional land use guidance is provided at the county level by the *Kauaʻi General Plan* (Appendix C.5.4.1) and supporting ordinances including the County Zoning Ordinance (CZO) and the North Shore Development Plan Ordinance (NSDPO) (Figure 4; Appendix C.5.4). Future land use is described in order to understand how changes across the landscape might affect land-based pollutants and ultimately to help target solutions to limit their generation and transport.

There are a total of 588 Tax Map Keys (TMK) assigned to parcels within the Hanalei Bay Watershed, including 350 Residentially-zoned lots. Using TMK records, 272 actual single family homes are estimated on the residential lots. Within the larger Hanalei town area there are numerous single family lots that are used as vacation rentals and bed and breakfasts. Depending on occupancy, the transient population of the watershed varies over time as does water use and disposal into wastewater system. It is unknown what percentage of people in the watershed at various times of the year are visitors versus residents. Table 3 depicts the number of parcels within the Hanalei Bay Watershed grouped by Pitt Code.[16]

Table 3. Parcel Characterization

Pitt Code	Parcel Attributes	Number of Parcels	Percent of Total Parcels	Average Parcel Size (acres)	Number of Parcels with Buildings
100's	Single Family Residence	350	59.5	0.47	270
200's	Apartment	2	0.3	0.19	2
300's	Commercial	19	3.2	1.27	17
400's	Industrial	1	0.2	1.07	1
500's	Agricultural	131	22.3	2.83	35
600's	Conservation	38	6.5	431.82	5
700's	Hotel and Resort	2	0.3	7.00	0
800's	Homestead	0	0.0	0.00	0
999	Multiple Pitt	27	4.6	131.34	4
0	Undefined	18	3.1	4.59	0
Total		**588**	**100**		**100%**

Single family residences range in size from 0.004 to 4.24 acres. Although they represent less than 1% of the total land area, there are a large number of single family residences located within close proximity to the shoreline and other surface water bodies. Agricultural parcels range in size from 0.0085 to 117.78 acres. While there are a large number (131) of agricultural parcels, 12 of them are greater than five acres and account for 85 percent of all the agricultural lands.

3.3.1 Land Use Districts

All lands in Hawaiʻi fall within one of four State Land Use Districts as defined by the Hawaiʻi Land Use Law, Chapter 205 Hawaiʻi Revised Statutes (HRS). Land within the Hanalei Bay Watershed falls

[16] Pitt Codes are used state-wide to identify the Real Property Assessment Tax Class (tax rate applied to the property).

into three district types classified by the State Land Use Commission: Conservation, Agricultural, and Urban (Table 4, Figure 3).

Table 4. Land Use Districts [17]

Watershed	Conservation (acres)	Agricultural (acres)	Urban (acres)	Total (acres)
Hanalei	13,714	1,180	231	**15,125**
Waiʻoli	3,191	218	74	**3,483**
Waipā	1,450	141	1	**1,592**
Waikoko	64	394	0	**458**
Total	**18,419**	**1,933**	**306**	**20,658**
Percent	89%	9%	1%	100%

3.3.1.1 Conservation District

Lands in the Conservation District are administered by DLNR's Office of Conservation and Coastal Lands. Conservation lands are further subdivided into sub-zones that are arranged in a hierarchy based on environmental sensitivity ranging from the most environmentally sensitive to the least sensitive (protective, limited, resource, general, or special). Conservation District lands are comprised primarily of lands in existing forest and water reserve zones and include areas necessary for protecting watersheds and water sources, scenic and historic areas, park, wilderness, open space, recreational areas, and habitats of endemic plants, fish and wildlife. Conservation lands within the Hanalei Bay Watershed fall into the general, resource, limited, and protective subzones (Table 5; Figure 3; Appendix C.5.3). In general, the Conservation District includes the Open District under the County land use classification. The Open District provides for an adequate and functional amount of open land for recreational and aesthetic needs of the community, and for effective functioning of land, air, water, plant and animal systems or communities.

Lands designated Conservation District make up the majority of the watershed area, and above approximately 330 ft (100 m) msl elevation are classified as either protective or resource. The protective classification covers the upper elevations of Waiʻoli and Waipā Watersheds, and the western portion of Hanalei Watershed's upper elevations. There are two small coastal parcels along Hanalei Bay in the Waikoko Watershed that are classified general and limited.

Table 5. Conservation District Subzones [18]

Watershed	General (acres)	Resource (acres)	Limited (acres)	Protective (acres)	Total (acres)
Hanalei	0	8,501	0	5,213	**13,714**
Waiʻoli	0	1,017	0	2,174	**3,191**
Waipā	0	745	0	705	**1,450**
Waikoko	20	37	7	0	**64**
Total	**20**	**10,300**	**7**	**8,092**	**18,419**

[17] As classified by the State Land Use Commission. Data derived from the Office of Planning, State of Hawaiʻi DBEDT GIS Program, 'State Land Use Districts'.

[18] As classified by the State Land Use Commission. Data derived from the Office of Planning, State of Hawaiʻi DBEDT GIS Program, 'Conservation District Subzones'.

3.3.1.2 Agricultural District

The Agricultural District extends across the *makai* regions of the watersheds, mostly separating the ocean and Urban lands from the Conservation District. Elevation ranges from sea level to 525 ft (160 m) msl, with a majority of the area in the low-lying coastal plain at elevations less than 80 ft (24 m) msl (Figure 3). Jurisdiction over the Agricultural District is shared by the State Land Use Commission and counties. The Agricultural District protects land use needs for existing and potential agriculture, while providing for different levels of involvement through various parcel sizes. The CZO details allowable subdivisions and dwelling units for agriculture parcels. The NSDPO makes amendments to the CZO for the purpose of protecting and perpetuating agriculture uses within the region, establishing more restrictive dwelling limits and subdivision lot sizes (Appendix C.5.4.4).

3.3.1.3 Urban District

Urban District lands are found in Hanalei and Waiʻoli Watersheds, mainly fronting Hanalei Bay, and comprise only two percent of the watershed area (Figure 3). The majority of the Urban District has elevations less than 66 ft (20 m) msl. Counties have responsibility for zoning within the Urban District.[19] The CZO details allowable land uses in the districts (Appendix C.5.4.5). For the Residential District, it regulates the number of people living in a given area by specifying the allowable number of dwelling units that may be developed on a parcel. Commercial Districts are located in relation to land suitability and patterns of use such as residential areas, and transportation and community facilities. The NSDPO limits the locating of certain types of residential homes within residential sub-districts and allows residential and commercial activities to occur within the same structure.

3.3.2 Major Land Owners, Managers and Uses

Land ownership across the subwatersheds includes Federal, State, and County governments, and private individual owners and corporations (Figure 4). A few of the larger private land owners include Kamehameha Schools; Princeville Operating Company, LLC; the Wilcox family; and Waiʻoli Corporation (Table 6; Figure 5 - Figure 8). State and Federal governments are the largest land owners in the Hanalei and Waiʻoli Watersheds. Kamehameha Schools owns a majority of Waipā Watershed. State lands extending from the middle zone of the these watersheds up to the watershed divides classified as Conservation is the largest and accounts for nearly 70 percent of the total of government-owned land. Small parcels of Conservation land in the upper part of Waiʻoli Watershed and Hanalei Watershed are owned by Kamehameha Schools and Alexander and Baldwin (respectively).

The Federal government owns and manages the Hanalei National Wildlife Refuge (NWR), a 917 acre (371 ha) parcel in the Hanalei Watershed. The refuge was established in 1972 as a nesting and feeding habitat for endangered Hawaiian water birds (i.e. Hawaiian duck (*Koloa maoli*), Hawaiian coot (*ʻAlae keʻokeʻo*), Hawaiian moorhen (*ʻAlae ʻula*), Hawaiian stilt (*Aeʻo*), and Hawaiian goose (*Nēnē*)). A partnership arrangement allows local taro farmers with historical ties to the land to preserve their culture by growing taro in the refuge. This is done via special permits that contain

[19] Specific information on County-level districts is too detailed to include in this plan. The information is available from the Kauaʻi County Planning Department.

terms for protection of the water birds. The taro *loʻi* provide additional habitat as well as a traditional food source for the birds. The refuge contains 60 acres (24 ha) of intensively managed wetlands, 141 acres (57 ha) of taro *loʻi*, and 24 acres (10 ha) of dikes and ditches for the recovery of the endangered Hawaiian waterbirds and wintering habitat for migratory waterfowl and shorebirds. To ensure adequate protection, most of the refuge is closed to the public, but it can be viewed from the Hanalei Valley Overlook.

Table 6. Large Land Owners[20]

Land Owner	Hanalei Watershed	Waiʻoli Watershed	Waipā Watershed	Waikoko Watershed	Total (acres)
State of Hawaiʻi	12,522	3,029	43	0	15,594
Kamehameha Schools	16	158	1,525	39	1,738
US Government	937	0	0	0	937
Princeville Development	719	0	0	0	719
Waikoko Land Corp	0	0	0	420	420
Mowry	230	0	0	0	230
Kobayashi	0	146	0	0	146
Wilcox Family	43	0	0	0	43
Alexander & Baldwin	38	0	0	0	38
Waiʻoli Corporation	7	26	2	0	35
Ben Dor	21	0	0	0	21
Ohana Hanalei,LLC	20	0	0	0	20
Kauikeolani, LLC	19	0	0	0	19
County of Kauaʻi	5	0	0	0	5

Land use in the Hanalei Bay Watershed includes agriculture, wildlife habitat, urban, and tourism that are dependent upon the watershed's natural resources (Table 7). Ranching (cattle and/or buffalo) is conducted on the Princeville Ranch and Mowry properties. Numerous wetlands and taro *loʻi* located adjacent to the lower reaches of the Hanalei River provide important habitat for year round native, endemic, and migratory waterbirds and area for taro cultivation (Table 8). Seventy-nine percent of taro grown in the State is harvested from the taro *loʻi* in the area.

The Hanalei River is actively used for cultural, recreational, and regulated commercial activities including subsistence fishing and gathering, paddling and swimming. Currently, signs posted along the Hanalei River by DOH warn people not to swim due to water pollution issues. Hanalei Bay is a significant recreational and commercial use area for both *kamaʻāina* and visitors. Ocean recreation activities occurring at the beach parks and in Hanalei Bay includes a variety of water sports such as wave riding, swimming, boating, paddling (outrigger canoes), kayaking, windsurfing, kiteboarding, and diving. The bay is also a popular place to anchor boats during the summer months when wave energy is at annual minimums.

[20] Data derived from the Office of Planning, State of Hawaiʻi DBEDT GIS Program, 'Major Landowners'. All area in acres.

Table 7. Land Use / Land Cover[21]

Watershed	Area (acres)	Urbanized		Agricultural		Forested		Other	
		acres	%	acres	%	acres	%	acres	%
Hanalei	15,125	335	2%	712	5%	10,338	68%	3,740	25%
Wai‘oli	3,483	65	2%	66	2%	2,161	62%	1,191	34%
Waipā	1,592	7	0.5%	35	2%	1,088	68.5%	462	29%
Waikoko	458	22	5%	56	12%	242	53%	138	30%
Total	**20,658**	**2%**		**4%**		**67%**		**27%**	

Table 8. Taro *Lo‘i*

Watershed	Taro *Lo‘i* (acres)	Notes[22]
Hanalei	205	141 ac: Hanalei NWR 64 ac: various owners[23]
Wai‘oli	37	
Waipā	8	[24]
Waikoko	49	One land owner
Total	**299**	

3.3.3 Future Land Use

Little information is available on specific plans for future land use in the Hanalei Bay Watershed. No specific development plans for the project area were found. Future land use is guided by the *Kaua‘i General Plan* (County of Kaua‘i 2000), which puts forth a framework for future land use that includes "preserving Kauai's rural character"; maintaining and preserving historic structures such as the Hanalei one lane bridge; and ensuring that policies relating to land, waters, and culture are in place "for managing human activities to maintain the quality of the environment - particularly the quality of Kauai's waters and watersheds". The General Plan provides guidance for land use regulations, the location and character of new developments and facilities and planning for County and State facilities and services (Appendix C.5.4.1). One of the components of the vision for Kaua‘i 2020 included in the General Plan is "a community which cares for its land and waters, leading the way with best management practices in the development of roads and other public facilities and in its land development and environmental regulations". The *North Shore Development Plan* is an addendum to the General Plan for the larger north shore region. It establishes development plans, zoning maps and design criteria to guide and regulate future development and protect physical and social characteristics that are found to be of particular public value (Appendix C.5.4.3).

Due to the topography and presence of wetlands and other surface water bodies that place physical limitations on the buildable areas in the watersheds, the amount of land for moderate to large scale

[21] Source: C-CAP (2001). Land covers were grouped as follows: Urbanized (Medium Intensity Developed, Low Intensity Developed, Open Space Developed); Agricultural (Cultivated, Pasture/Hay); Forested (Evergreen Forest, Palustrine Forested Wetland); Other (Unclassified, Grassland, Scrub/Shrub, Palustrine Scrub/Shrub Wetland, Palustrine Emergent Wetland, Barren Land, Open Water).

[22] Source: Except where noted, owners derived using GIS and 2010 satellite image.

[23] Source: USFWS for Hanalei NWR *lo‘i.*

[24] Source: Waipā Foundation.

developments within the Urban District is limited. Most future building will likely involve restoring or rebuilding on existing built-out lots. The one potential exception is the proposed 64 acre (26 ha) Hanalei Plantation Resort. Nine acres are located in the Hanalei Watershed along the east side of the Hanalei River above Black Pot, and the balance is located in Waileia Watershed. The nine acre parcel is classified as "Hotel and Resort" under Kauai County zoning.

Building Collaboration: Toward Co-management for the Hanalei Ahupuaʻa, Kauaʻi, Hawaiʻi contains a detailed discussion of three issues related to future land use in the Hanalei Bay Watershed: construction of a wastewater disposal facility; perpetuation of taro farming; and coordination of tourism practices with environmental considerations (Dong et al. 2002). Along with a description of the issues, the document contains suggestions for future management of the *ahupuaʻa* in a manner that is collaborative and mutually beneficial for all stakeholders.

4. Physical and Natural Features

4.1 Watershed Boundaries

A watershed is a geographical area that shares a common location where surface water runoff concentrates or is drained to (e.g. the mouth of a stream). Watershed boundaries are formed by topographic divides and within any size watershed, smaller subwatersheds can be delineated within the larger boundary (Figure 9 - Figure 12). Manmade drainage features such as ditches, pipes, and other structures can convey runoff across natural topographic watershed boundaries and artificially increase or decrease the watershed area (Figure 13). In the Waiʻoli Watershed a portion of the water diverted from its stream for irrigating taro *loʻi* is returned in the Hanalei Watershed. The watershed divide in the lower coastal zone of the Waipā and Waiʻoli Watersheds is subtle, and the topographical boundary is hard to discern.

Table 9. Watershed Characteristics

Watershed	Area (acres)	Maximum Elevation (ft)	Percent of Total Area
Hanalei	15,125	5,148	73%
Waiʻoli	3,483	4,409	17%
Waipā	1,592	3,675	8%
Waikoko	458	751	2%
Total	**20,658**		**100%**

4.2 Hanalei Bay

Hanalei Bay is a marine embayment covering approximately 4.5 mi^2 (11.6 km^2) of ocean water along the north shore of Kauaʻi (Figure 14). The crescent shaped bay is approximately 1.25 miles (2 km) wide between the two headlands, and has two fringing reefs and six distinct reef habitats that support a high diversity of fish species (Friedlander and Parish 1998). The well-developed fringing reef extends 500-1,000 ft (152-304 m) offshore along the generally rocky headland coast of Princeville east to Kapukaʻamoi Point. The Bay is a Federally protected marine sanctuary for the humpback whale, and is heavily used for ocean recreation.

4.3 Topography

The topography of the watersheds in the Hanalei Bay Region is typical of many Hawaiian watersheds. Deep valleys have been cut by running water that destabilize the slopes by tearing away rock fragments, including local collapses, and debris remains in talus slopes or is carried downstream by floods (Lau and Mink 2006) (Figure 15). The sides of the river valleys have near vertical *pali* (cliffs) with crests that lead up to ridge lines dividing the numerous subwatersheds. At their base, these steep *pali* transition into more moderately sloped valley walls with toes located in the valley bottoms. The Hanalei Bay watersheds, and their steep and rugged topography, are testimony to the erosive power of water that has shaped the landscape. Each of four watersheds, from the shoreline to the *mauka* direction, contains a broad coastal plain with elevations from sea level at the shoreline up to 40 ft msl (12 m). The width of the coastal plain varies across the four watersheds, with Hanalei being the largest. The lower portions of the main-stem rivers and streams of the watersheds contain floodplains that are part of the coastal plain and provide topography conducive to taro cultivation. Most of the “developed” portions of the watersheds and the residents occupy the lands of the coastal plains and beach zones.

The average slope of all surfaces in each of the four watersheds was computed using GIS. The average slope for Hanalei, Waiʻoli, and Waipā Watersheds is approximately 26 degrees, while Waikoko is 17 degrees. The range was the same for all watersheds, with maximum slopes of nearly 90 degrees (vertical), and minimums of less than a degree in the coastal plains near the ocean.

Topographical breaks such as a ridge form a dividing line between adjacent watersheds, and in most areas the divides between the watersheds, are identifiable on maps and on the ground. The exception is the watershed divide between Waipā and Waikoko Watersheds. Near level ground conditions along their border from the shoreline at the Bay inland for approximately 1,000 feet make identification and delineation of the watershed divide difficult. From a geological perspective these two watersheds are merging and will eventually be one.

4.4 Geomorphology

Geomorphology is a sub-discipline of geology that discusses the processes that shape the earth surface. Fluvial geomorphology refers to the topography shaped by water. The morphology or shape of a stream channel is a function of the geological stratum it is in contact with, slope, hydrology (rainfall, flow volume, and their frequency), as well as landscape features (groundcover, slope angles, and soil types) that control overland flow and runoff to the channel. In general, steeply sloped channels are more entrenched than low slope channels.[25] Channels with steep profiles usually have sufficient energy to transport fine materials through their reaches, and as a result the rock particles along their bed and banks are usually coarse gravel size or larger.[26] As rivers level out or become less steep, materials they transport begin to fall out, creating “bars” within the active channel and “terraces” on adjacent land when they over top their banks at high flows. In many river

[25] Entrenchment is the ratio of a channel’s width to depth measured horizontally from the top of the left bank to the top of the right bank and vertically from this line to the bed of the channel at its deepest point. Entrenchment is used by fluvial geomorphologists as one variable to classify the subject stream into a stream type. Entrenchment can also refer to the width to depth of a valley, and would be called valley entrenchment.

[26] Coarse gravel consists of particles with a median diameter of 2.5 inches.

systems the steep sections are generally net transporters of sediments generated from stream bank erosion and delivered into their channels, while the less steep sections where deposition occurs have a net accumulation. The rivers draining into Hanalei Bay show evidence of this scenario, and it is apparent to farmers who, after large floods, have to dig out from deposits of silt and mud left in *loʻi*, pastures, and other areas.

During periods of high rainfall, and corresponding large discharges in the rivers, it is expected that sediment generated from the upper areas of the watersheds will be carried downstream, and a portion out into the ocean. Sediments will also be deposited along the floodplains. These sediments have created the fertile areas, which in part make farming a viable use of the floodplains.

During dry periods, when sediment input from the watersheds is minimal and stream energy is low, there are naturally very low sediment loads being carried by the rivers. During these periods, inputs of fine sediments and other matter from human sources can have a disrupting effect on the "dry" period water quality. The fine materials can remain in suspension for a long time, and often make it to estuary reaches or the ocean.

4.5 Soils

The Hanalei Bay Watershed soil composition "consist of alluvial, non-calcareous flatland soils in the lowlands and along valley streams and considered to be most important for agriculture; coral sandy soil, mixed with calcareous marine organism fragments, concentrated in the ocean front; a small batch of latosols, which sits at the intersections of Hanalei, Waipā, and Waiʻoli; vegesols and lithosols, not usually effective for maintaining traditional agriculture, were concentrated *mauka* of Hanalei *ahupuaʻa*, where wild species and vegetation grew" (Earle 1978).

Table E1 and Figure 16 illustrate the soil series in the Hanalei Bay Watershed as classified by the NRCS.[27] These series come from seven major soil orders in addition to rock (Table 10; Appendix E).

Table 10. Soil Orders

Order	Acres	% (inc. rock)	% (exc. rock)
Alfisols	100	0.49	1.21
Andisols	116	0.57	1.40
Histosols	73	0.36	0.88
Inceptisols	5,951	29.11	71.75
Mollisols	843	4.12	10.16
Oxisols	1,096	5.36	13.21
Spodosols	115	0.56	1.39
Rock	12,149	59.43	--
Total	**20,443**	**100%**	**100%**

Silty clay soils, including the Hanalei, Hihimanu, and Hulua series of the Inceptisols order, are predominant throughout the watersheds. Clay soils contain very small void spaces, which act to retain moisture for long periods using capillary action and chemical bonds. These small voids are

[27] Detailed information on the soil series can be found at http://soils.usda.gov/technical/classification/scfile/index.html.

prone to compaction and reduction of pore volume from mechanical actions that exert shear stress on the soil horizons, resulting in reduction of infiltration rates and water holding capacities. The susceptibility of these soils to compaction can often lead to erosion problems by reducing infiltration and creating concentrated surface runoff and flow along the compacted surface.

Clay soils are generally resistant to detachment due to the chemical bond between particles. However because of their planar shape and small size, once detached they are readily transported via wind and water and can remain in suspension in water for long periods. The particles that comprise clay soils are referred to as colloids, and they present a difficult challenge to control once they are detached and become suspended in surface water runoff. These particles can remain in suspension for long periods of time and/or become re-suspended under low turbulent conditions such as when small waves break along the shoreline.

4.6 Land Cover

Land cover is the description of the physical material, including natural and manmade, on or above the earth surface, e.g. trees or parking lots. Land cover is broadly delineated as either pervious or impervious surfaces.[28] Pervious surfaces are present within all three Districts of the two watersheds, with examples including forested zones, fallow and active agricultural lands, and rural landscaped areas. Examples of impervious surfaces within the watersheds include naturally occurring sections of exposed rock, paved and concrete surfaces, buildings, and other man made features (Figure 17; Box D2).

Land cover in the Hanalei Bay Watershed has been mapped (Figure 18). Land cover in the Conservation District consists largely of evergreen forest and scrub/shrub, with small patches of grassland, palustrine wetlands, and bare land scattered throughout. The Conservation District in the Hanalei Watershed also contains some low intensity developed areas, mainly along the river and along the eastern edge. There are three types of palustrine wetlands: forested, scrub/shrub, and emergent. Land cover in the Agricultural District consists of a mixture cultivated land (predominantly taro *loʻi*), pasture land, evergreen forest, scrub/shrub, palustrine wetlands, grassland, with some pockets of low intensity developed land. Land cover in the Urban District is mainly low intensity developed and open space developed with some pockets of medium intensity developed, evergreen forest and grassland.

4.7 Climate

4.7.1 Precipitation

Ancient Hawaiians distinguished the annual precipitation cycle into two 6-month seasons: *kau* (May to October) and *hoʻoilo* (November to April) (Lau and Mink 2006), which is the same distinction currently used by DOH. The climate of the Hawaiian Islands is controlled in large part by the presence of the Pacific Subtropical Anticyclone, a high-pressure ridge located north and east of the islands. The Pacific Subtropical Anticyclone generates winds that blow from its base and travel from a northeasterly direction toward the island chain. These winds are referred to as 'trade winds'. During the summer season, when trade winds are most persistent, areas of maximum

---

[28] Pervious surfaces allow rainwater to pass through them and soak into the ground. Impervious surfaces prevent rainfall from infiltrating into the ground.

rainfall are generally located on windward slopes where orographic effects are most pronounced (Chu and Chen 2005).[29] During the winter season, the trade winds are often interrupted by mid-latitude frontal systems, upper-level troughs, and cutoff lows in the upper-level subtropical westerlies, locally known as *Kona* storms (Chu and Chen 2005). These three mechanisms generate widespread rainfall and are major sources of winter season rainfall.

Kaua'i is subject to a complicated but distinct diurnal trade wind regime that influences rainfall spatial and temporal patterns across the island (Chen and Nash 1994). The mean annual rainfall for the island indicates that maximum rainfall occurs at elevations ranging from 2,000–5,000 ft (610–1,524 m)along the windward slopes (Giambelluca et al. 1986). High rainfall in these windward regions is caused by thermally forced diurnal circulations, including land–sea breezes and mountain–valley winds, which enhance orographic uplifting of the trade winds and induce low-level convergence (Chen and Nash 1994). A trade wind inversion occurring around 6,500 ft (1,981 m) (Giambelluca et al. 2011), acts as a lid to vertical motion and convection, and a much drier climate prevails at higher elevations. During the winter season, southeasterly winds associated with large scale systems can bring heavy rainfall to both the leeward and windward side of the island.

Rainfall in Hawai'i is characterized by steep spatial gradients (Figure 19) (Giambelluca et al. 1986). Average annual rainfall at Hanalei is 74 inches, but increases dramatically to the south (*mauka*) where more than 220 inches (5,588 mm) occurs at an elevation of 2,500-3,500 ft (Giambelluca et al. 2011). The change in mean annual rainfall of 318 in (8,077 mm) from the shoreline near Hanalei to the summit of Mt. Wai'ale'ale results in a rainfall gradient of 35 in/mile, one of the steepest gradients reported worldwide. The daily rainfall temporal pattern around Hanalei is generally characterized by daily maximum rainfall occurring between 0400-0900 hours, particularly during the summer season, which is consistent with the diurnal wind pattern (Roy and Balling 2004). Approximate mean rainfall from the mouth and crest of each of the Hanalei Bay Watersheds is presented in Table 11 (Giambelluca et al. 2011). Sustained rains and/or flash flooding in the precipitous interior often generate flooding in the coastal zone.

Table 11. Mean Rainfall

Watershed	Mouth		Crest	
	in	mm	in	mm
Waikoko	86	2,186	110	2,796
Waipā	86	2,190	140	3,568
Wai'oli	86	2,198	195	4,974
Hanalei	75	1,928	393	9,989

4.7.2 Temperature

Temperatures in the Hanalei Bay Watershed at sea level are mild and generally range from a daily mean minimum of 65-70° Fahrenheit (F) (18.3-21.1 °C) to a maximum of 80-85° F (26.7-29.4 °C),

[29] *Orographic*. Of or pertaining to the effects of mountains on weather; resulting from the effects of mountains in forcing moist air to rise.

with the warmest temperatures occurring in August and September.[30] Temperatures vary with elevation and generally decrease three degrees Fahrenheit per 1,000 ft elevation gain.

4.7.3 Natural Hazards

The Hawaii Coastal Hazards Atlas describes hazards inherent to the region. The Overall Hazard Assessment for the Hanalei Bay region is high and changes to moderate at Makahoa Point (Fletcher et al. 2002).

The stream flooding hazard rating is high, except at Makahoa Point, due to the high annual rainfall of this area. The rating is supported by numerous flood events. Between 1946 and 1996 at least 20 flood events occurred in the Hanalei Bay Watershed. “The Hanalei River, which most directly drains the wettest region of Mt. Waiʻaleʻale, overflows its banks at the coast nearly every year” (Fletcher et al. 2002). “Three decades of stream gauge data show that the Hanalei River overflowed its banks at the Hanalei Bridge 29 out of the last 32 years”. One particularly damaging event occurred in 1996 when 9 in (23 cm) of rain fell in 12 hours along the coast. The amount that fell on the uplands is not known. This event caused flooding in Hanalei town and led to a temporary closure of the Hanalei Bridge, the resident’s only access to the rest of the island. More recent flooding events have occurred since 1996 that have also caused property and crop damage, disrupted commerce, and impaired water quality in the Bay.

Hazards due to high waves and storms are high. The north shore of Kauaʻi is subject to high waves every winter ranging between 20-40 ft (6-12 m) due to north and northwest swells. Between 1968 and 1998, and least nine events of damaging waves and high waves due to hurricanes have affected the north shore of Kauaʻi, including Hanalei Bay Watershed.[31] These events are associated with erosion and overwash of coastal property. Coastal erosion in the area is moderately high except for Makahoa Point, although Hanalei Beach appears to be stable.

Sea-level rise and volcanic seismic hazards are moderately low to low. Between 1868 and 1964, a damaging tsunami has reached Kauaʻi on average once every 12 years (Fletcher et al. 2002). However only two of these impacted the Hanalei Bay Watershed; the 1946 event, which measured 19 ft (5.8 m) and the 1964 event, which measured 6 ft (1.8 m).

4.7.4 Climate Change

While uncertainty remains as to future rates of sea level rise because of uncertainty about future carbon emission rates and the oceans’ response, it is reasonably certain that three feet of sea level rise from the 1990 level will occur by the end of the 21st century (Vermeer and Rahmstorf 2009; Fletcher 2009). Sea level rise is expected to alter the location of the shoreline and impact infrastructure layout (i.e. buildings, roads). It will also impact the water table of aquifers currently in contact with the ocean, and in some locations may increase the salinity level of the ground water, reducing availability for fresh water uses. Sea level rise may cause salt water intrusion into low-land agriculture (e.g. taro *loʻi*) or inundate freshwater and brackish coastal wetlands needed by waterbirds. Most of the dwellings and other built areas are located in the low elevation coastal plains, and in some of the lowest lying areas properties and structures may be threatened by higher

[30] http://www.ncdc.noaa.gov/oa/ncdc.html

[31] These do not include high waves due to tsunamis.

sea levels. In addition, the rise in the ground water table will likely adversely impact disposal of effluent from individual wastewater systems that are located throughout the watershed. HAR §11-62 requires vertical spacing between the bottom of discharge points of the various outlets used for wastewater disposal and the top of the ground water table. Systems may be out of compliance in the event the ground water table rises.

Global warming is likely to impact the Hawaiian trade wind regime and may have negative impacts on Hawaiian rainfall. A decrease in atmospheric circulation in the tropical Pacific Ocean has already been observed and attributed to global warming (Vecchi et al. 2006). Timm and Diaz (2009) noted that significant changes in the wind fields around Hawaiʻi are forecast to occur by the late twenty-first century under one of several climate change scenarios described by the Intergovernmental Panel on Climate Change (IPCC 2007).

However, the predicted impact on rainfall is not clear and Timm and Diaz (2009) concluded that the most likely scenario for Hawaiʻi is a 5 to 10% reduction of wet-season rainfall and a 5% increase of dry-season rainfall as a result of changes in the wind field. Recent studies show that rainfall has declined state-wide with observable negative effects on freshwater availability on four of the main Hawaiian Islands including Kauaʻi, Oʻahu, Molokaʻi, and Maui. Using a regional rainfall index compiled from 27 rain gage stations on three of the main Hawaiian Islands Chu and Chen (2005) showed that state-wide wet season rainfall (November-March) has declined from 1905 to 2002. Similarly, Oki (2004) reported significant decline in annual rainfall at 17 locations state-wide from 1913 to 2001, including three gages located in the Lihue area. As an apparent response to rainfall decline, annual mean total stream base flow also declined significantly in seven streams from 1913 to 2002 on the islands of Kauaʻi, Oʻahu, Molokaʻi, and Maui (Oki 2004). Research on the trends of infrequent intense rainfall events has found that rare storms that generate 12 in/day (300mm/day) used to occur at a 20 year return period, and are now less rare, occurring at 3-5 year return periods (Chu et al. 2010).

4.8 Hydrology

Hydrology refers to the movement and fate of water across the watershed, its quality, and the man-made and natural drainage networks.

Box 1. Hydrologic Cycle

The hydrologic cycle is the most fundamental principle of hydrology. Water evaporates off the ocean and land surfaces and is carried over the earth in atmospheric circulation as water vapor, it precipitates out as rain or snow and is intercepted by trees and vegetation, provides runoff over the land surface, infiltrates in the soils, recharges ground water, discharges into streams and all ultimately flows out to the oceans from which it eventually will evaporate once again. The hydrologic cycle is fueled by solar energy, driven by gravity, and proceeds endlessly in the presence or absence of human activity. However, human activity can significantly alter the hydrologic cycle, especially the processes that occur on land.

A key component of the hydrologic cycle is what happens to rainfall that reaches the earth's surface. Raindrops can be intercepted by plants, where they collect on leaves, branches and twigs and then either evaporate, drip off to the ground surface beneath the canopy (through flow), or flow down the trunk or stem of a plant to the ground (stemflow). Rainfall may directly hit the ground surface and some of this infiltrates into the soil, filling pores, and used by plants. A portion of the infiltrated water percolates beneath the soil layer flowing into aquifers or along subsurface flow paths and emerging down slope as springs or seepage into water bodies (e.g. streams, ocean). Ground water that flows into streams is referred to as baseflow. A portion of the total rainfall reaching the ground becomes surface runoff. Surface runoff occurs either when the rainfall rate exceeds a soil's infiltration rate (Hortonian overland flow) or when the soil is saturated and cannot absorb any additional water (saturated overland flow). The fate of water running over a watershed is of particular importance and plays a significant role in the transport of pollutants and formation of the landscape. Alterations to a watershed by people, plants, and animals can affect all of the pathways, and in many cases the alterations results in adverse impacts to the ecosystem.

4.8.1 Hydrology of the Waterways in the Hanalei Bay Region

A network of streams and rivers drain the Hanalei Bay Watershed (Figure 20). The largest by length and volume the Hanalei River is 17 miles (27 km) in length and the largest stream system in the State by volume with a annual mean daily discharge of 204 cubic feet per second (cfs) (5.8 cubic meters per second (cms), 12-year average calculated from 1993 to 2004 (Appendix F).[32] The mean daily discharge varies by month, with lowest values occurring June- August, and annual maximum in March. The headwaters of the Hanalei River are near the summit of Mt. Wai‘ale‘ale where average annual rainfall is 380 in (9,652 mm) (Giambelluca et al. 2011). The upper headwaters are dominated by extreme slopes with rivulates that plunge down, creating numerous waterfalls and cascades. The numerous tributaries draining the basin combine to create the Hanalei River, which flows in a mostly south to north direction slowing in its estuary before spilling into the Bay.

Box 2. Watershed Hydrology

Discharge or stream flow of Hawai‘i streams tend to be naturally flashy, meaning it rises and falls quickly during and following rainfall due to small steep watersheds and intense rainfall rates. Stream flow occurs when either or both surface flows of sufficient volume are delivered to a stream or a steady baseflow is intercepted by the stream.[33] Under either situation, when the volume of water delivered to the stream is sufficient to maintain conditions of continuous water in the channel, the stream is classified as perennial. When the water delivery is intermittent the stream is classified as intermittent, and when the channel flows only following rain it is classified as ephemeral. All of the streams that drain the four Hanalei Bay subwatersheds are classified by the State as perennial.

Along their longitudinal profile streams have sections where ground water drains into the stream increasing surface flow volume in the channel, and other sections where the channel loses water through its bed and banks. During rainy years the stream likely flows for longer periods when compared to low rainfall years. Under natural or pre-urbanized conditions only a small percentage of the rainfall that reaches the ground results in runoff. This is due to infiltration of water into the soil, detention of water on surfaces such as plants, and retention of water in small depressions common in natural landscapes. A portion of water infiltrates into the soil and recharges ground water, some of which makes its way slowly though subsurface flow paths into the streams as baseflow. Alterations to vegetation and ground cover by humans and animals that reduce infiltration rates of rainfall into the soil generally increase the amount of runoff for given storm event and decrease the time of runoff generated when compared to undisturbed or unaltered conditions.

Table 12. Watershed Characteristics

Watershed	Total Stream Length (miles)	Watershed Area	
		(acres)	(mi^2)
Hanalei	77	15,125	23.63
Wai‘oli	16	3,483	5.44
Waipā	9	1,592	2.48
Waikoko	1	458	0.72
Total	**103**	**20,658**	**32.27**

No continuous discharge records for the three other streams, Wai‘oli, Waipā and Waikoko, were found during preparation of this report. They are assumed to not exist, thus reporting of flow

[32] Source: http://hi.water.usgs.gov/.

[33] *Baseflow* is commonly referred to as the volume of flow in river or stream that is derived from ground water.

statistics is not possible.[34] Waipā Foundation does maintain a stream gage that records stream stage on Waipā Stream. Approximately 4 cfs of water is diverted from this stream, which is approximately 75 to 85 percent the stream's mean base flow (M. Rosener, pers. comm.). Of the volume diverted, about 1 cfs is routed into Waikoko Watershed. What percentage the imported water contributes to surface water derived from within Waikoko Watershed is unknown. Due to the Waiʻoli, Waipā, and Waikoko Watershed relative sizes and average elevations, the total annual and mean daily flows are probably highest in Waiʻoli Stream and lowest in Waikoko Stream. The cumulative base flow volume of Waiʻoli, Waipā, and Waikoko Streams are estimated to be no more than ten percent of the base flow volume of the Hanalei River. As a result the amount fresh water delivered into the Hanalei Bay during baseflow periods (dry) is primarily from the Hanalei River.

4.8.2 Ground Water Resources

Ground water is water found in underground layers of rock or sediment, referred to as an aquifer. An aquifer is roughly defined as an area in which the spaces (voids) are filled with water. The water table is the upper elevation of the water in an aquifer. Similar to surface water, water in an aquifer flows under the force of gravity. The flow rate of water through an aquifer is a function of the elevation head (or slope) of the water table, the hydraulic conductivity of the substrate it encounters, the cross section of the area it flows through, and the viscosity of the water. In general flow rates through dense material are slower compared to flow through loosely packed materials if all other variables are the same. Water in aquifers can either be fresh, salt, or brackish.

All aquifers in Hawaiʻi are classified using a system developed and reported by Mink and Lau (1992). The classification is based on an eight digit code using the following parameters:

- Island code
- Sector: Areas with similar hydrogeological properties
- System: Sub area of a sector with hydrogeological continuity
- Type: Sub area of system with uniform hydrologic and geologic features

The aquifers beneath the Hanalei Bay Watershed are in the same Sector (02,) and System (02,) both named Hanalei, and are separated into three types: High Level (2), Unconfined (1), Dike (2) located primarily in the steep sections of the watersheds; Basal (1), Unconfined (1), Dike(2) located in the middle elevations; and Basal (1), Unconfined (1), Sedimentary (6) located along the coastal plains.

In addition to the aquifer code, the State has a ground water Status Code that is assigned to each aquifer type. The five digit Status Code describes the aquifers with respect to five categories: development stage, utility, salinity, uniqueness, and vulnerability to contamination. The categories are based on EPA directives and were developed so that ground water resources would receive protection from adverse impacts. The dike aquifers in the watersheds are classified (21111): Potentially Developed, Drinking, Fresh, Irreplaceable, and High. The sedimentary aquifer is coded (22211): Potentially Developed, Ecologically Important, Moderate salinity (1,000-5,000 mg/l Cl^-), Irreplaceable, and High.

[34] As part of Surfrider Foundation's contract with DOH to monitor water quality, flow measurements are being collected (Section 5.3).

4.8.2.1 High Level, Unconfined, Dike Aquifer

The High Level (2), Unconfined (1), Dike (2) Aquifer is located beneath the land surface from the top of the watersheds down to approximately 500 (152 m) elevation. High level means the water is fresh and does not contact seawater. Unconfined means the top of the water table in the aquifer is the upper surface. Dike means that the water is held in dike compartments. Dike compartments are similar to boxes that are filled with water. The sides of the compartments are dense rock aligned in a mostly vertical pattern. Dikes fill up as water percolates down into the box, and drain out when the box fills, or through leaks in the sides or bottom. The high level aquifers occur in moderate to high rainfall zones, and function as mountain reservoirs. The outflow and leakage of water from the dikes during periods free of rainfall sustain the flow of water in the upper reaches of the streams, and are a significant hydrogeologic feature of the watersheds.

4.8.2.2 Basal, Unconfined, Dike Aquifer

The Basal (1), Unconfined (1), Dike (2) Aquifers are located beneath the watersheds from the contact line with the high level dike aquifers to the land surface elevation at approximately 100 ft (33 m) elevation. Basal water is a fresh water layer that is in contact with seawater. The fresh water in the aquifer is buoyed above the deeper saltwater layer because fresh water is less dense than saltwater. A brackish water zone of varying thickness is usually located between the fresh and salt water layers. In basal aquifers the water table can vary spatially, as can the flow rate of water through the aquifer. Unconfined means that water percolating through soils can recharge the aquifer. However, this water is then contained within the dike compartment, and as described above the rate a which it leaks out is variable.

4.8.2.3 Basal, Unconfined, Sedimentary Aquifer

The Basal (1), Unconfined (1), Sedimentary (6) Aquifer is located beneath the watersheds from the land surface at approximately 100 ft (300 m) elevation to the shoreline. The water in this aquifer differs from the other two primarily in that the ground water is contained in sediments. The aquifer is comprised of terrestrial sediments, carried by surface water running over the landscape and deposited along the flat coastal zone, and calcareous sediments, sourced from coral reefs and deposited by ocean waves. The water table in this aquifer varies, however its depth below the ground surface is generally small due the low elevation of the ground surface in this area of the watersheds. In areas with ground elevations equal to or less than 10 ft (3 m) the ground water table is approximately 3 to 4 ft (1 m) beneath the ground surface. The issue of contamination carried in percolating water is of concern, in part due to the aquifer's close proximity to the shoreline. Most of the land uses occurs on this aquifer type, making potential contamination of the aquifer high.

4.8.3 Floodway Issues

Areas subject to coastal flooding or tsunami inundation are identified on Flood Insurance Rate Maps (FIRM) prepared by the Federal Emergency Management Agency, Federal Insurance Administration. For the Hanalei community the flood prone areas extend over large tracts of the land along the lower reaches of the river, and in the low lying areas in the three other subwatersheds. Flood hazard areas, which include tsunami inundation areas, are categorized by the probability of hazard, based upon USACE surveys. Figure 21 depicts the FIRM map flood zone classifications and Box 3 provides definitions.

Box 3. FIRM Flood Zone Designations[35]

Zone A: Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Since detailed analyses are not performed for such areas; no depths or base flood elevations are shown in these zones.

Zone AE: Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. In most cases, base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

Zone B, X: Areas outside the 1% annual chance floodplain, areas of 1% annual chance sheet flow flooding where average depths are less than 1 foot, areas of 1% annual chance stream flooding where the contributing drainage area is less than 1 square mile, or areas protected from the 1% annual chance flood by levees. No Base Flood Elevations or depths are shown within this zone. Insurance purchase is not required in these zones.

Zone D: Areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted. Flood insurance rates are commensurate with the uncertainty of the flood risk.

4.9 Biotic Environment

The biotic environment of the Hanalei Bay Watershed contains both native and non-native flora and fauna. Higher elevation areas contain large patches of native vegetation that are capable of supporting native species such as threatened and endangered native songbirds, insects, and invertebrates. These areas contain designated critical habitat for some species.[36] Although lower elevations are dominated by non-native vegetation, managed areas such as the Hanalei NWR and area wetlands support some native flora and fauna and enhance overall ecosystem health. Preservation and protection of native populations in all areas of the Hanalei Bay Watershed is a priority and essential for improving the health of the Hanalei Bay.

4.9.1 Plant Species and Communities

Vegetation maps are a key foundation for sampling, analyzing, and interpreting other ecological data relative to erosion and fine sediment transport through the watershed. Vegetation maps for the Hanalei Bay Region are available from C-CAP, the USGS GAP Analysis Program (Figure 22), and Jacobi and Ambagis (2007). The most detailed of these was developed by Jacobi and Ambagis (2007) using spectral analysis of digital images and ground-truthing. They produced a detailed map depicting the distribution of 26 native and non-native plant communities and species. According to Jacobi and Ambagis (2007) the majority of native dominated plant communities were found above 2,500 ft (762 m) elevation, particularly on the upper western side of the Hanalei River valley.

The Hanalei, Waiʻoli, and Waipā Watersheds contain several threatened and endangered plant species, as well as some candidate species and species of concern.[37] Table 13 lists the plant species with some type of conservation status that have been observed in the Hanalei Bay Watershed.

Eleven plant species have designated critical habitat in the upper elevations of Hanalei, Waiʻoli, and Waipā Watersheds (Table 14). When evaluating areas for critical habitat designation, USFWS employed an ecosystem-based approach because many of the listed species in this area share the

[35] FEMA website: http://msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=-1&content=floodZones&title=FEMA%20Flood%20Zone%20Designations.

[36] When a species is listed as endangered or threatened under the U.S. Endangered Species Act (16 U.S.C. §§1531 et seq.), one of the requirements, with limited exceptions, is to designate critical habitat for that species. Critical habitat includes specific areas within the geographical area occupied by the listed species that contain physical or biological features that are essential to the conservation of the species and that may require special management considerations or protection.

[37] Candidate species are those that have been studied and USFWS has concluded they should be proposed for addition to the Federal endangered and threatened species list. Species of concern is an informal term used by USFWS that refers to those species which might be in need of concentrated conservation actions.

same habitats. USFWS designated three different ecosystem types in the Hanalei and Waiʻoli Watersheds as critical habitat; montane wet, wet cliff and lowland wet, although some of these lands may not contain currently listed species (Figure 23).

Table 13. Plant Species of the Hanalei Bay Watershed with Conservation Status

Scientific Name	Common Name	Conservation Status
Adenophorus periens	pendant kihi fern	Endangered
Bidens campyoltheca sbsp. Campyoltheca	koʻokoʻolau	Species of Concern
Chamaesyce remyi var. remyi	ʻakoko, euphorbia remyi	Endangered
Cyanea recta	hāhā, upright cyanea	Threatened
Cyanea remyi	hāhā, Remy's cyanea	Endangered
Cyrtandra cyaneoides	haʻiwale, mapele	Endangered
Cyrtandra limahuliensis	haʻiwale, limahuli cyrtandra	Threatened
Cyrtandra oenobarba	haʻiwale, shaggystem cyrtandra	Endangered
Cyrtandra pickeringii	haʻiwale, Pickering's cyrtandra	Species of Concern
Dubautia waialealae	naʻenaʻe, Waiʻaleʻale dubautia	Endangered
Gardenia remyi	nānū, Remy's gardenia	Candidate
Hedyotis fluviatilis	kampuaʻa	Candidate
Hesperomannia lydgatei	_	Endangered
Isodendrion longifolium	aupaka, longleaf isodendrion	Threatened
Joinvillea ascendens var. macraeana	_	Candidate
Keysseria erici	Alakai Swamp island-daisy	Endangered
Labordia helleri	kāmakahala, Heller's labordia	Endangered
Labordia lydgatei	kāmakahala, Wahiawa Mountain labordia	Endangered
Labordia pumila	kāmakahala, Kauai labordia	Endangered
Myrsine fosbergii	Kōlea	Candidate
Phyllostegia helleri	Mt. Kahili phyllostegia	Species of Concern
Plantago princeps	kuahiwi laukahi, ale	Endangered
Platydesma rostrata	pilo kea lau liʻi	Endangered
Pritchardia viscose	loulu, stickybud pritchardia	Endangered
Pteralyxia kauaiensis	kaulu, Kauai pteralyxia	Endangered

Jacobi and Ambagis (2007) concluded that the vast majority of the Hanalei Bay Region is dominated by non-native species, which "is likely due to the rapid invasion of this area by several alien plant species, particularly following major damage to the native plant communities during hurricanes Iwa and Iniki in 1982 and 1992, respectively."

Invasive plants of concern include: Koster's curse (*Clidemia hirta*); Tufted beardgrass (*Schizachyrium condensatum*); Rose apple (*Syzgium jambos*); shoebutton ardisia (*Ardisia elliptica*); Australian tree fern (*Sphaeropteris cooperi*); Red ginger (*Alpinia purpurata*); bamboo (*Phyllostachys* spp.); paperbark (*Melaleuca quinquenervia*); common guava (*Psidium guajava*); strawberry guava (*Psidium cattleianum*); cat's claw (*Caesalpinia decapetala*); Malabar melastome (*Melastoma* *candidum*); Downy rose myrtle (*Rhodomyrtus tomentosa*); hau bush (*Hibiscus tiliaceus*); and albizia (*Falcataria moluccana*). "Much of the valley floor and the lower slopes above the [Hanalei] river are dominated by guava with an understory of Clidemia and Lantana. It also appears that several highly invasive plant species, including Albizia, Australian treefern, strawberry guava, Malabar melastome, and rose myrtle, are rapidly increasing in both distribution and abundance across the lower part of the watershed" (Jacobi and Ambagis 2007).

Table 14. Watersheds with Critical Habitat for Listed Plant Species

Scientific Name	Common Name	Hanalei Watershed	Wai'oli Watershed	Waipā Watershed
Adenophorus periens	pendant kihi fern	✓	✓	✓
Cyanea recta	hāhā, upright cyanea	✓	✓	
Cyanea remyi	hāhā, Remy's cyanea	✓	✓	
Cyrtandra cyaneoides	ha'iwale, mapele	✓	✓	
Cyrtandra limahuliensis	ha'iwale, limahuli cyrtandra	✓	✓	✓
Hesperomannia lydgatei	–		✓	
Isodendrion longifolium	aupaka, longleaf isodendrion	✓	✓	
Labordia lydgatei	kāmakahala, Wahiawa Mountain labordia	✓	✓	
Myrsine linearifolia	Kōlea	✓	✓	
Plantago princeps	kuahiwi laukahi, ale	✓	✓	
Pteralyxia kauaiensis	kaulu, Kauai pteralyxia	✓		
Total Species		**10**	**10**	**1**

4.9.2 Biota

4.9.2.1 Freshwater Aquatic Biota

DLNR Division of Aquatic Resources (DAR) has conducted aquatic surveys of streams in Hawai'i with the objective of quantifying the distribution and abundance of organisms, both native and introduced, to provide critical information for monitoring, assessing, managing, and protecting freshwater resources. This statewide database has attempted to collect historical biota information and methodically assign labels and rankings to features within Hawai'i's watersheds.[38]

The DLNR-DAR biological surveys concluded that the watersheds of the Hanalei Bay Region and its streams have the ability to support abundant terrestrial and aquatic life (Parham et al. 2008). The DLNR-DAR watershed atlas contains biotic information about three of the streams in the Hanalei Bay Region based on in-stream surveys (Parham et al. 2008); Waikoko Stream has not been sampled. Native species of fish and crustacean species known to be present are listed in Table 15. Streams in the Hanalei River watershed contain at least seven species of native fish, more than 19 species of native insects, and more than five species of native macrofauna including two crustaceans. Newcomb's snail (*Erinna newcombi*), an endangered species that is restricted to the island of Kaua'i, lives in the high springs that feed the Hanalei River and a few other streams on the north shore of Kaua'i. The upper watershed has been designated as critical habitat for the

[38] Details can be found at: http://www.hawaiiwatershedatlas.com/key3.html.

Newcomb's snail.[39] Wai'oli Stream contains at least five species of native fish, one species of native insect, and more than five species of native macrofauna including two crustaceans. Waipā Stream contains at least three species of native fish, two species of native insects, five species of native crustaceans, and two species of native worms. Non-native fish and crustaceans are also present.

Table 15. Native Fish and Crustaceans

Scientific Name	Common Name	Stream				Status
		Hanalei River Watershed Streams	Wai'oli Stream	Waipā Stream	Waikoko Watershed Stream	
Crustaceans						
Amphipod sp.	Amphipods			X		
Atyoida bisulcata	*'Opae-kaka'ole*	X	X	X		
Copepod sp.	Copepods			X		
Macrobrachium grandimanus	Hawaiian river shrimp	X	X	X		
Ostracod sp.	Seed shrimp			X		
Fish						
Awaous guamensis	*O'opu nakea/* Pacific river goby	X	X	X		Indigenous
Eleotris sandwicensis	*'O'opu akupa* or *'O'opu okuhe/* Predator 'sleeper'	X	?	?	?	Endemic
Gobiid sp.	Goby	X	X	X		
Kuhlia sandvicensis	*'Āhole / 'Āholehole*	X	X	X		
Kuhlia sp.	Flagtails	X	X			
Lentipes concolor	*'O'opu hi'ukole/* Huikole goby	X	X			Endemic
Sicyopterus stimpsoni	*'O'opu nopili/* Nopoli rockclimbing goby	X	X			Endemic
Stenogobius hawaiiensis	*'O'opu naniha/* Naniha goby	X				Endemic

[39] Critical habitat for Newcomb's snail is designated for all flowing waters associated with the Hanalei River and its tributaries, including springs and seeps, and riparian habitat necessary to maintain the integrity of the watershed (Sub-Unit II(b): Hanalei River). The Hanalei River location designated includes 4.71 mi (7.58 km) of stream channel and 876 ha (2,165 ac) and falls within the elevational contours of 400 to 1,500 ft (122 to 457 m), excluding ditches and flumes. The four subpopulations found within this stream system represent the largest number of Newcomb's snail sub-populations occurring within a single watershed. Segments of several named tributaries to the Hanalei River are included in this designation, and these include Kaapoko, Kaiwa, and Waipunaea Streams. This stream segment is located within the Halela Forest Reserve on State lands. The critical habitat that contains the Hanalei River subpopulations of Newcomb's snail is essential to the conservation of the species because this area is needed to maintain one of the six existing known populations of snails. A complex of stream diversion works that includes dams, ditches and tunnels, is found at the 1,240 ft (378 m) elevation of the Hanalei River, in the vicinity of the upper two main-channel Hanalei River sub-populations and upstream of the Kaapoko tributary sub-population at an elevation of 1,300 ft (396 m). These dams and associated ditches and tunnels historically diverted large volumes of water out of Kaapoko tributary and the Hanalei River to watersheds in the southeast portion of the island for irrigation use. Typical diversion structures in Hawaiian streams completely divert all of a stream's flowing water during moderate to low-flow periods, leaving the stream channel below the dam completely dry. The water diversion structures and associated ditches and tunnels in the upper Hanalei River and its tributaries have been in disrepair since the early 1990s. Although these human-made features locally alter flow characteristics, no water is currently diverted out of the Hanalei Watershed. http://ecos.fws.gov/docs/federal_register/fr3934.pdf.

All five species of native *oʻopu* occur in streams in the Hanalei Bay Watershed. *Oʻopu* has an amphidromous life cycle.[40] The *oʻopu alamoʻo* (*Lentipes concolor*) and *oʻopu nopili* (*Sicyopterus stimpsoni*) live in the fast flowing waters of the river. They have sucker-like fins that allow them to climb waterfalls and can be found at the headwaters of the Hanalei River. The *oʻopu naniha* (*Stenogobius hawaiiensis*) and *oʻopu akupa* (*Eleotris sandwicensis*) live in the lower, slower sections of the river. The *oʻopu nakea* (*Awaous guamensis*) provides an important fisheries resource to the Hanalei community, when after floods large numbers of fish come downstream to spawn on riffles situated just upstream of the ocean. Since *oʻopu* need to pass through a stream mouth twice during their lives, once as an egg and the other as a juvenile traveling back up the stream, they must have access to and from the ocean. Stream channelization and diversions are great threats to the native fish populations. Other threats include poor water quality, sedimentation, and predation.

4.9.2.2 Avian Species

The Hanalei Bay Watershed support both native and migratory bird species including waterfowl, shorebirds and other wetland birds. The majority of these are found at the Hanalei NWR, in and around Hanalei Bay, and at area wetlands. At least nine species have some type of conservation status. The Hanalei NWR contains one of the largest concentrations of wetland birds in Hawaiʻi. At least 23 species of waterfowl and 19 species of shorebirds have been observed at the refuge.

The Hanalei Valley, particularly the Hanalei NWR, is an important breeding, feeding, and resting area for the five endangered bird species: Hawaiian stilt; Hawaiian coot; Hawaiian moorhen; Hawaiian duck; and Hawaiian goose. The Hawaiian stilt (*Aeʻo*, *Himantopus mexicanus knudseni*), the Hawaiian coot (*ʻAlae keʻokeʻo*, *Fulica alai*), and the Hawaiian moorhen or *ʻAlae ʻula* (*Gallinula chlorops sandvicensis*) can all be seen and heard around the managed wetlands in Hanalei. The Hawaiian duck (*Koloa maoli*, *Anas wyvilliana*) frequents the long stretches of the Hanalei River itself, and can be seen flying around the wetlands in the morning or evening. The Hawaiian goose (*Nēnē*, *Branta sandwicensis*) has been released on the Hanalei NWR as part of the recovery program for this species. Hawaiian geese utilize the wetlands in this area frequently, not a common trait in other areas. Although taro *loʻi* of Hanalei NWR are regularly used by endangered waterbirds, no part of the *loʻi* area has been designated as critical habitat.

At least five species of seabirds are regular visitors to the Hanalei Bay area including: Newell's/Townsend's shearwater (*ʻAʻo*, *Puffinus auricularis newelli*), federally listed as threatened; and the wedge-tailed shearwater (*ʻUaʻu kani*, *Puffinus pacificus chlororhunchus*), listed by USFWS as a Bird of Conservation Concern. Research conducted by Ainley et al. (1997) suggests that vegetation in the mountains above Hanalei Bay provides nesting grounds for Kauaʻi's Hawaiian petrel (*ʻUaʻu*, *Pteredroma sandwichensis*), a federally listed endangered species.

At least 10 migratory species regularly return to the Hanalei Bay area including the White-faced ibis (*Plegadis chihi*), listed by USFWS as a Bird of Conservation Concern. Other migratory species

[40] Amphidromous refers to a unique life cycle where animals live in two different environments during life stages. Adults live in streams as adults and lay their eggs in the stream. Upon hatching, the larvae migrate downstream and are swept out to sea. After living in the ocean plankton community for a time, the postlarvae return to the stream habitat. Maintaining the natural patterns of water flow in streams is essential for supporting this life cycle and protecting native Hawaiian stream animals.

include: Pacific Golden plover (*Kōlea*, *Pluvialis fulva*); Sanderling (*Hunakai*, *Calidris alba*); Northern pintail (*Koloa māpu*, *Anas acuta*); Green-winged teal (*Anas crecca*); Blue-winged teal (*Anas discors*); Bufflehead (*Bucephala albeola*); and the occasional Laysan albatross (*Mōlī*, *Diomedea immutabilis*) and Baikal Teal (*Anas formosa*).

Although a comprehensive forest bird survey of the Hanalei Bay Watershed has not been conducted, available information gives an indication of the potential species present. Three sites within the Hanalei Bay Watershed were surveyed as part of an island wide bird survey conducted between 1968-1973. Native forest bird species that were detected included: *ʻApapane* (*Himatione sanguinea*), Kauaʻi *ʻElepaio* (*Chasiempis sandwichensis sclateri*), *ʻAnianiau* (*Magumma parva*), Kauaʻi *amakihi* (*Hemignathus kauaiensis*), and the endangered *Akekeʻe* (*Loxops caeruleirostris*) (DOFAW 2010). In addition, there are three species of endangered forest birds that are known to exist in the nearby Alakaʻi plateau that could potentially occur in the upper Hanalei Bay Watershed, as they once inhabited most if not all of the island: the Kauaʻi creeper (*ʻAkikiki*, *Oreomystis bairdi*), Kauaʻi *ākepa* (*ʻAkekeʻe*, *Loxops caeruleirostris*) and the Kauaʻi thrush (*Puaiohi*, *Myadestes palmeri*). The population of each of these species in the Hanalei Bay Watershed is unknown. Changes in habitat, including an increase in non-native species and deadly avian diseases carried by mosquitoes, have likely had a negative impact on these bird species.

4.9.2.3 Other Native Species

Hawaiʻi's only native terrestrial mammal, the endangered Hawaiian hoary bat (*apeʻapeʻa*, *Lasiurus cinereus*) has been observed in the Hanalei Bay Watershed.

4.9.2.4 Marine Biota

Hanalei Bay is important to many native fish such as mullet (*amaʻama*, *Mugil cephalus*) and flagtails (*aholehole*, *Kuhlia snadwichensis*). Schools of juvenile fish move into the Hanalei Bay to feed and develop away from large predators. Non-native fish also inhabit the Hanalei Bay and impact native species. For example, non-native predatory swordtails (*Xyphophorus helleri*) eat *oʻopu* larvae as they pass the mouth of the river to travelling out to the ocean or back up the river.

A survey performed in 2002 did not detect any non-native algae species in Hanalei Bay (Smith et al. 2002). The closest survey site with non-native algae present was ʻAnini Beach, approximately 3 miles (4.8 km) to the east, which at the time had about 40% cover of one species, *Acanthophora spicifera*.

NOAA National Marine Fisheries Service is currently reviewing the status of 82 coral species for potential listing under the U.S. Endangered Species Act. Nine of these species are found in Hawaiʻi waters, and at least one, Sandpaper Rice Coral (*Montipora patula*), has been recorded in Hanalei Bay.

Green sea turtles (*honu*, *Chelonia mydas*) are a federally listed species (threatened in Hawaiʻi) that although not common, have been recorded in Hanalei Bay and documented basking on the beach near the mouth of the Hanalei River. The Hawaiian monk seal (*Monachus schauinslandi*), a federally endangered species endemic to the Hawaiian Islands, has rarely been seen in Hanalei Bay but does utilize ocean waters and beaches in the surrounding areas. In recent years the number of Green sea turtles and monk seals recorded on the north shore of Kauaʻi has increased. Green sea turtles and

Hawaiian monk seals are protected under Federal and State laws and rely on a healthy marine ecosystem for foraging and population recovery.

4.9.2.5 Non-native and Invasive Species

Non-native species like the cattle egret (*Bulbulcus ibis*), black-crowned night heron (*Nycticorax nycticorax*), barn owl (*Tyto alba pratincola*), bullfrog (*Rana catesbeiana*), cane toad (*Bufo marinus*) as well as dogs, cats and rats, have had a negative impact on the population of the native waterbirds. Their primary impact is through the predation of the adults, chicks, and eggs.

Invasive plant and feral animals in the upper conservation areas of the Hanalei Bay Region pose a threat to the watershed and its water resources. Habitat destruction and the introduction of invasive species have been the prominent causes of the loss of biodiversity in Hawaiʻi for over a century (El-Kadi et al. 2008). In Hawaiʻi feral pig populations thrive, with the greatest densities typically existing within wet forest habitat due to the availability of food and water (Cuddihy and Stone 1990). In the 20th century pig population densities began to increase and the negative impacts associated with their presence were observed. Population growth resulted from an increase in area disturbed by humans and the expansion of non-native plants preferred by pigs, which in turn are spread by pig grazing and browsing (Cuddihy and Stone 1990). There are no known counts of pigs in the upper portion of the Hanalei Bay Region, however pigs are known to frequent the area and pig damage can be readily observed. The strong correlation between non-native plant presence and feral pig activity leads Aplet et al. (1991) to suggest the possibility that field observations of plant composition could be used to estimate the relative amount of pig activity. Although the effects of feral pigs on native ecosystems are wide ranging, there is emerging evidence that their presence alone may be linked to increases in runoff and soil loss (Browning 2008). Fares (2007) contends that feral pigs activity is one of the major causes of pollution in the Hanalei Watershed, with the soil disturbance resulting in increased sedimentation in the coastal areas. To date there are no efforts for feral ungulate control in the Hanalei Bay Watershed with the exception of the upper areas of Hanalei and Waiʻoli Watersheds that are designated as State hunting grounds for wild pigs and wild goats.

The Asian clam (*Corbicula fluminea*) is a non-native small freshwater bivalve mollusk. The most prominent effect has been biofouling, though it also alters benthic substrates and competes with competes with native species for limited resources.[41] It feeds on plankton, requires high levels of dissolved oxygen (DO), and is intolerant of pollution. The Asian clam spawns prolifically and continuously, and larvae are released into the water column as active post-larval juveniles, with the ability to resist downstream transport by currents. Populations can reach high densities, potentially releasing several million juveniles daily into the same area of the water column. They are widely distributed in streams, reservoirs and taro *loʻi* on Kauaʻi, Maui, and Oʻahu, including in the Hanalei Bay Watershed. In areas of high concentration, clams filter out nutrients in the water. The main problem from this non-native species to taro farmers is their burrowing activities, which create holes in the *lo'i* that let water out. Farmers may also injure themselves by stepping on the sharp edges of the shell.

[41] Biofouling is the undesirable accumulation of microorganisms, plants, algae, and/or animals on wetted structures.

Golden apple snails (Channeled Apple Snail, *Pomacea canaliculata*) are a non-native, invasive pest that inhabits wetlands, ponds, springs, lower stream reaches and taro *lo'i* in Hawai'i (Section 6.4.3). The population density per square meter of golden apple snails in Hanalei is thought to be one of the highest in the world (Levin 2006). Golden apple snails can breathe on land and underwater and can hibernate in the mud for months, making them very difficult to eradicate. They are listed as one of the worst 100 global invasive species.

5. Watershed Condition

This section describes the current watershed conditions in terms of classification, ratings, priority/listing status, monitoring data, and coral reef ecosystem condition.

5.1 Surface Water Classifications

There are various designations and classifications for waters in the Hanalei Bay Region. Some of these offer protections to water resources while others rank the area to support needed action. The Hanalei Bay Watershed has been designated as a priority by the Land Based Pollution LAS of DLNR-DAR's Coral Program to address key threats to coral reefs.[42] Hanalei Bay is within the boundaries of the Hawaiian Islands Humpback Whale National Marine Sanctuary co-managed as a Federal-State partnership by DLNR, NOAA's National Ocean Service, and the Office of National Marine Sanctuaries. The bay is within the North Shore Kauai Ocean Recreation Management Area managed by DLNR. Hanalei River is designated as an American Heritage River.[43]

Inland waters of the Hanalei Bay Region are designated as Class 1 and Class 2 by HAR §11-54-3: Water Quality Standards, Classification of Water Uses (Box 4). Segments from both classes are pollution sources for the Bay. Class 1 waters are afforded the State's highest level of protection. Portions of Hanalei Stream System that run through the Hanalei NWR (lower stream reach and upper estuary) are Class 1.a. A portion of the upper reach tributaries of Hanalei Stream System are Class 1.b., as are the upper reaches of Wai'oli Stream and Waipā Stream. All remaining waters, including a large portion of Hanalei Stream upper reaches; the lower reach of Hanalei Estuary; the lower reaches of Wai'oli Stream and Waipā Stream and their estuaries; and the entire Waikoko Stream System (stream and estuary) are Class 2. The waters of Hanalei Bay are designated as Class AA, marine waterbody (embayment). Hanalei Bay's designated uses include "conservation of coral reefs and wilderness areas ... and aesthetic enjoyment."

Box 4. Classification of Water Uses (HAR §11-54-3)

It is the objective of *Class 1* waters that these waters remain in their natural state as nearly as possible with an absolute minimum of pollution from any human caused source. To the extent possible, the wilderness character of these areas shall be protected. Waste discharge into these waters is prohibited. Any conduct which results in a demonstrable increase in the levels of point or non point source contamination in Class 1 waters is prohibited.

The uses to be protected in *Class 1.a.* waters are 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 nondegrading uses which are compatible with the protection of the ecosystems associated with waters of this class.

[42] http://www.hawaiicoralreefstrategy.com/

[43] http://water.epa.gov/type/watersheds/named/heritage/

The uses to be protected in *Class 1.b.* waters are domestic water supplies, food processing, protection of native breeding stock, the support and propagations of aquatic life, baseline references from which human-caused changes can be measured, scientific and education purposes, compatible recreation and aesthetic enjoyment.

The objective of *Class 2* waters is to protect their use for recreational purposes, the support and propagation of aquatic life, agricultural and industrial water supplies, shipping and navigation. The uses to be protected in this class of waters are all uses compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters. These waters shall not act as receiving waters for any discharge which has not received the best degree of treatment or control compatible with the criteria established for this class. No new treated sewage discharges shall be permitted within estuaries.

It is the objective of *Class AA* waters that these waters 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. To the extent practicable, the wilderness character of these areas shall be protected.

5.2 Watershed Rating

An assessment by DLNR-DAR scored watersheds and streams with a standardized rating system that ranges from zero to ten (zero is the lowest and ten is the highest rating based on the quality of specific criteria) (Parham et al. 2008). The 'Total Watershed Rating', 'Total Biological Rating' and 'Overall Rating' for each watershed are shown in Table 16.[44]

Table 16. Watershed Ratings

Watershed	Total Watershed Rating	Total Biological Rating	Overall Rating
Hanalei	9	6	8
Waiʻoli	7	6	7
Waipā	6	5	6
Waikoko	3	NR	NR

5.3 Water Quality Data

Water quality is assessed based on measurements of physical, chemical and biological parameters (Appendix D.1). Waterbodies in the Hanalei Bay Watershed have undergone water quality sampling for about two decades. Monitoring data are critical to characterizing the watersheds. Without such data, it is difficult to evaluate the condition of the waterbodies in the watersheds (EPA 2008). Various sources of data exist, from the HWH volunteer monitoring program (Hanalei Volunteer Water Quality Monitoring Project), to DOH and USGS data, as well as numerous scientific research studies. The volunteer water quality monitoring program began shortly after the river's heritage designation in 1999. Monitoring efforts have been ongoing by this program through annual funding agreements with DOH Clean Water Branch (CWB) Monitoring Section. The monitoring stations for development of the Phase 1 TMDL are spread across the four watersheds as well as Hanalei Bay (Figure 24). Monitoring is done along rivers and streams, in the estuaries, and in the bay.

Other water quality monitoring efforts underway include: North Shore Water Quality Monitoring Project conducted by the Surfrider Foundation for DOH to sampling at TMDL stations, other

[44] Total Watershed Rating is based on the combination of criteria that includes land cover, shallow water, stewardship, size, wetness, and reach diversity. Total Biological Rating is based on the combination of criteria that includes native species, introduced genera, and all species. The Overall Rating is a combination of the Total Watershed Rating and the Total Biological Rating.

locations within the watersheds, and the greater north shore Kaua'i region[45]; researchers from Stanford University to refine source assessments of bacteria using molecular tests and genetic markers; and DOH sampling for pharmaceuticals in surface waters, for analysis by USGS laboratories.

Water quality varies spatially and temporally based on wet and dry season flows and location relative to pollutant sources. However, surface water generally exceeds water quality standards and is not meeting its beneficial uses. Data collected over many years and used in the TMDL process have shown frequent exceedances of water quality standards (Appendix D.2) for bacteria and turbidity and occasional exceedances for nutrients (Nitrogen and Phosphorus) (Section 2.4). Sampling sites are shown on Figure 24. Research conducted by Stanford University scientists has shown that the Hanalei River is the biggest contributor of nutrients and bacteria to the bay, delivering 64% of the bay's total dissolved inorganic Nitrogen and 80% of the bay's phosphate, as well as 60% of E. coli and 50% of *enterococci* (Boehm 2010).

A complete description and analysis of water quality data for bacteria, nutrients, and turbidity is presented in the Final Phase 1 and Draft Phase 2 TMDL reports (Tetra Tech and DOH 2008, Tetra Tech and DOH 2011). These reports provide details on the concentration of the various pollutants sampled, the regulatory definitions used in developing the TMDL, and the TMDL pollutant load allocation for each of the impaired water bodies. The Phase 1 TMDLs were prepared for the rivers and estuaries and contain specific load allocations for each water body listed.

5.3.1 Physical Water Quality

Hanalei Bay Watershed is listed for one physical water quality parameter, i.e. TSS. Review of data in the Phase 1 TMDL, and subsequent water quality data collected, indicates most of the total load is delivered into the Bay from the Hanalei River. Average turbidity concentrations in Hanalei Bay are shown in Table 17.[46]

Table 17. Average Turbidity Concentrations in Hanalei Bay

(Source: Tetra Tech and DOH 2011)

Sampling Area	Mean Concentration	Minimum Found	Maximum Found	% of Samples Exceeding WQS
Hanalei Bay: Pavilion	6	1	14	93
Hanalei Bay: Landing (Pier)	7	2	17	100
Hanalei Bay: Mooring Station	No data	No data	No data	No data
Hanalei Bay: Wai'oli Beach	6	1	51	95

Notes: Based on data collected between 2003-2008. Units are Nephelometric Turbidity Units (NTU). The applicable water quality standards are 1.5 NTU geometric mean, not to exceed 10% of time 3 NTU, and not to exceed 2% of

[45] Hawaii DOH contracted the Surfrider Foundation (Kaua'i Chapter) to collect water quality sampling to assess and identify potential water quality changes since the development of the TMDL. The data will help target implementation activities.

[46] TSS concentrations and turbidity both indicate the amount of solids suspended in the water, whether mineral (e.g. soil particles) or organic (e.g. algae). However, the TSS test measures an actual weight of material per volume of water, while turbidity measures the amount of light scattered from a water sample (more suspended particles cause greater scattering). This difference becomes important when trying to calculate total quantities of material within or entering a waterbody. Such calculations are possible with TSS values, but not with turbidity readings (Box D1).

time 5 NTU. Minimum found = lowest concentration found during sampling period. Maximum found = highest concentration found during sampling period. % exceedance = percentage of samples that exceeded the geometric mean water quality standard.

5.3.2 Chemical Water Quality

Nutrients, including Nitrogen and Phosphorus, are known pollutants in the Hanalei Bay Watershed. Potential sources of these nutrients include agricultural runoff, including from taro *lo'i*; vegetative and sediments inputs from Conservations lands; and individual wastewater systems. Although Hanalei Bay, streams, and estuaries are not listed on the 303(d) list for nutrients, numerous samples collected over many years from these waterbodies show that there have been consistent exceedences of water quality standards over the years. The data indicate that standards for Ammonia, Nitrite plus Nitrate, and Total Phosphorous are consistently exceeded in all five estuaries and in the streams. Part of the reason nutrients are not listed is that samples were collected without an approved quality assurance quality control plan, and in some of the water bodies there were not sufficient number of samples. Because of these exceedances, unofficial "informative TMDLs" were also calculated for nutrients.

5.3.3 Biological Water Quality

In the Hanalei Bay Watershed sources of microbes include humans, feral pigs, cattle, horses, rats, birds, and naturally occurring strains. Human sources are tied to wastewater systems such as effluent from wastewater disposal. Animal inputs can be diffuse or concentrated depending on the number of animals and their spatial distribution.

Table 18. Percentage of Samples Exceeding Water Quality Standards for *Enterococcus*

(Source: Tetra Tech and DOH 2008, 2011)

Monitoring Station	Water Quality Criteria	Percent Exceedance
Hanalei Bay: Pavilion	Geometric Mean	8%
	Single Sample Max	12%
Hanalei Bay: Landing (Pier)	Geometric Mean	46%
	Single Sample Max	23%
Hanalei Bay: Mooring Station	Geometric Mean	0%
	Single Sample Max	9%
Hanalei Bay: Wai'oli Beach	Geometric Mean	5%
	Single Sample Max	7%
Hanalei River Estuary	Geometric Mean	99%
	Single Sample Max	75%
Wai'oli Stream Estuary	Geometric Mean	100%
	Single Sample Max	91%
Waipā Stream Estuary	Geometric Mean	100%
	Single Sample Max	86%
Waikoko Stream Estuary	Geometric Mean	100%
	Single Sample Max	96%
Hanalei River	Geometric Mean	82%
	Single Sample Max	41%

For Bay sites: Samples from 1995 – 2008; Geometric Mean Water Quality Criteria = 35 cfu/ml; Single Sample Max Water Quality Criteria = 104 cfu/ml. For Estuary/River sites: Samples from 1995 – 2006; Geometric Mean Water Quality Criteria = 33 cfu/ml; Single Sample Max Water Quality Criteria = 89 cfu/ml.

In Hanalei, local residents have long been reporting excessive incidents of ear infections, staph infections and gastro-intestinal problems after swimming in Hanalei Bay. The water quality measurements performed to ascertain whether there is a human health risk are not based on actual bacterial pathogens of concern, but rather on levels of fecal indicator bacteria. The indicator species used in the United States and Hawaiʻi is *Enterococci*. Water quality monitoring from 1995-2008 has shown consistent exceedance of the water quality standards for *Enterococci.* Table 18 shows the percentage of samples exceeding water quality standards over this time period in Hanalei Bay and its contributing freshwater bodies, as analyzed for the Phase 1 and 2 TMDLs. This data supports the theory that land-based pollutants from the watersheds are impairing the coastal water quality as rivers and streams have much more frequent exceedances than the bay. The percentage exceedance is based on the applicable water quality criteria for the respective water bodies.

5.3.3.1 Enterococci

Table 19 shows average *enterococci* concentrations for all areas. Water quality analyses also found that areas of the bay with the highest levels of *enterococci* are closest to the mouth of Hanalei River, which shows correlation between concentrations and inputs from watershed areas drained by the river. The Mooring Station is farthest from the shore and concentrations there are much lower.

Table 19. Average *Enterococci* Concentrations – All Areas

(Source: Tetra Tech and DOH 2011)

Sampling Area	Mean Concentration	Minimum Found	Maximum Found	% of Samples Exceeding WQS
Hanalei River	129	7	816	82
Hanalei River Estuary	234	27	1042	99
Waiʻoli Stream Estuary	421	68	1896	100
Waipā Stream Estuary	375	64	1740	100
Waikoko Stream Estuary	966	70	4739	100
Hanalei Bay: Pavilion	17	0	104	8
Hanalei Bay: Landing (Pier)	48	1	543	46
Hanalei Bay: Mooring Station	11	2	22	0
Hanalei Bay: Waiʻoli Beach	16	1	58	5

Notes: Based on data collected between 1995-2008. Units are CFU/100ml. The applicable water quality standards are 35 CFU/100ml for the bay and 33 CFU/100ml for the river and estuaries. Minimum found = lowest concentration found during sampling period. Maximum found = highest concentration found during sampling period. % exceedance = percentage of samples that exceeded the geometric mean water quality standard.

5.3.3.2 Identifying Sources of Bacteria and Nutrients

Dr. Alexandria Boehm of Stanford University has collected and analyzed water quality data to determine the sources of bacteria and nutrients in several surface waterbodies around the Hanalei Bay Watershed using state of the art techniques, including genetic markers to assess for bacteria sources from humans, cattle, pigs, and birds. Results of her latest study, titled "Bacterial and Nutrient Contamination of Hanalei Area Rivers and Streams and Their Potential Impacts on Coastal Water Quality" were presented to the community in 2010. Water sampling was conducted at the outlets of the four main river/streams into the ocean.[47] This research answered questions about the sources and fluxes of bacteria and nutrients. The results showed that although the relative concentrations of nutrients and bacteria were much higher in the waters of the three smaller watersheds, the Hanalei River contributed the largest amount of these pollutants to the bay (64% of the bay's dissolved inorganic Nitrogen and 80% of Phosphate). Fecal bacteria tested were *E. coli* and *enterococci*, with the Hanalei River delivering 60% and 50% of the bay's total respectively. A positive correlation was found between these parameters and urbanized or cultivated areas and a negative correlation with forested areas. A contribution of these pollutants to surface water bodies via groundwater seepage is suspected, but this has yet to be confirmed by research.

The study used some new genetic methods to test samples containing fecal contamination for the source species. This was done with DNA markers for human, pig, and ruminant feces and an RNA marker for human enterovirus. Markers allow determination of the contribution of fecal bacteria by source, e.g. if samples are high in pig markers, there must be a feral pig population in the watershed contributing bacteria. If human markers are high, that might point towards contributions from cesspools. Samples were taken in March of 2008 and 2009 in each river/stream and the culvert that drains Hanalei town and discharges into Waiʻoli Stream. The study results indicate that many areas have occasional influxes of human fecal contamination, which is suspected to come from cesspools and other sewage related issues.[48] Another observation from the study was a higher amount of fecal indicator bacteria in samples with pig markers, suggesting that pigs are the major source of fecal indicator bacteria in Hanalei Bay (Section 6.4).

Additional sampling was conducted during kayak trips on the Hanalei River and in the USFWS refuge. In the river, 29 out of 49 samples (60%) were above State standards for *enterococci*. Some water samples from the river contained bacteria levels that were ten times higher than the standard. Riverbank sediments were also examined. Since *enterococci* can naturally occur in Hawaiian soils, it is important to be aware that during high precipitation time periods, large amounts of non-sewage related *enterococci* could be washed into the bay. The riverbank sediments sampled contained extremely high levels, some up to 100 times higher than water levels. This could cause a huge influx of bacteria into the water during wet weather events when riverbanks are eroded. River water and sediment samples were also tested for DNA markers, which showed that fecal material came from human and pig sources.

Samples were also taken in the USFWS refuge from drainage ditches, taro *loʻi*, and bird *loʻi*. These results indicated high concentrations of bacteria in the water and sediment of drainage ditches. In the taro *loʻi*, there were relatively low concentrations in both water and sediment. In the bird *loʻi*, low concentrations were recorded in the sediment, but high concentrations in the water, where birds are frequently found.

---

[47] Sampling locations included Waikoko Stream, Waipā Stream, Waioli Stream, and Hanalei River.

[48] The study noted that even on Oʻahu, where there are sewer lines, human markers were found all over the island. It is suspected that the extremely aged sewer line system might be responsible.

5.4 Coral Reef Ecosystem Status

Several factors threaten the health and abundance of coral reefs in Hawai'i including land-based sources of pollutants, such as sediment, nutrients, and other pollutants (Appendix D.3.1). Land-based pollutants are generated from eroding land surfaces, and as the by-products of day-to-day activities occurring on the watershed. These pollutants are transported to the ocean in surface water runoff and in ground water. They are delivered in varying amounts ranging from large loads carried in storm water runoff from intense rainfall events to smaller chronic loads such discharge from seeps and springs. Land-based pollution is responsible for eutrophication, increased sedimentation, toxins, and introduction of pathogens on coral reef systems.

Hanalei Bay is part of the Coral Reef Assessment and Monitoring Program (CRAMP) established in 1997-1998. CRAMP describes Hanalei Bay as "white sand beach extends to shallow carbonate platform. Gradual slope to deeper areas with various reef structures. Diverse reef community." Friedlander et al. (1997) described Hanalei Bay as "characterized by well developing fringing reefs bordering an extensive area of unvegetated carbonate sediments in the center that stretches from beyond the mouth of the bay to the shoreline in the southeast quadrant". Permanent transects established in 1992 Hanalei Bay by Friedlander and Brown were surveyed in 1993, 1999, 2003, 2004 and 2005. Surveying of permanent transects at two depths (3 m and 8 m) established by CRAMP began in 1999. The information gathered has been used to examine the temporal trends in coral reef community structure among other things.

Table 20 shows the average percent coral cover at selected depths in Hanalei Bay for sites that were surveyed over a 13 year period. The overall percent change from the initial survey to the last survey is shown in the last column. Research by Friedlander and Brown (2006) concluded that while overall live coral cover in Hanalei Bay was low (ca. 14%), between 1993 and 1999 the average coral cover increased by 5% and from 1999 to 2004 cover remained stable.

Table 20. Percent Coral Cover at Selected Depths in Hanalei Bay from 1993 to 2005

Sources: Friedlander et al. 1997; Jokiel et al. 2004; Friedlander and Brown 2006

Depth (m)	Year							
	1993	1999	2000	2002	2003	2004	2005	% Change
3	15	16	26	17	17	7	5	-9
5	6	6				8	8	2
7	17	23				23	16	-1
8	20	28	30	26	36	29	29	10
8	8	17				11	12	4
14	21	17				25	19	-1
16	15	25				22	18	3

CRAMP studies of coral planulae recruitment reveal that although there are large numbers of recruits in offshore stations, there is little recruitment near the discharge of the Hanalei River. Long term studies of the live coral cover of the Waipā Reef site, adjacent to Waikoko Stream, have shown a decline in cover although there was ample coral larval recruitment. *Cleaning of Waikoko Stream Discharge in Kauai* (2007-2009), a cooperative project led by Dr. Carl Berg and funded by the NOAA Coral Program and the National Fish and Wildlife Foundation, sought to determine if best management practices (BMP) implemented in taro pond field agriculture in Waikoko Watershed would reduce the nutrient, turbidity, and fecal bacteria pollution levels in Waikoko Stream and prove effective in improving health of the coral reefs immediately offshore. The study used live coral cover as one measure of project success and relied upon long term data collected at permanent CRAMP transects at Waipā Reef. As compared to previously collected CRAMP data, the shallow water reef (3 m depth) had an increase of 30.5% of live coral cover over the course of the project, and the deep water site (8-9.1 m) had a 3.9% increase in live coral cover.

In 2004, a coral disease assessment was added to the CRAMP protocol at three sites within Hanalei Bay. Corals along established belt transects were examined for signs of disease (Aeby 2007). Signs of disease were found at all three sites. "*Montipora* is the dominant coral on the reefs and two *montiporid* diseases were documented including *Montipora* white syndrome and an unusual *Montipora* banded tissue loss disease, which has not been found elsewhere in the Hawaiian archipelago. Heavy sediment stress was evident on the reefs, which might explain the occurrence of the unusual disease." At the site "Hanalei Wall" the reef slope was covered with sediment and majority of corals showed signs of stress. The highest level of coral disease was found at this site. In addition, the *Cleaning of Waikoko Stream Discharge in Kauai* project also looked at the number of *Montipora* infected with disease and found that rates of coral disease decreased during the project implementation. During 2007-2008, at the 3 m site there was a 61.7% decrease and at the 8-9.1 m site there was an 83.5% decrease. That data was also collected as part of the CRAMP protocol.

6. Pollutant Source Assessment

This section presents general information about sources and characteristics of NPS pollutants, and includes specifics about their presence in the Hanalei Bay Watershed.

6.1 Non-Point Source Pollutants Overview

Pollutants transported in runoff, including storm water, agricultural, and urban runoff can be categorized as either point source or NPS pollution. Point source pollutants are discharged directly into surface waters from a conveyance feature (e.g. pipe) and are managed under the CWA via the National Pollutant Discharge Elimination System (NPDES) permit process (Appendix C.3). These sources include municipal sewage treatment plants, combined sewer overflows, and storm sewers. There are no NPDES permits for such discharges in the Hanalei Bay Watershed. NPS pollutants are derived from diffuse origins (e.g. streets, parking lots, forested lands, agriculture parcels, and other areas within a watershed). NPS pollutants travel off watersheds in both surface and ground waters and the specific transport mechanisms and rates vary by substance. NPS pollutants degrade water quality, place stressors on biotic organisms, alter trophic level functions, and may render the water non-usable or unsafe to humans. The NPS pollutants nutrients, bacteria, and TSS have been identified to be impairing various water bodies in the Hanalei Bay Watershed.

A primary objective of this characterization is to identify the land uses and conditions that generate NPS pollutants to facilitate the development of targeted remedial actions aimed at reducing pollutant loads delivered to Hanalei Bay. The rate at which NPS pollutants are generated, and their transport and fate, has been the subject of numerous scientific studies. Some of these studies have helped with quantifying the amount of NPS pollutants that occur naturally versus from human uses and activities. However, there are still uncertainties with respect to exactly how much of the various pollutants are generated from specific locations within the watersheds.

Table 21. Major Categories of Storm Water Pollutants, Sources and Related Impacts[49]

Storm Water Pollutant	Major Sources	Related Impacts
Nutrients: Nitrogen, Phosphorus	Fertilizers from taro pond fields and farm fields; effluent from wastewater systems; urban runoff; feral and domestic animals; erosion of uplands and stream banks; gardens; lawns; woodlands; fertilizers; construction soil losses	Algal growth; reduced clarity; lower dissolved oxygen; release of other pollutants; visual impairment; recreational impacts
Solids: Sediment (clean and contaminated)	Construction sites; other disturbed and/or non- vegetated lands; urban runoff; stream bank and shoreline erosion	Increased turbidity; reduced clarity; lower dissolved oxygen; deposition of sediments; smothering of aquatic habitat including spawning sites; sediment and benthic toxicity
Oxygen-depleting substances	Biodegradable organic material such as plant; fish; animal matter; leaves; lawn clippings; sewage; manure; food wastes; other applied chemicals	Suffocation or stress of adult fish, resulting in fish kills; reduction in fish reproduction by suffocation/stress of sensitive eggs and larvae; aquatic larvae kills; increased anaerobic bacteria activity resulting in noxious gases or foul odors often associated with polluted water bodies; release of particulate bound pollutants
Pathogens: Bacteria, Viruses, Protozoans	Domestic and natural animal wastes; urban runoff; IWS; natural generation	Human health risks via drinking water supplies; contaminated shellfish growing areas and swimming beaches; incidental ingestion or contact
Metals: Lead, Copper, Cadmium, Zinc, Mercury, Chromium, Aluminum, others	Normal wear of automobile brake pads and tires; automobile emissions; automobile fluid leaks; metal roofs; gutters; landfills; corrosion; urban runoff; soil erosion; atmospheric deposition; chemicals contained in pesticides	Toxicity of water column and sediment; bioaccumulation in aquatic species and through food chain
Hydrocarbons: Oil and Grease, Polyaromatichydrocarbons (PAHs) - e.g., Naphthalenes, Pyrenes	Industrial processes; automobile wear; automobile emissions; automobile fluid leaks; waste oil	Toxicity of water column and sediment; bioaccumulation in aquatic species and through food chain; lower dissolved oxygen; coating of aquatic organism gills/impact on respiration
Organics: Pesticides, Polychlorinated biphenyls (PCBs), Synthetic chemicals	Applied pesticides (herbicides, insecticides, fungicides, rodenticides, etc.); nurseries; orchards; lawns; gardens; taro *lo'i*	Toxicity of water column and sediment; bioaccumulation in aquatic species and through food chain contaminated soils/wash-off
Inorganic Acids and Salts (sulphuric acid, sodium chloride)	Irrigated lands; landfills	Toxicity of water column and sediment

6.2 NPS Pollution: Sediments

In general, sediments are the result of surficial erosion on the land and streambanks. Surficial erosion is the process by which soil and rock particles are removed either by raindrop impact or overland flow transported via surface runoff, and then deposited. Mass wasting, the failure of slopes under the force of gravity, is another source of sediments. Evidence of mass failures is abundant on the steep slopes of the four subwatersheds. The large block of earthen material moved by mass

[49] Modified from Field et al. 2004.

wasting can be deposited on the lands below the failure becoming prone to surface erosion and transport, or can fall directly into waterways. Sediment is also sourced from stream banks that are prone to erosion primarily during high flows. These processes occur naturally, as is evidenced by the landscape and topography of the Hanalei Bay Watershed. Other potential sources are associated more directly with human uses including those that release sediments directly into water ways (e.g. dirt piles placed in close proximity) or remove vegetation, making the ground surface more vulnerable to erosion.

Several studies focusing on the source of sediments that are deposited in the watersheds and the fate of sediments delivered into the Bay by the Hanalei River have been conducted. One study sought to determine the contribution of the sources of sediments deposited on the floodplain from upland soils, stream banks, within the stream channel, and mass wasting (Ritchie and Pedone 2008). The amount of sediment deposited on the Hanalei River floodplain was measured and tied back to the four sources using Cesium isotopes in the sediments. Preliminary results indicate that stream banks are probably the most significant source of sediments deposited on the flood plain, followed by mass wasting. The study found that deposition of sediments on the flood plain was moderate, meaning that a portion of sediments carried by the river makes it past the floodplain to the Bay. During flows where water is contained within the river channel, it is logical to conclude that very little deposition occurs on the floodplain. However, when the channel over tops and spills across the floodplain, deposition occurs.

Draut et al. (2009) looked at the supply and dispersal of sediments deposited by the Hanalei River into the Bay. Large rainfall events that generate high river flows and carry large volumes of suspended sediments often coincide with high wave energy periods. Sediments carried into the Bay are often moved around, and carried out beyond the reef, lessening the thickness of sediments deposited in the Bay and reducing the time the sediments stay in the Bay. Sediment discharge events that occur during low wave energy periods such as the summer months have the potential to cause more ecological damage since the sediments are not reworked and remain within the Bay for longer periods of time. The adverse impacts of sediment during the summer months could be exacerbated by human generation of sediments and potential increase in frequency of storm events during this period. Because corals spawn in the Bay during the summer months, the introduction of sediments in even low concentrations is of concern as the coral larvae are very vulnerable to sediment.

A portion of the small (fine) sediments eroded from the watersheds is carried in streams and rivers in suspension where it affects water clarity or turbidity. Larger sediment particles are transported along the bed of the stream channels, bouncing and rolling when energy generated by high flows overcomes the resisting force of the particle. From a water quality perspective, suspended sediments are the primary concern (Appendix D.1.3). Bedload is a concern when it causes rapid morphologic changes and shifts the channel alignment, especially on floodways that are developed for human uses. Sediments can be deposited along the waterways and/or transported into Hanalei Bay directly. During floods when stream water spills out onto floodways, some of the sediment deposits, building up the land. Along the Hanalei River one farmer has observed deposited layers of sediment up to three feet thick following a large runoff event (Fitzgerald, pers. comm.).

The rate of erosion and the amount of sediment generated is primarily a function of rainfall intensity, land cover, slope, and the physical properties of soil. Removal of vegetation and decrease in ground cover, canopy density, and structure, and surface disturbances by humans and animals, accelerate erosion rates and sediment generation. Based on extensive review of scientific literature, discussion with residents of the Hanalei region, and professional judgment, the following specific activities were identified as the mostly likely to increase the rate of erosion over background, and subsequently water turbidity:

- Feral and domestic animals, via consuming/trampling vegetation, and creating trails.
- Removal of vegetation in the watershed or along its stream banks.
- Changes to vegetation types and structure on the watershed and along stream banks.
- Resuspension of fine sediments in *lo'i*.

The relative and absolute amount of increase of erosion rates and turbidity attributed to these four activities has not been conclusively determined by scientists or as part of the two TMDLs. However, the damage to forest and agricultural lands attributed to feral pigs is significant. Recent panel discussions have been held to discuss the damage feral pigs cause to watersheds across the State (Tummons 2011). Feral pigs have accelerated rates of erosion; altered hydrologic and ecologic processes; and seriously degraded physical, biological, and chemical parameters of waters in the Hanalei Bay Watershed. Fares (2007) used the AnnAGNPS watershed model to evaluate simulated runoff and soil erosion in a 50 km^2 area in the upper portion of Hanalei Watershed. Nearly 90% of the study area was affected by feral pig activity (42% with high pig disturbance, 37% with light pig disturbance, and 9% with trace pig disturbance). Model results predicted sedimentation at a rate of 2.5 times than that without pig damage (Fares 2007).

Domestic animals such as cattle can increase stream and *'auwai* (ditch) bank erosion rates and sediment inputs by removing vegetation and trampling. In areas where cattle have direct access to water bodies, bank vegetation may be grazed and the soil trampled, leaving it exposed and damaged. Animals may also induce bank failure directly into a water body. During preparation of this report two locations were observed where *'auwai* were impacted by sedimentation caused by animal trampling. A parcel owned by Princeville Agricultural LLC is used as pasture for approximately 67 head of cattle. A ditch that drains a portion of this parcel and terminates in the Hanalei River upstream of the Dolphin Restaurant is used as water source by the cattle. A similar situation is occurring on the north side of the Hanalei River on a parcel owned by Martha J. Mowry. Approximately six buffalo were observed using an *'auwai* that drains into the Hanalei River for watering and wallowing. In addition to sediments that appear to route directly into the Hanalei River, animal feces and urine are likely carried into the river water. The waste contains bacteria and nutrients. This scenario of animal damage to *'auwai* and the riparian zone occurred previously in Waipā Watershed and was the driver for installation of riparian fences to restrict cattle encroachment onto *'auwai* and stream banks. There are probably other paddocks in the Wai'oli and Hanalei Watersheds that are subjected to domestic animal impacts that were not observed during preparation of this report.

Changes to watershed vegetation communities from native-endemic species to non-native dominated have been both deliberate and incidental to human uses and activities. The working hypothesis proposed by scientists in Hawaiʻi is that non-native vegetation alters the hydrologic process by reducing groundwater recharge, increasing rates of erosion, and increasing evapotranspiration. There are several ongoing studies testing this hypothesis, and information gathered during preparation of this WMP seems to support this hypothesis. Without question, removal of vegetation from steep slopes increases rates of erosion and timing and magnitude of surface overland flow.

Along the rivers and streams of the Hanalei Bay Watershed, hau bush (*Hibiscus tiliaceus*) has been suspected of causing stream bank erosion and sedimentation. The hydraulic and fluvial processes along a river course are complex and dynamic, and not easily explainable. Hau bush may both increase and decrease erosion deposition rates in and along the streams depending on flow conditions and site geometry, which vary spatially and temporally. In general, woody vegetation along a stream bank increases the coefficient of drag or friction and slows water velocity, which lowers kinetic energy and erosive energy needed to detach bank sediments. However, due to variations in plant morphology and root tensional strength, the range of friction and bank protection varies significantly. Plants like hau bush with high tensional root strength, that are flexible, and that can withstand periodic submergence, are most resistant to bank erosion. Constriction of stream channel width by hau bush, such as along the Hanalei River upstream and across from the Dolphin Restaurant, is posited by some community members to divert the direction and magnitude of water velocity towards the opposite downstream bank, increasing erosion rates and failure. Hau bush removal has been conducted from sections of the Waipā River in the Waipā Watershed. Initial hau bush removal efforts were conducted by HWH in 2003, and more recently by Matt Rosener and staff of the Waipā Foundation. Preliminary results show that river substrate size has increased and bed morphology has become more variable (M. Rosener pers. comm.). This is likely due to an increase in stream velocities associated with hau bush removal and an associated increase in stream energy that lifts and carries the fine sediments that dominated the stream bed prior to hau bush removal.

Activities that re-suspend fine sediments occur in some of the wetlands and *loʻi*. Some taro farmers enter into their *loʻi* during growing periods to pull weeds, perform crop inspections, apply fertilizers and pest controls, perform *ʻauwai* maintenance, and harvest leaves. Wet tilling occurs in *loʻi* across the watershed. These activities may cause unintended re-suspension of fine materials such as sediments, plant detritus, and bird waste, which increases turbidity of *loʻi* water. The re-suspended material can discharge out of the *loʻi* via its *ʻauwai* to other waterbodies when outlets are left open. Taro *loʻi* drain directly into the Hanalei River and the three streams that drain the other watersheds. The turbid waters that are known to periodically flow out of the *loʻi* are most likely carrying some nutrients as well as TSS. The issue of sedimentation from *loʻi* is not new. Check gates to block several *ʻauwai* were installed in the Hanalei NWR to cause sediment settlement (Section 0). By all accounts the structures worked and lessened the amount of sediment transported into the Hanalei River. Scientists with the HWH estimated an 11% decrease in turbidity from taro *loʻi* due to the check gates (HWH 2006). Baffle boxes, another type of BMP, were also installed to trap sediments in some of the Hanalei NWR *ʻauwai*, and for the most part they functioned. However maintenance, which was to be performed by farmers, did not continue and the structures became obsolete. Re-suspension of fine sediments and organic matter may also occur from waterbirds using taro *loʻi* and wetlands.

The relative and absolute amounts of sediments generated from forested conservation, agriculture, and urban land types in the four subwatersheds and the differences between background and natural rates has not been conclusively determined. However, observation during and following a large rainfall event demonstrates that the waterways draining the watersheds become sediment laden and carry large amounts of fine material and plant matter into the Bay. The largest percentage of land area in each watershed is moderately to extremely sloped Conservation lands that are prone to continuous damage by feral pigs, mostly covered in non-native vegetation, and subjected to geologically recent landscape level disturbances such as hurricanes. Based on these reasons, it is reasonable to surmise that sediment generated from Conservation lands now occurs at rates higher than background. The degree of sediment generation that is above background has not been determined (Tetra Tech and DOH 2008). Scientists studying the rates of erosion for pre-human contact and the present have found that rates are similar for the two time periods (M. Rosener, pers. comm.). A review of the suspended sediment data collected at the USGS Hanalei River stream gage found that a small percentage of the total annual sediment load in the Hanalei River is carried during low stream flows. This results from low stream energy during low flows, and that the amount of available fine sediments input to the streams is tempered by the decrease in rainfall events during the dry season. Human disturbance, such as direct input of fine mud and sediment into the waterways and re-suspension of fine materials, has the effect of increasing suspended sediment loads and turbidity during the dry season primarily downstream of the USGS gage. Sediment discharges have the potential to cause disproportional adverse impacts to water quality and ecology during the dry summer months. Since ocean wave energy is at an annual low, and mixing and transport of material delivered into the Bay is correspondingly low, the resident time and deposition is less and higher respectively for material delivered by the streams during the summer months (Storalzzi et al. 2009).

There have been documented instances of land owners dredging and filling wetlands and conducting grading and grubbing operations without proper permits or use of construction best management practices to control discharges of sediments into natural and manmade waterways. One property, located along the east side of the Hanalei River above Blackpot and owned by Ed Ben Dor, was issued a Finding of Violation and Order for Compliance under the CWA by the USEPA in 2002 for such a matter. Concerns over potential ongoing violations of the CWA on this property were raised by community members during preparation of the HBWMP. These concerns were likely the result of their observations of maintenance to waterways on the Ben Dor parcel. Subsequent conversations with DOH and EPA found that the land owner was in compliance with the CWA and that no enforcement actions were being pursued.

6.3 NPS Pollution: Nutrients

Nutrients (Nitrogen and Phosphorus) have been found to frequently exceed water quality criteria in the watershed. Sources of nutrients are derived from atmospheric, geological and vegetative matter, fertilizers, and human and animal waste. Similar to sediments, nutrient levels in soils and water bodies occurs naturally. Human and animal uses and impacts to the watersheds can increase the level of nutrients above background. Human impacts from soil erosion, fertilizers, human waste, food waste, and cleaning products can increase bacteria and nutrients.

Elevated levels of Nitrogen and Phosphorus can trigger algal blooms in ocean and fresh water bodies respectively. Nitrogen has been identified as the nutrient limiting algae growth in Hanalei Bay and has been tied to fertilizers (Derse et al. 2007). The transport of Nitrogen off the watershed into the Bay is by both surface and ground waters. Phosphorus is primarily carried in surface waters and shows a positive correlation to suspended sediments. Research undertaken to identify the sources of nutrients to the near shore waters of Hanalei Bay found that Nitrate + Nitrite Nitrogen carried in submarine groundwater may provide 2.7 times the amount carried into the Bay by the Hanalei River (Knee et al. 2008). The same study reported that submarine groundwater may deliver 15% and 20% of the load of Phosphorus and Ammonium, respectively, as the Hanalei River delivers to the Bay. This study also found that nutrients and bacteria discharged into the nearshore waters of the Bay were highest along the shore and decreased with distance away from it. Additionally, the authors concluded that local controls on ground water quality exist, meaning that there is potential for cesspool effluent to affect the water quality in proximity to and along the flow path the water follows to the ocean. This study also sampled for fecal indicator bacteria, which were found at most of the samples collected. The fecal samples were tested using genetic markers to determine the source of the bacteria, which indicated humans as the source.

Nutrients have been an issue of concern for years in the Hanalei Bay Watershed. Dr. C. Berg has experimented with practices to reduce the amount of nutrients from fertilizers applied to taro pond fields in Waikoko Watershed. Slow-release fertilizer was applied to several *lo‘i* to compare export of Nitrogen and Phosphorus, crop growth, and yields to conventionally fertilized *lo‘i*. Slow-release fertilizers were found to reduce the amount of nutrients applied to the *lo‘i* and exported to receiving waters while resulting in equivalent crop yields. A similar study by University of Hawai‘i researchers is underway on the Hanalei NWR.

6.3.1 Waterbirds

The Hanalei NWR, with its *lo‘i*, supports a large waterbird population. The approximately 200 acres of *lo‘i* at the Hanalei NWR, 60 acres of which are intensively managed as waterbird habitat and 141 acres of which are managed for growing taro, provide habitat for waterbirds including the Hawaiian duck (*Koloa maoli*), Hawaiian coot (*‘Alae ke‘oke‘o*), Hawaiian moorhen (*‘Alae ‘ula*), Hawaiian stilt (*Ae‘o*), and Hawaiian goose (*Nēnē*) (Figure 13). These birds are a potential source of Nitrogen and Phosphorus into Hanalei Bay. The water levels in the *lo‘i* are managed by a series of ditches and dikes that eventually allow the water to be carried to the Hanalei River. Although some nutrients are likely sequestered and/or remediated by biogeochemical processes prior to transport out of the *lo‘i*, some portion of bird feces is likely carried to the river and eventually the bay, especially during heavy rainfall events.

Monthly bird counts conducted at the Hanalei NWR from December 2009 through December 2010 indicate that the average total yearly population of the five main waterbird species, is just over

1,300 birds.[50] The loading rates of bird waste from the *lo'i* and surrounding land into the Hanalei River are difficult to compute due to lack of species-specific information on the amount of waste produced per bird and the amount of Nitrogen and Phosphorus it contains. However, there are a variety of studies examining the effects of bird-derived nutrients on water quality, especially for Canada geese (*Branta canadensis*), a close relative of the *Nēnē* (Pettigrew et al. 1998, Scherer et al. 1995, Manny et al. 1994, Brandvold et al. 1976, Manny et al. 1975). Recent bird counts coupled with nutrient content of Canada geese feces taken from these studies indicate that approximately 365 lb (173 kg) of Nitrogen and 115 lb (52 kg) of Phosphorus are potentially being deposited in the *lo'i* yearly from the 131 *Nēnē* alone.[51] The average *Nēnē* population represents approximately 10% of the population of the five main waterbird species.

Most researchers agree that the degree of impact by bird-derived nutrients depends on the number of birds in an area and the size and type of waterbody. In general, while there is potential for birds, especially waterbirds, to contribute to eutrophication, the impact of bird-derived nutrients alone on water quality, even from relatively large bird populations, are not usually enough to cause water quality to exceed accepted standards (Pettigrew et al. 1998, Post et al. 1998, Scherer et al. 1995, Marion et al. 1994). Although previous studies have focused on different species than are present at the Hanalei NWR and were not conducted in a tropical environment, based on the results of these studies, the average number of birds present at the Hanalei NWR, and that some degree of natural attenuation is probably occurring, it is unlikely that the bird population is a significant contributor of Nitrogen and Phosphorus into Hanalei Bay.

6.4 NPS Pollution: Bacteria and Parasites

Microbial pathogens such as bacteria, parasites, fungi, viruses, and protozoans are organisms that pose a human health risk by causing disease. The ecology of microbial organisms including bacteria is complex, and as a result their sources and relative and absolute numbers at background and elevated levels are not completely understood (Appendix D.1.2). Some bacteria occur naturally in soil, water, and in intestines of warm blooded animals. From a water quality perspective, pathogenic bacteria from humans and animals are a primary concern due to the potential to transmit disease through sores, ingesting contaminated water, and by contact with contaminated soils.

In the Hanalei region, human waste is a source of pathogenic bacteria and parasites. In addition, wild birds, particularly waterbirds, and feral pigs are sources of microbial pathogens. Although potentially challenging to identify sources and distinguish from background levels, recent advances in using genetic markers of indicator bacteria have confirmed that human and animal waste are present in some of the surface water bodies and soils in Hanalei Bay Watershed (Appendix D.1.5.1). Sources of microbial organisms and how they are introduced into the environment are described in this section.

---

[50] Average monthly count by species: Hawaiian duck (*Koloa maoli*) = 269; Hawaiian coot (*'Alae ke'oke'o*) = 390; Hawaiian moorhen (*'Alae 'ula*) = 293; Hawaiian stilt (*Ae'o*), = 239; and Hawaiian goose (*Nēnē*) = 131.

[51] Calculations based on an average of 68.3 defecations per bird, per day with each defecation weighing 1.2 g of which 4.4% is Nitrogen, and 1.3% is Phosphorus (Pettigrew et al. 1998, Scherer et al. 1995, Manny et al. 1975).

6.4.1 Individual Wastewater Treament and Disposal Systems

There is no centralized wastewater treatment and disposal facility in Hanalei town and the greater north shore region. Princeville Development utilizes a secondary wastewater treatment system and deep injection wells for disposal, but the collection system does not extend down into the Hanalei Valley. Properties in Hanalei town and the surrounding area handle wastewater, including sewage, with IWS. The types of IWS used in the Hanalei Bay Watershed include package plants, cesspools, septic tanks, aerobic treatment units, and injection wells (Appendix D.6). An estimate of the total number and types of IWS was generated based on extensive review of DOH databases, TMKs, air images, and investigation by EPA personnel (Table 22; Figure 25 - Figure 27).[52]

The issue of sanitary wastewater treatment and disposal has been a topic of concern in the Hanalei community for nearly two decades. In 2002 the HWH and the community conducted a feasibility assessment of various alternatives that utilized a centralized wastewater treatment facility. The primary driver of the assessment was the identified need to replace cesspools, which provide little to no treatment of waste, and septic tanks that service most of the parcels in the area. The feasibility assessment resulted in the selection of a constructed wetland as the preferred treatment method. However due to logistical issues, such as lack of a parcel of suitable size for siting a wetland, the centralized option did not move forward. Subsequently, the HWH, in collaboration with local community partners, sought and acquired Federal funds to replace cesspools identified as sources of pollutants to the Hanalei and Waipā Rivers. Between 2005 and 2010 ten cesspools were replaced with septic tanks. The Federal funds allocated to the upgrades were used to replace the County-owned cesspool at the Hanalei Pavilion, and upgrade three other systems (two along the beach on County lands and one at the County Maintenance yard). Four cesspools were replaced on the Hanalei NWR and two in Waipā Watershed. These cesspool replacement projects were deemed successful with respect to both how collaborative projects can work, and with improving water quality. Water quality samples collected at a few of the replacement sites along the Hanalei River in the Hanalei NWR prior and subsequent to replacement showed reductions in nutrients, bacteria and other water quality parameters (M. Rosener, pers. comm.).

Table 22. Individual Wastewater Systems

Type of IWS	Number of IWS Units per Parcel	Notes
Package Plant	2	Hanalei Center & Ching Young Village
Cesspool	171	Potentially 41 more
Septic Tank	169	Potentially 41 less
Aerobic Treatment Unit	3	
No Plumbing	1	N/A
Other	1	Unidentified
Total	**347**	

The issue of wastewater collection, treatment, and disposal is still of concern since the numerous IWS are likely sources of nutrients and bacteria to surface and ground waters that flow into the Bay. Approximately 98 percent of the IWS are within 0.4 mi (0.64 km) of the Hanalei Bay shoreline. Most

[52] The numbers of IWS and their types estimated by EPA should be considered the best estimate to date and correlate closely to numbers and types SRGII derived independently.

of the IWS in the Hanalei Bay Watershed are located at ground elevations equal to or less than 25 ft (7 m) msl, with a large percentage of those located at lower elevations. Except for the non-conforming large capacity cesspools (LCC) that are still in use, all other IWS are permitted and conforming, and no citations for permit violations or illicit discharges associated with operations of these IWS have been issued.

6.4.1.1 Package Plants

The two commercial properties in Hanalei town, Hanalei Center and Ching Young Village, operate what are referred to as 'package plants'. The plants are permitted under the DOH Safe Drinking Water Branch. The DOH Underground Injection Code (UIC) permits are UK-1898 and UK-2232 for the Hanalei Center and Ching Young Village respectively. The plants receive wastewater collected from buildings that house retailers, restaurants, and offices. The wastewater is treated to secondary wastewater treatment levels and the partially treated effluent is discharged below ground via injection wells at depths of 7 ft (2.3 m) msl and 4 ft (1.3 m) msl respectively. Neither plant is required to disinfect the partially treated effluent prior to injecting into the ground. The injection wells from the two plants are located approximately 600 ft (183 m) apart, and approximately 1,300 ft (396 m) from the shoreline of Hanalei Bay.

The plant at Ching Young Village processes 8,000 gallons/day (30,283 L/day) and the Hanalei Center plant processes 7,000 gallons/day (26,498 L/day). Table 26 shows pollutant load estimates from these facilities. The UIC permits regulate various water quality parameters that must be met, the maximum amount of wastewater that the plants can treat per day, and the frequency of sampling and maintenance that must be conducted. Per conversations with the operators there are no issues with the plants. The Hanalei Center does periodically disinfect the partially treated effluent with bleach prior to injecting. This is not required and done voluntarily in order to reduce the chance that bacteria might migrate via ground water into Hanalei Bay.

6.4.1.2 Cesspools

Cesspools have frequently been listed as a problem source of excess nutrients and bacteria in Hawai'i. Cesspools are extremely outdated and although EPA does not regulate cesspools of single family homes or of facilities serving less than 20 people, it recommends that all households still using cesspools switch to septic tanks that provide treatment to waste water in both the septic tank and the systems disposal field. DOH Wastewater Branch does regulate cesspools and maintains a database of registered cesspools for all islands. Under HAR §11-62-05, the entire island of Kaua'i is designated as a Critical Wastewater Disposal Area. Construction of new cesspools is prohibited in these areas. Upgrades to small capacity cesspools may be triggered by redevelopment/addition to homes, etc. DOH Safe Drinking Water Branch has delineated UIC lines that are used to protect drinking water sources (ground water) from contamination. UIC injection permits and cesspools are not permitted *mauka* of the UIC line.

Table 23. Pollutant Contributions from Commercial Center Wastewater Treatment Plants

Water Quality Parameter	Average (mg/L)		Daily (kg)		Annually (kg)		Daily (lbs)		Annually (lbs)	
	Hanalei Center	Ching Young	Hanalei Center	Ching Young	Hanalei Center	Ching Young	Hanalei Center	Ching Young	Hanalei Center	Ching Young
TSS	17.48	27.86	0.46	0.84	169.05	307.90	1.02	1.86	372.69	678.79
NH_4^+ (as N)	6.86	4.66	0.18	0.14	66.36	51.47	0.40	0.31	146.30	113.48
NO_x (as N)	1.99	1.75	0.05	0.05	19.24	19.36	0.12	0.12	42.42	42.68
Total Kjeldahl Nitrogen (as N)	7.88	9.28	0.21	0.28	76.21	102.61	0.46	0.62	168.01	226.22
Total P	4.71	5.60	0.12	0.17	45.56	61.92	0.28	0.37	100.44	136.50
Orthophosphate (as P)	2.96	4.02	0.08	0.12	28.64	44.49	0.17	0.27	63.14	98.08
Fecal Coliform (in MPN)	726.45	1067.33	19.25 million	32.32 million	NA	NA	7 billion	11.8 billion	NA	NA

Notes: All measurements were rounded to two decimals. All measurements are in the units stated in column heading except Fecal Coliform, which is in most probable number (MPN). Averages are results of effluent water quality testing performed by Hanalei Center from 1997-2009 and Ching Young Village from 2004-2006 as reported to DOH. The daily and annual loads were calculated based on effluent test results and total wastewater processed in each plant. Ching Young Village processes 8,000 gallons per day. Hanalei Center processes 7,000 gallons/day. This effluent is injected into the ground via injection wells.

Table 24. Typical Onsite Wastewater Effluent by Treatment Type

(Source: WRRC and Engineering Solutions 2008)

Type	BOD (mg/L)	TSS (mg/L)	Total N (mg/L)	Total P (mg/L)	Fecal Coliform (CFU/100ml)
Raw Domestic Wastewater	100-400	100-400	14-40	5-20	100 million
Septic Tank Effluent	132-217	49-161	39-82	11-22	1-100 million
Cesspool Effluent	100-400	100-400	15-90	5-20	1-100 million

Cesspools do very little to treat wastewater and are considered disposal systems rather than treatment systems. In the Hanalei Bay Watershed there are 171 cesspools (Table 22). Many of these units are in close proximity to surface water bodies, and all are above the ground water, resulting in a high probability for contamination. Water quality for various pollutants from raw domestic wastewater and effluent from both cesspools and septic tanks are shown in Table 24. A key finding is that cesspools essentially pass through pollutants with no reduction or treatment, while septic tanks provide some level of reduction.

LCC are defined as residential multiple-dwelling, community or regional systems or non-residential if serving over 20 people per day (e.g. churches and beach parks). The construction of new LCC was banned by EPA in 2000 and existing ones were banned effective April 5, 2005. All LCC that had not been closed by that date were required to do so immediately. However, in Hanalei there is still at least one known LCC in use servicing the buildings on the parcel occupied by the Tahiti Nui Bar.

6.4.1.3 Septic Tanks

There are 169 septic tanks in the Hanalei Bay Watershed (Table 22). Similar to cesspools the majority of septic tanks are located in the low lying coastal plains of the watersheds and in close proximity to surface water bodies. A septic tank differs from a cesspool in that the raw wastewater is treated by microorganisms that live in the tank. In addition, the resident time of liquid in the tank is greater when compared to cesspools. In general, the longer the liquid remains in the tank, the greater the reduction of pollutants. Septic tanks are normally fitted with an effluent disposal component commonly referred to as a leach (absorption) field. Leach fields are located below ground and are lined with various mediums such as sand, and gravel. When the effluent is discharged into the leach field it undergoes additional levels of treatment via physical filtering of the medium lining the field and bioremediation by the microbes that live in the field.

Routine maintenance is required to insure efficient and effective remediation of waste. A tank that is pumped out on a routine basis will have more storage capacity before it fills up and discharges to the leach field, and will maximize the system's effectiveness.

Both septic and cesspool systems that receive more wastewater than the system was designed for have an increased risk of failure. In Hanalei some single family homes have been converted to transient vacation rentals. IWS units that have not been upgraded or resized to accommodate more waste load are more prone to failure.

6.4.1.4 Aerobic Treatment Units

Aerobic treatment units are structurally similar to septic tanks. The major difference is that the units have a second chamber tank (aerobic) that utilizes aeration to enhance microbial decomposition of sewage. The forced air mixes the microbes and the sewage physically and the oxygen increases the microbial action. A third chamber is used for additional settling of solids and is fitted with filter on the effluent disposal system. Similar to a septic tank the effluent can be disposed of in an absorption field. These units are effective and suited to the Hanalei area where IWS are in close proximity to the water table and surface water bodies. A potential drawback is that they require energy to power blower motors. Similar to a septic tank, routine maintenance should be conducted to maximize the system's efficiency.

6.4.2 Diseases from Birds and Feral Pigs

Feces and urine of birds and feral pigs can harbor and spread potential human pathogens including *Campylobacteriosis*, *Cryptosporidium*, and *Salmonella* (Dunkell 2009, Geldreich and Shaw 1993). An estimated 5 to 20 percent of the bird population is periodically infected with *Salmonella* and other intestinal organisms that are pathogenic to humans (Glicker 1999). Although some *Cryptosporidium* species that are pathogenic to humans do not affect birds, birds can be carriers (Clement 1997). Studies in Australia have shown that feral pigs can transmit and excrete a number of infectious waterborne organisms pathogenic to humans (Hampton et al. 2006). Feral pigs are suspected to be the source of *Cryptosporidium* oocysts and *Giardia* spp. cysts detected in some water sources (Atwill et al. 1997). Parasite pathogens, such as *Balantidium* and *Entamoeba*, have been detected in the feces of feral pigs caught in metropolitan drinking water catchments (Hampton et al. 2006).

Diseases that are transmissible from birds and feral pigs to humans that could potentially occur in the Hanalei region waters are depicted in Table 25. Only bacteria and parasites that can remain viable and be transported in water and soil are included.

Table 25. Zoonotic Diseases from Birds and Feral Pigs

Disease in Humans	Pathogen	Carrier	Source	Transmitted By	Notes
Amebiasis	Parasite - *Entamoeba histolytica*	Pig	Feces	Drinking contaminated water	
Balantidiasis	Parasite - *Balantidium coli*	Pig	Feces	Drinking contaminated water	Rare disease
Campylobacteriosis	Bacteria - *Campylobacter*	Bird and pig	Feces	Drinking contaminated water	Can be transmitted from human to human. Can persist in the soil for years after the death of an infected animal.
Cryptosporidiosis	Parasite – *Cryptosporidium*	Bird and pig	Feces	Drinking contaminated water	Can be transmitted from human to human. Can persist in soil and water for long periods of time. Commonly found in streams.
Gastroenteritis	Bacteria - *Escherichia coli*	Bird and pig	Feces	Drinking contaminated water	Can be transmitted from human to human. Can persist in water for long periods of time.
Giardiasis	Parasite - *Giardia lamblia*	Pig	Feces	Drinking contaminated water	Can be transmitted from human to human. Can persist in water for long periods of time.
Leptospirosis	Bacteria – *Leptospira*	Cattle, pig and rodents	Urine	Soil or water contaminated with infected urine	Transmitted by mud or animal urine entering human through eyes, nose, mouth or broken skin.
Salmonellosis	Bacteria – *Samonella*	Bird and pig	Feces	Drinking contaminated water	Can be transmitted from human to human. Can persist in soil and water for long periods of time.

For bacteria, the indicator organisms *Escherichia coli* (*E. coli*) for fresh water and members of the genus *enterococcus* for fresh and marine water, are used as an indicator of fecal contamination. Their presence in water generally indicates fecal contamination, and while the fecals themselves are not generally disease causing, their presence can provide an indication of the potential presence of harmful pathogens. *Enterococci* and *E. coli* abundance has been shown to correlate well with incidence of illness reported by swimmers, particularly gastrointestinal illness. According to EPA studies, enterococci have a greater correlation with swimming-associated gastrointestinal illness in both marine and fresh waters than other bacterial indicator organisms, and are less likely to “die off” in saltwater.[53] Boehm (2010) measured *E. coli* levels much higher than the Federal standard (35 CFU/100ml) at the outlets for the Hanalei River as well as Waiʻoli, Waipā, and Waikoko Streams. Based on genetic sample testing methods, Boehm (2010) suggests that pigs are a significant contributor of fecal indicator bacteria into Hanalei Bay (Section 5.3.3.2).

A number of studies indicate that waterfowl and other wildlife can be a predominant source of fecal contamination of waterbodies (Hasbrouck 2005, Levesque et al. 1993, Valiela et al. 1991, Benton et al. 1983). For example, the fecal coliform level in an average fresh goose dropping is about 1.53×10^4 to 3.6×10^4 per gram (Alderisio and DeLuca 1999, Hussong et al. 1979). Sun-dried fecal samples of Canada geese can also contain significant numbers of viable fecal coliform bacteria. Fecal coliform in old sun dried samples ranged from 8.2×10^2 to 3.0×10^5 per gram. Bacteria remain viable in streambed sediments for long periods of time and are more prevalent in turbid waters because they live in soils and attach to sediment particles. Although increases in the level of bacteria in rivers has been linked to the presence of large number of waterfowl, particularly geese and ducks during times of migration, most research indicates that acceptable Federal standards for *E. coli* are not usually exceeded during periods of average use.

6.4.3 Other Disease Vectors

Feral cats can carry many diseases, but a disease of major concern is toxoplasmosis. Toxoplasmosis is caused by the parasite *Toxoplasma gondii* and although it is found in many species of birds and animals, including humans, cats are the definitive host (i.e. the host in which the parasite reproduces). The most dangerous form of the bacteria is the oocysts, the egg encapsulated form, which is not killed when exposed to air or water (fresh or salt). Toxoplasmosis can be transmitted by exposure to cat feces in the soil, exposure to water carrying the eggs, and ingestion of infected animals. Toxoplasmosis can spread to humans and other animals and has been linked to deaths of Hawaiian monk seals, spinner dolphins, and several species of birds. Since 2006, *T. gondii* has been given as the confirmed or probable cause of death by the USGS-National Wildlife Health Center for six Hawaiian geese and one Hawaiian coot from the Kauai NWR Complex, which includes two Hawaiian geese and one Hawaiian coot from the Hanalei NWR (K. Uyehara, pers. comm.). If toxoplasmosis does not kill animals outright, it can leave them in a weakened state that makes them more vulnerable to predation and other diseases.

Golden apple snails are a vector for disease and can carry the *Angiostrongylus cantonensis* parasite (rat lung worm), which when ingested causes varying degrees of sickness in humans and other mammals. Each year a small number of people in Hawaiʻi are hospitalized with rat lungworm

[53] http://water.epa.gov/type/rsl/monitoring/vms511.cfm

disease after likely ingesting infected snails or slugs in unwashed vegetables (Ballantyne 2009, Stewart 2011). The most severe sickness is a serious form of meningitis, eosinophilic meningoencephalitis, which although not common, has been diagnosed in Hawaiʻi (at least six people in 2005, and four people in 2008 (Hollyer et al. 2010)). Incidence of this disease has only been tracked since 2005. Snails also serve as intermediate hosts to the larvae of trematodes, a parasitic flatworm. Trematodes are associated with infections of "swimmer's itch" and intestinal issues in some animals such as dogs and cats.

There is little information available on the effects of golden apple snails on water quality or competition for food and space with native freshwater biota (Levin 2006). However, a study completed by Carlsson et al. (2004) in Asia found that they have the ability to significantly alter ecosystem health and function. For example, a survey of natural wetlands in Thailand indicated that high densities of golden apple snails were associated with very low populations of native plant species, high nutrient concentrations and subsequent blooms in phytoplankton biomass.

Rats are the most common carriers of the bacteria that causes leptospirosis. Since rats and mongoose feed on golden apple snails, high numbers of snails in wet areas encourages the increased presence of rats and mongoose, which can result in increased incidence of leptospirosis. In addition, cuts from snail shells provide an increased avenue for leptospirosis infection, especially among taro farmers.

6.5 NPS Pollution: Urban (Commercial/Residential)

The urban section of the Hanalei Bay Watershed is primarily located within the larger boundaries of Hanalei town. The main pollutants generated from the urban area are contained in wastewater (Section 6.4.1). Urban areas such as home lots may also be pollutant sources from: pet waste; illicit and unintentional disposal of household products; automobile fluids; food waste; and other by-products of everyday activities and breakdown of building and infrastructure surfaces (Table 21). In general the properties in the urban area are well kept and not significant sources of NPS pollutants other than wastewater. There were no properties where egregious issues were observed or are known to occur. Fertilizers applied to lawns and landscaped areas are a possible source of nutrients. Due in part to the relatively high amounts of rainfall, it is probable that fertilizers are periodically leached into ground water and/or carried in surface water runoff. Though no attempts were made to quantify this scenario, it is presented to reinforce that proper application of fertilizers, pesticides and other chemicals used in landscaping is required to minimize their potential impact on the environment and water quality.

6.5.1 Hanalei Stormwater Management

Stormwater runoff is rainwater that flows over the ground after precipitation events and is eventually discharged into surface waters. The natural ability of soils to attenuate stormwater runoff is diminished by impervious surfaces (e.g. buildings, roads, and parking lots) because they do not allow stormwater to percolate into the ground. Runoff flowing over impervious surfaces picks up a variety of pollutants including nutrients, suspended solids, organic carbon and hydrocarbons, bacteria, trace metals, pesticides, trash, and debris. The resulting stormwater runoff can be a significant source of water pollution and appropriate control measures must be taken. The largest area of impervious surface in the Hanalei Bay Watershed is in the commercial zones of Hanalei Center and Ching Young Village. Contiguous impervious areas were observed in several areas within these zones. The impervious surfaces include building roofs, parking lots, sidewalks, and concrete deck areas. While seemingly benign, during rainfall events the impervious areas quickly generate runoff, which picks up pollutant particles that have accumulated on the ground and carries them offsite to receiving waters. Most of the impervious surfaces appear to be in relatively clean condition. This may be due to the frequency of rainfall that washes off the surfaces, or from upkeep by the property owners.

In the Hanalei Bay region, a Hawaiʻi Department of Transportation (DOT) designated "secondary highway", State Hwy 560 (Kuhio Highway), runs through Hanalei, from Princeville to Haena. A Separate Storm Sewer System (S4) is located along a portion of Kuhio Highway in Hanalei town (Figure 14).[54] The S4 contains the main features of a civil storm drain system and is comprised of curbs and gutters fitted with at least eight inlets that carry surface water runoff into a closed conduit subsurface pipe. Both sides of Kuhio Highway are fitted with these features extending from Cin Wai Tai Road to an *ʻauwai*/ditch located approximately 830 ft (253 m) to the east. The ditch collects water from taro *loʻi* in the western most section of Hanalei Watershed and runs underneath Kuhio Highway via a box culvert near the east end of the Hanalei Center. It eventually empties into the Hanalei River downstream of the Dolphin Restaurant. In addition to the four inlets on each side of the highway, there are inlets fitted to the Ching Young Village shopping center parking lot, where "all stormwater runoff is channeled into Kuhio Highway and Aku Road, where it runs into county drains" (G. Culverhouse, pers. comm.).

During preparation of this report the four storm inlets on each side of Kuhio Highway were inspected and all were found to contain sediment buildup and detritus around the inlets and inside the vaults. The observed conditions and build-up of particulate matter indicates that maintenance had not occurred recently.

Most private parking lots and driveways are bounded by grass or other pervious surfaces that filter storm water runoff and reduce its runoff volume and associated pollutant load. The end of Weke Road near the Hanalei Pier beach park terminates very near the Hanalei River. The last segment of this road dips and is sloped towards the river. As a result during rainy periods the runoff, and any pollutants it picks up, flow directly into the river.

6.6 Other Land Based Pollutants

In 2007 the USGS conducted a study to determine the presence and concentrations of persistent organic contaminants and elements in water, sediment, and biota of the Hanalei River (Orazio et al. 2007). Toxic chemicals investigated included: polycyclic aromatic hydrocarbons, Organochlorine, pesticides, polychlorinated biphenyls, metals and elements such as arsenic, selenium, chromium, lead, mercury and others. The samples were collected and analyzed in adherence with strict scientific protocols. None of the samples indicated a need for follow up actions or were found at concentrations that warranted regulatory action. Several of the chemicals were found at concentrations that reflect natural background levels, and other chemicals were not detectable at

[54] While S4 tend to be regulated via NPDES permits, since there is no designated Municipal Separate Storm Sewer System (MS4), there are no NPDES permits for the S4 or any other pollutant sources in Hanalei (Appendix C.3). However, this does not mean that there are no requirements regarding the discharge of stormwater into State waters, since CWA regulations still have to be followed.

all due to their extremely low concentrations. Samples were not collected from the three other watersheds that drain into Hanalei Bay. However, during preparation of this report there was no indication in the information reviewed that suggests that the other waterbodies would have toxic chemicals at levels greater than those reported for the Hanalei River watershed.

7. Data Gaps

There have been numerous studies and investigations in the Hanalei Bay Watershed focused on understanding the relationship between land uses and conditions; hydrology; and fresh, estuarine, and ocean water quality. In addition, projects to improve water quality, with the goal of reducing land-based pollutants and their delivery to the ocean, have been implemented for nearly a decade. Even so, questions remain and gaps in information and data exist. Additional information would facilitate a more detailed understanding of pollutant sources, land uses, land conditions, and transport mechanisms that are resulting in degraded water quality, impairment to the aquatic ecosystem, and threats to human health. Studies or projects to advance the body of knowledge and help with selection of projects to improve water quality are provided. Although the list is not exhaustive, these items are practical and address some of the basic issues that seem to exist.

Taro Pondfield Water and Nutrient Budget Study. There is no quantitative data on the amount of water and its quality entering and leaving a taro pondfield. A water/nutrient budget can be used to quantify these parameters. Water entering is from irrigation water via inlet and rainfall, and water leaving is the sum of surface outflow, seepage loss, evaporation, and plant transpiration. Water quality of both surface water inflow and outflows is relatively easy to measure. Losses to evaporation can be computed using analytical equations and/or with collected empirical data. Seepage loss could be computed similarly and its quality measured with use of monitoring well(s). The amount of nutrients added via fertilizer applications could be recorded and inputs from birds and other wildlife estimated. Taro plant tissues could be sampled to determine the amount of nutrients taken up by taro so that a complete budget could be computed. Such a study could be conducted concurrently on several *lo'i* representative of different soil types, hydrology, and cultivation practices.

Ground Water and Pollutant Transport Study. Land-based pollutants sourced from ground water have been implicated in the degradation of waters in rivers, estuaries, and Hanalei Bay. However, there been no physically-based ground water modeling studies to determine what types, how much, and travel rates of pollutants in ground water. To better understand the role ground water plays in delivering pollutants into surface waters, and develop strategies to remediate pollutant generation and transport of pollutants, a multi-dimensional ground water modeling study is recommended.

Nitrogen Isotope Signature Study. Researchers from Stanford University conducted nitrogen isotope analysis in 2007 on macroalgae growing in Hanalei Bay. Their work indicates that nitrogen contained in algal tissue was primarily sourced to fertilizers, though it did not specifically identify where the fertilizers were applied. A follow-up study using isotope analysis is recommended. The follow-up study could be used to trace specific types of fertilizers used, and assist in determining locations where the fertilizers are applied. The findings could be used to target specific locations for remedial strategies.

Appendix A. Figures

This page intentionally left blank.

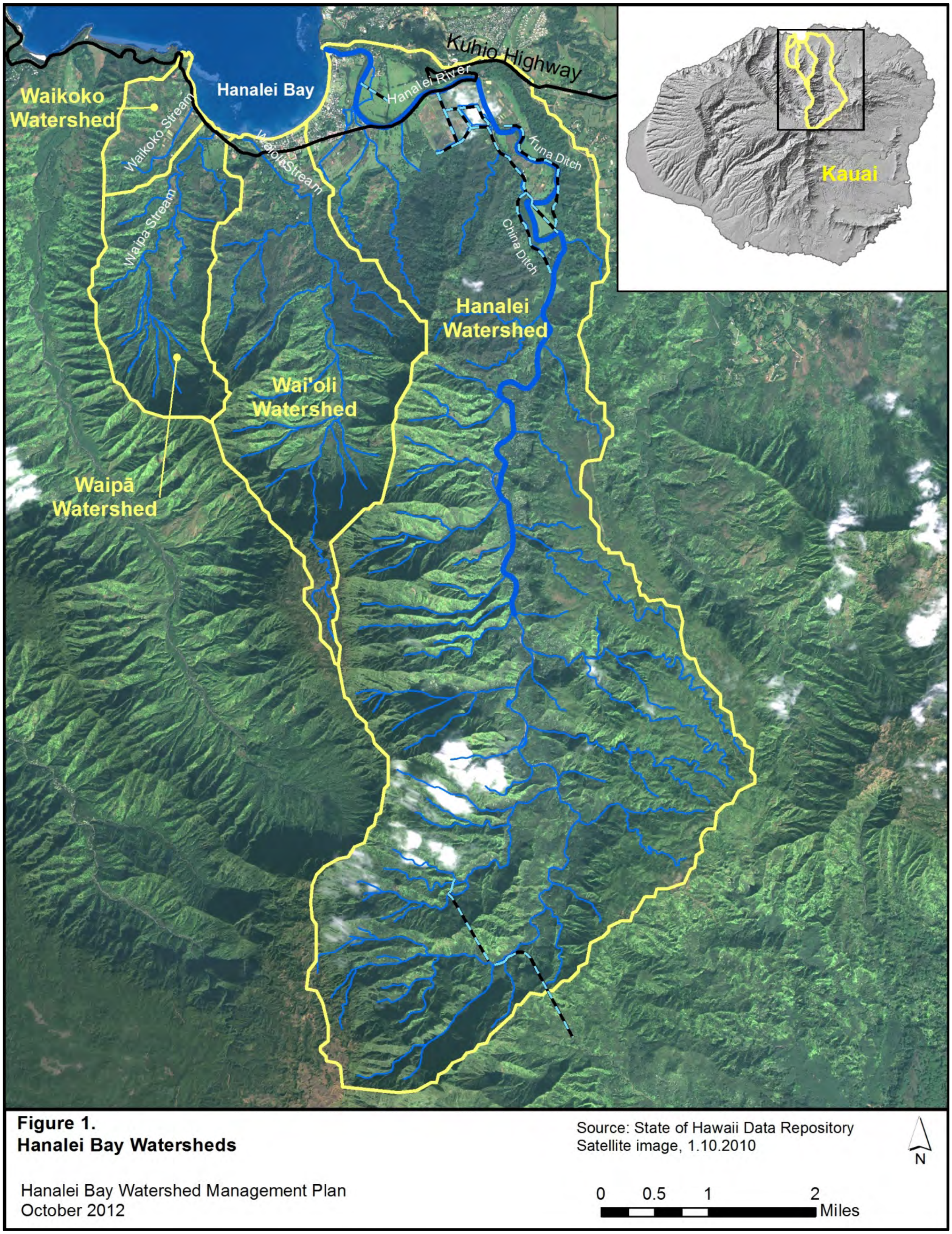


Figure 1.
Hanalei Bay Watersheds

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

Hanalei Bay Watershed Management Plan
October 2012

1

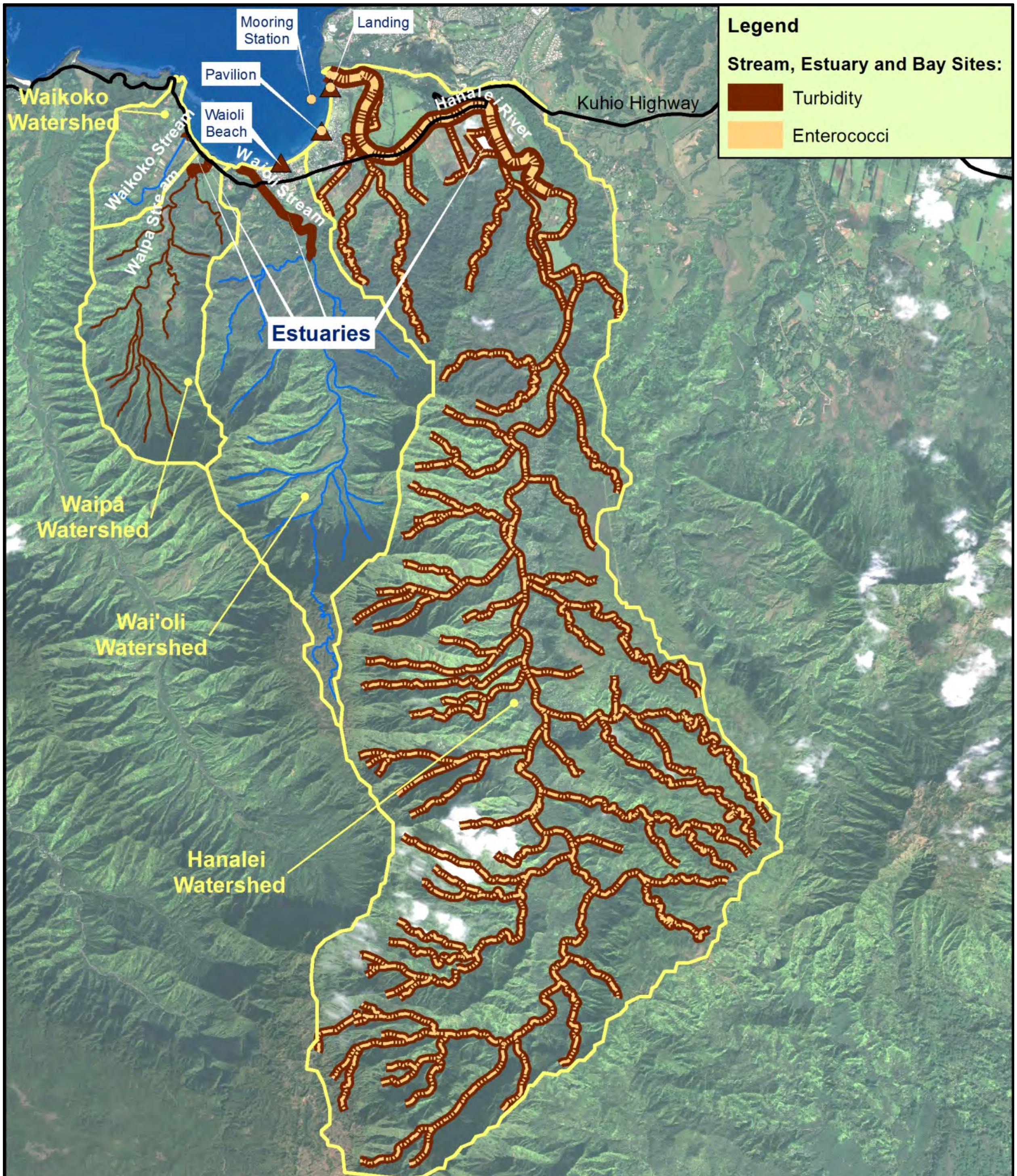


Figure 2.
Water Quality Limited Segments

Hanalei Bay Watershed Management Plan
October 2012

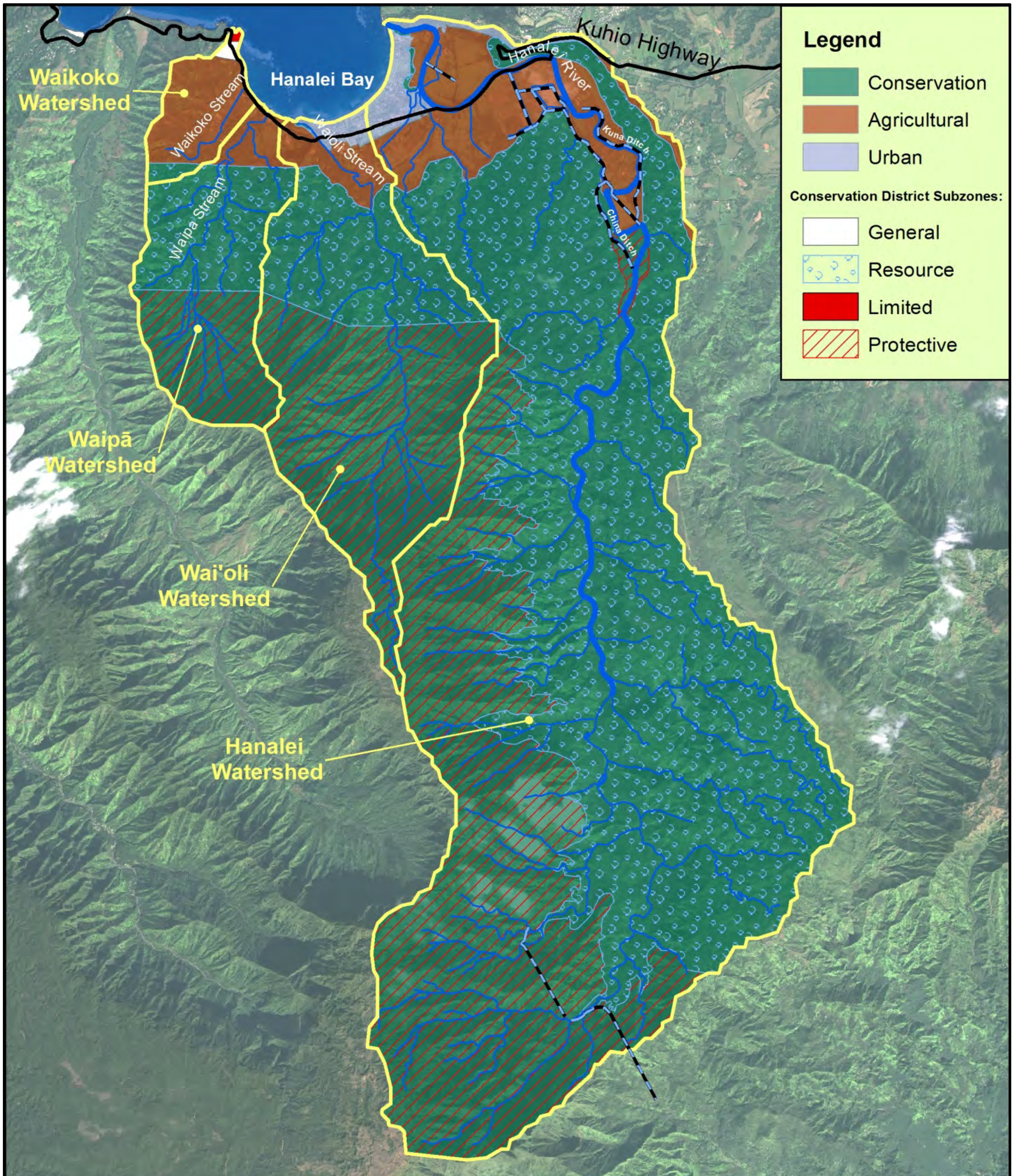


Figure 3.
State Land Use Districts

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.5 1 2 Miles

Hanalei Bay Watershed Management Plan
October 2012

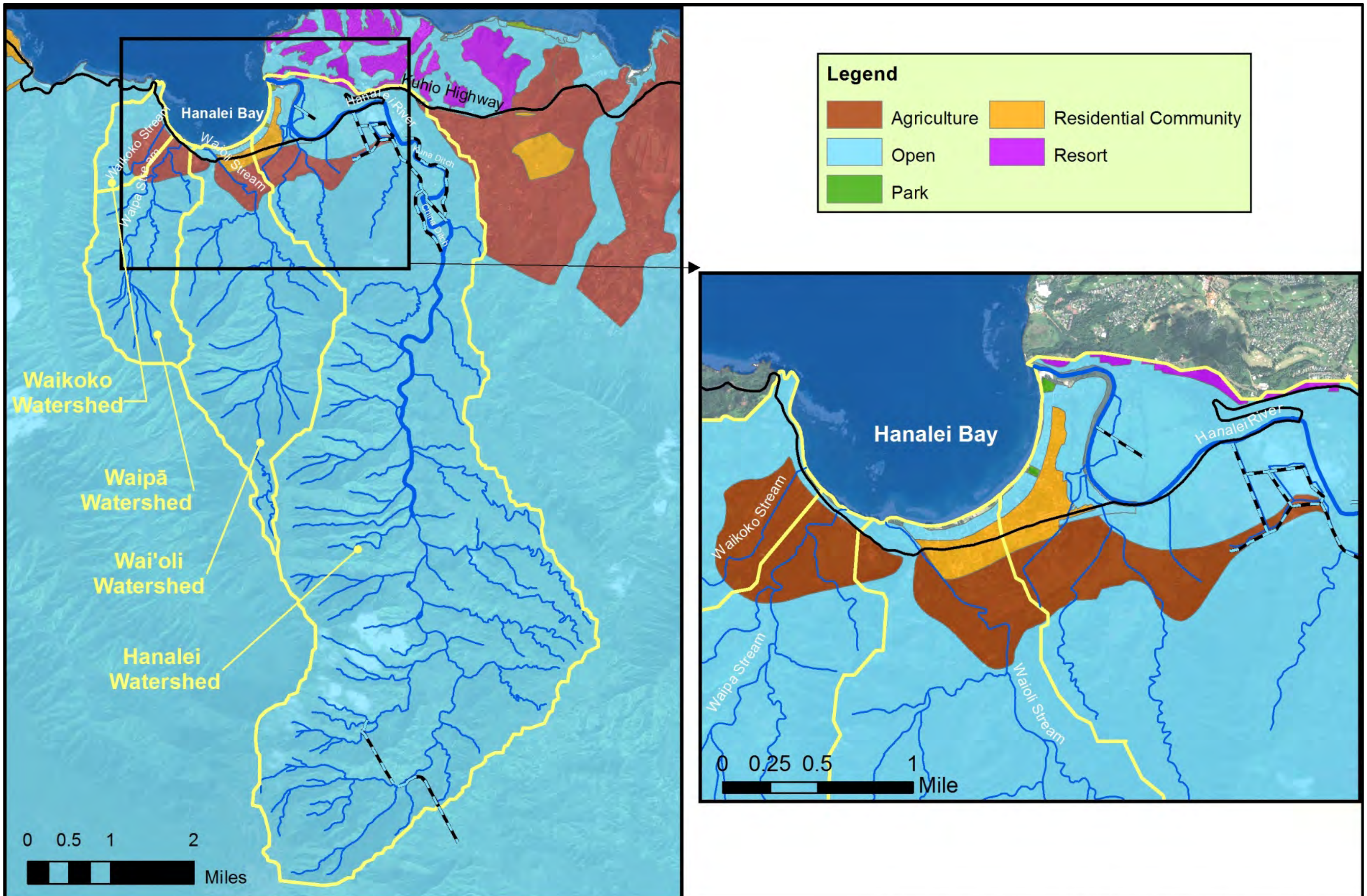


Figure 4.
County General Use Plan

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository, Kauai County
Satellite image, 1.10.2010

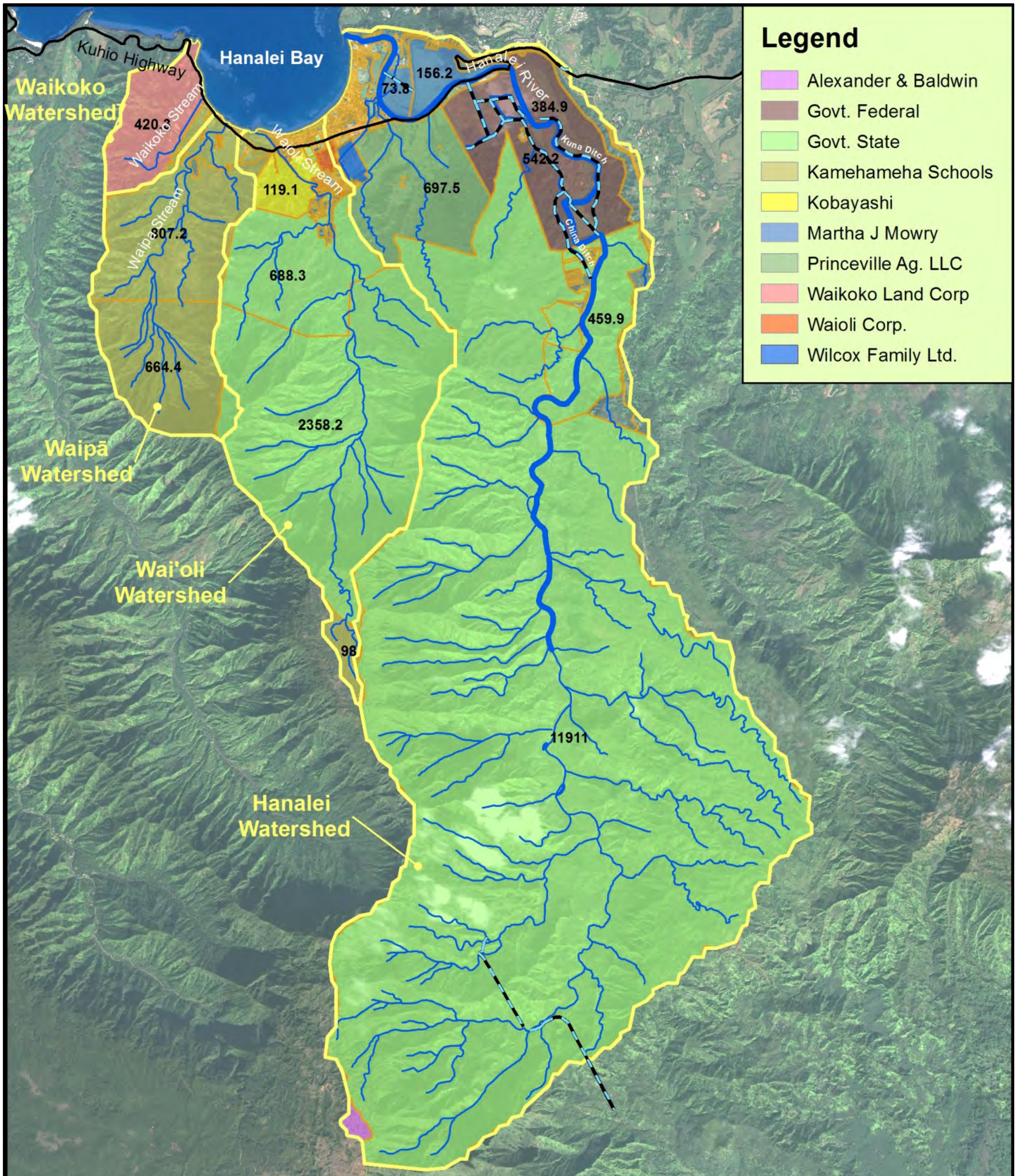


Figure 5.
Large Landowners - Hanalei Bay Watershed

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.5 1 2 Miles

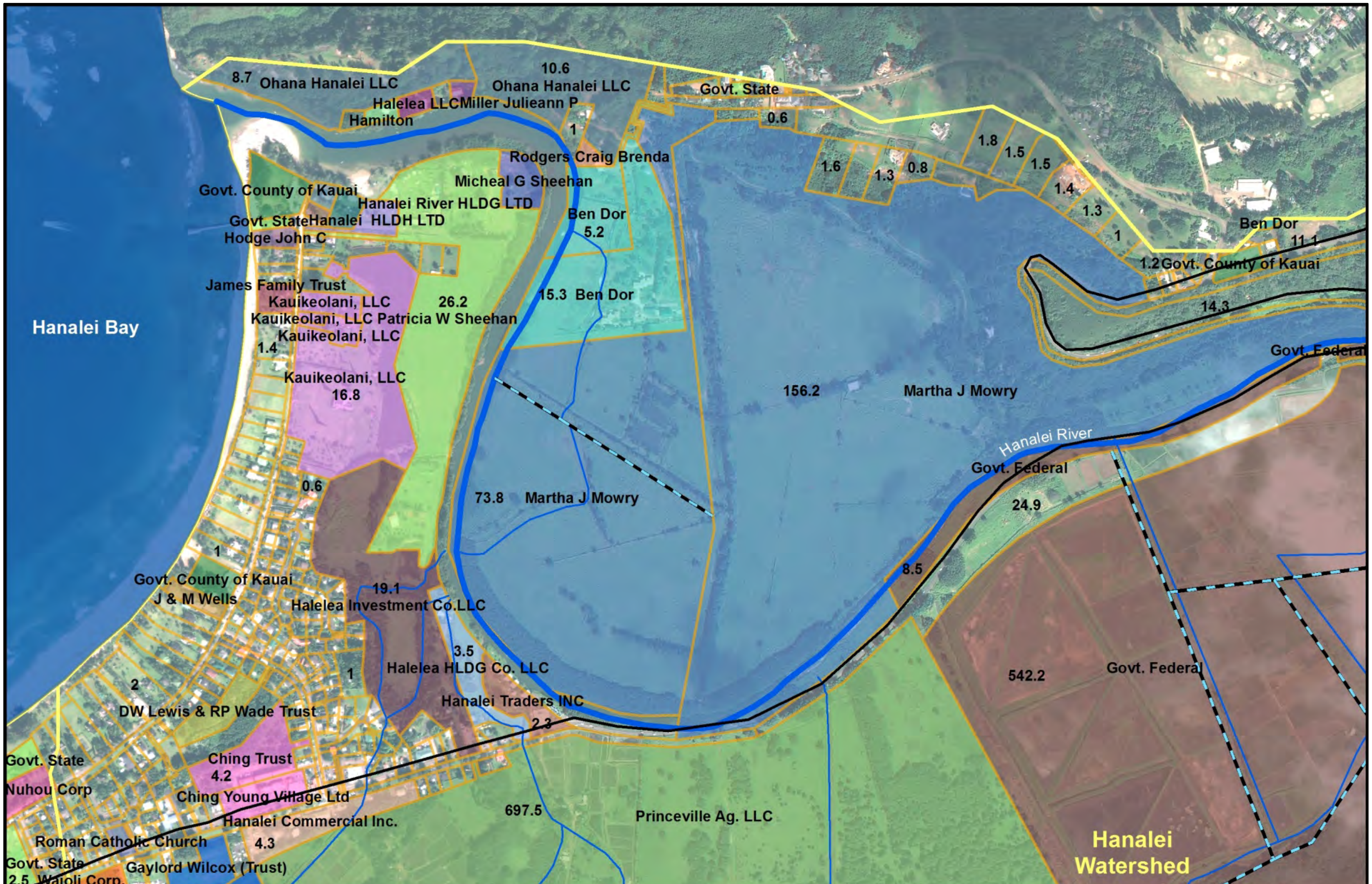


Figure 6.
Large Landowners - Hanalei Watershed

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.05 0.1 0.2
Miles

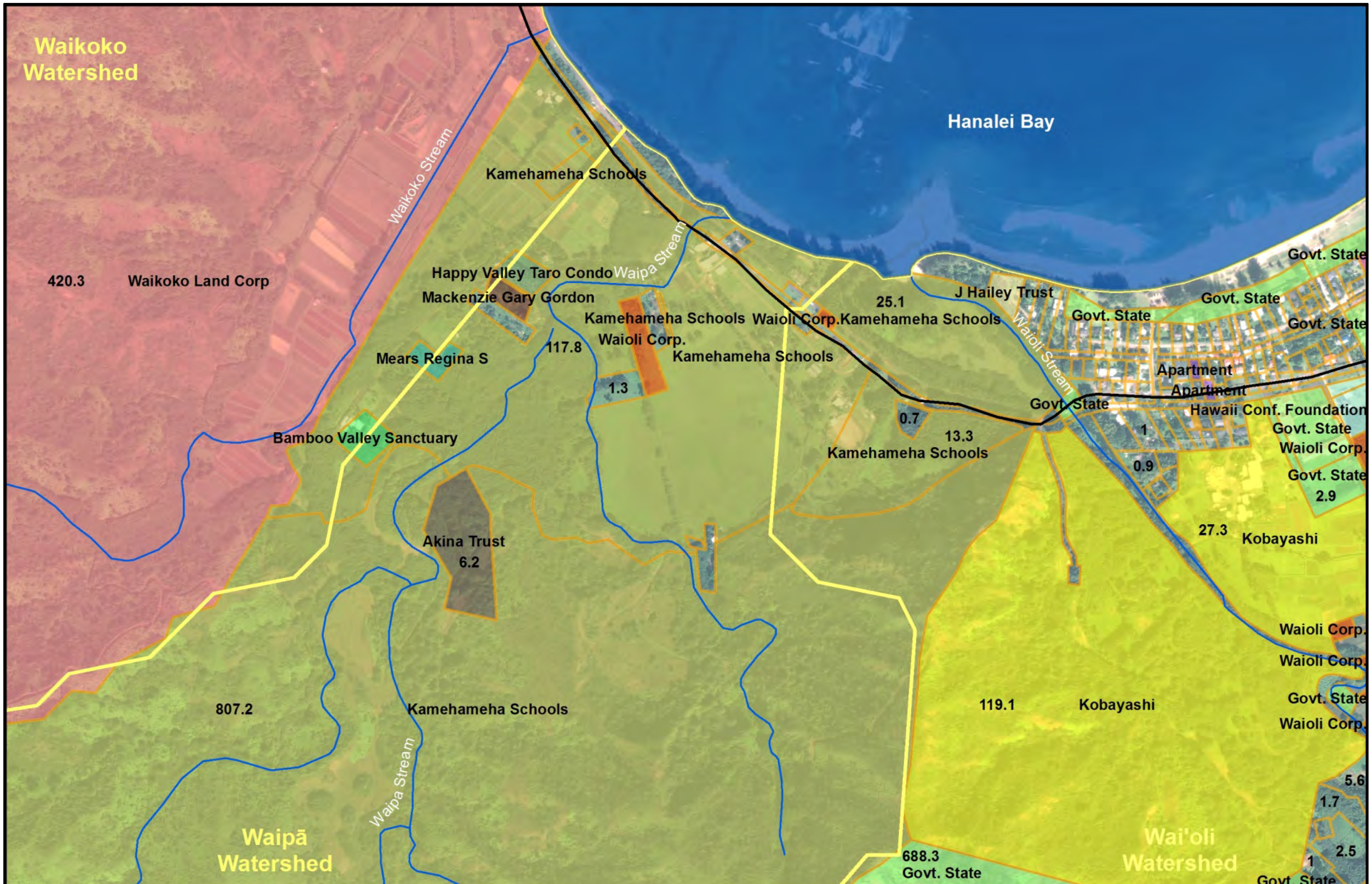


Figure 7.
Large Landowners - Wai'oli, Waipā & Waikoko Watersheds

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.05 0.1 0.2 Miles

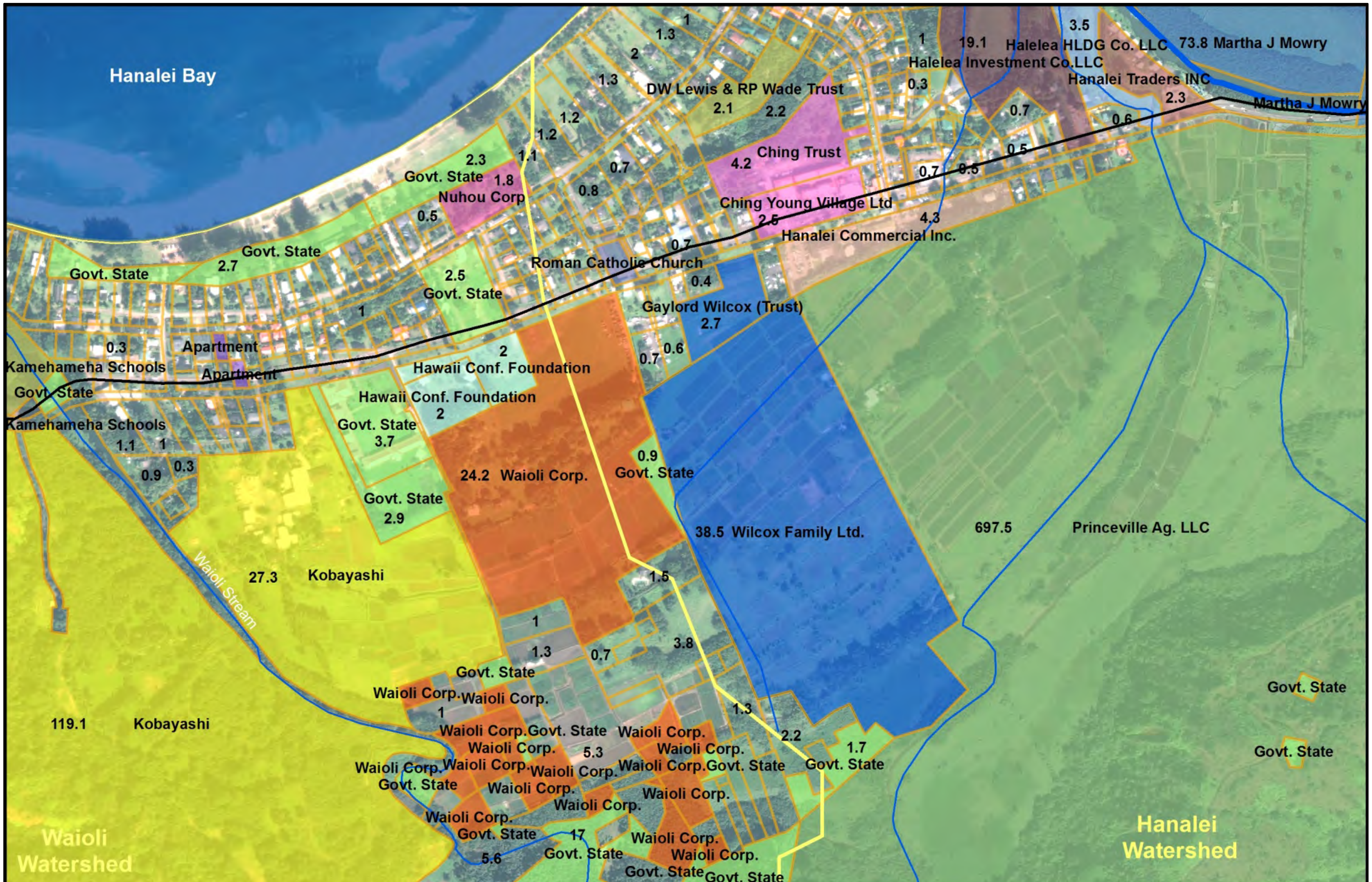


Figure 8.
Large Landowners - Hanalei Town

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.05 0.1 0.2 Miles

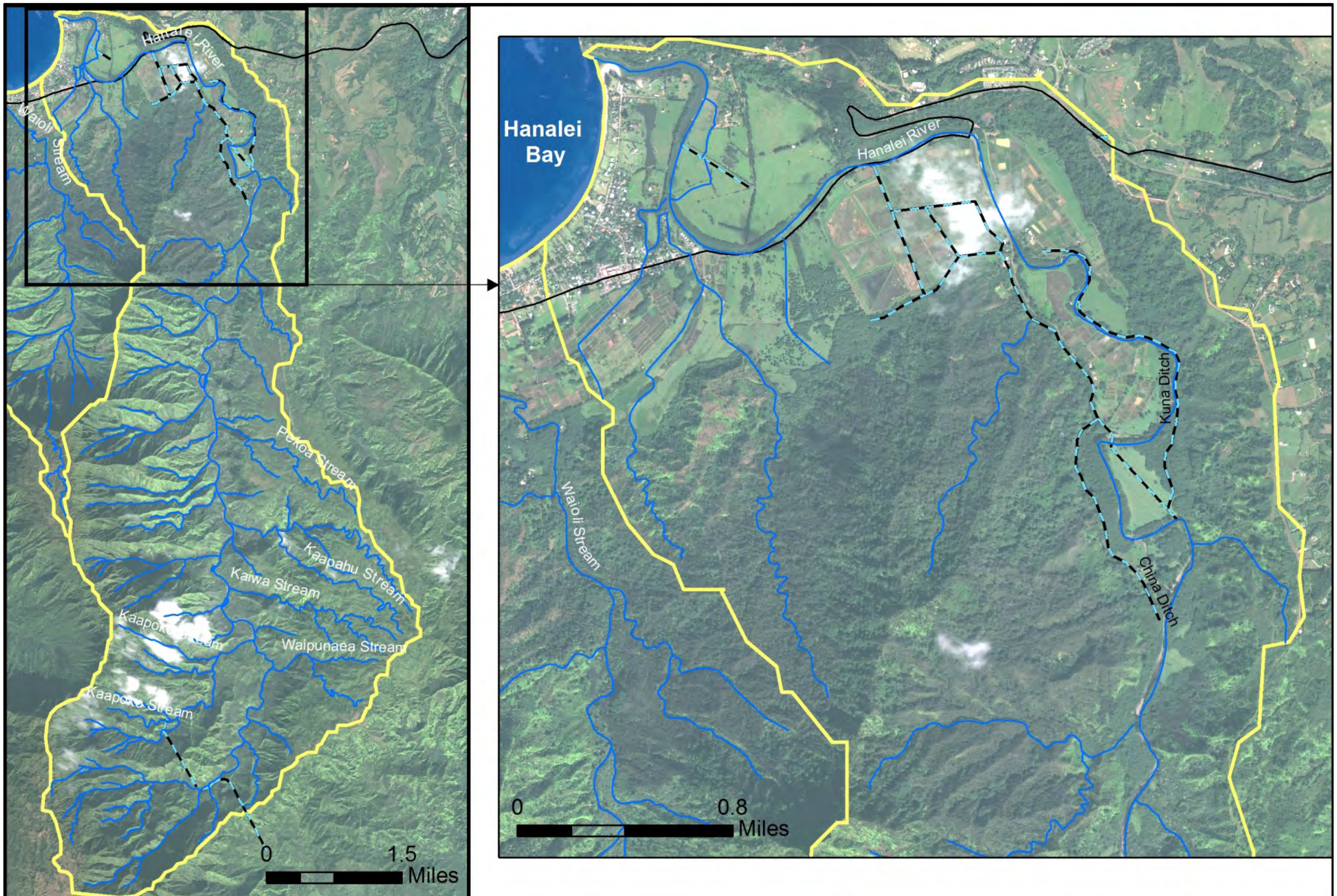


Figure 9.
Hanalei Watershed with Subwatersheds

Source: State of Hawaii Data Repository, NOAA, SOEST
Satellite image, 1.10.2010

N

Hanalei Bay Watershed Management Plan
October 2012

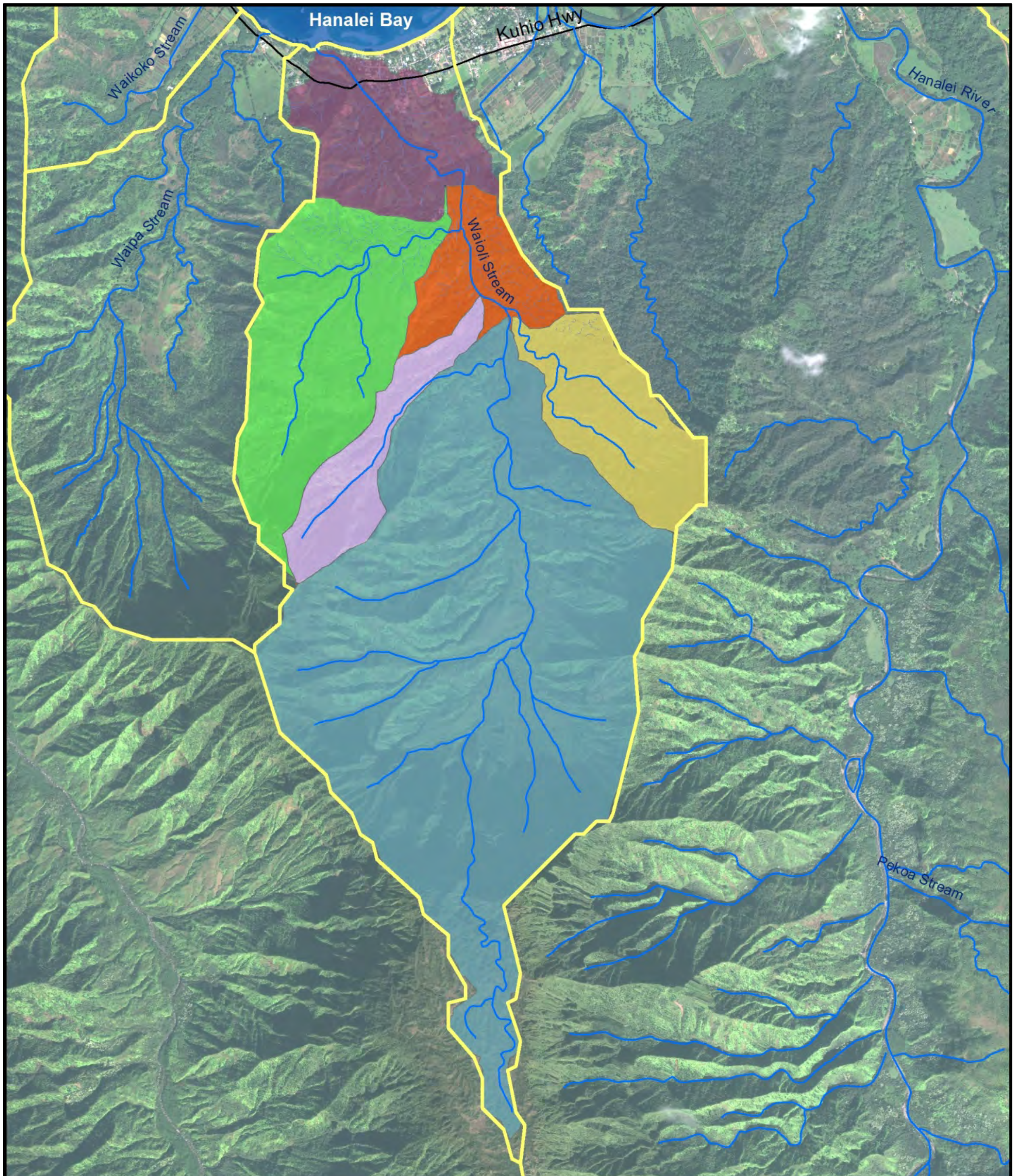


Figure 10.
Wai'oli Watershed with Subwatersheds

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository, SOEST, NOAA
Satellite image, 1.10.2010

N

0 0.4 0.8 1.6 Miles

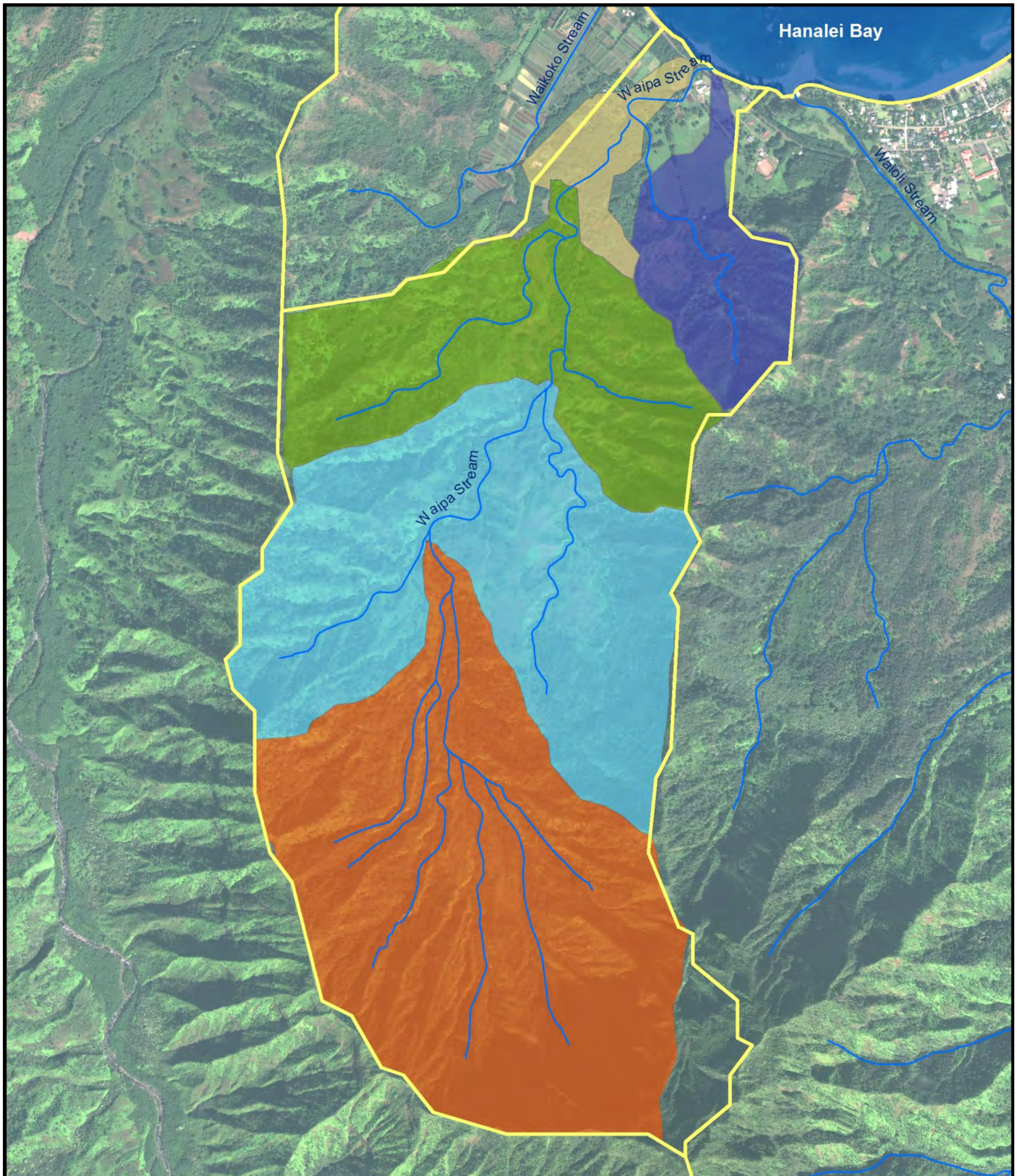


Figure 11.
Waipā Watershed with Subwatersheds

Source: State of Hawaii Data Repository, SOEST, NOAA
Satellite image, 1.10.2010

N

Hanalei Bay Watershed Management Plan
October 2012

0 0.125 0.25 0.5 Miles

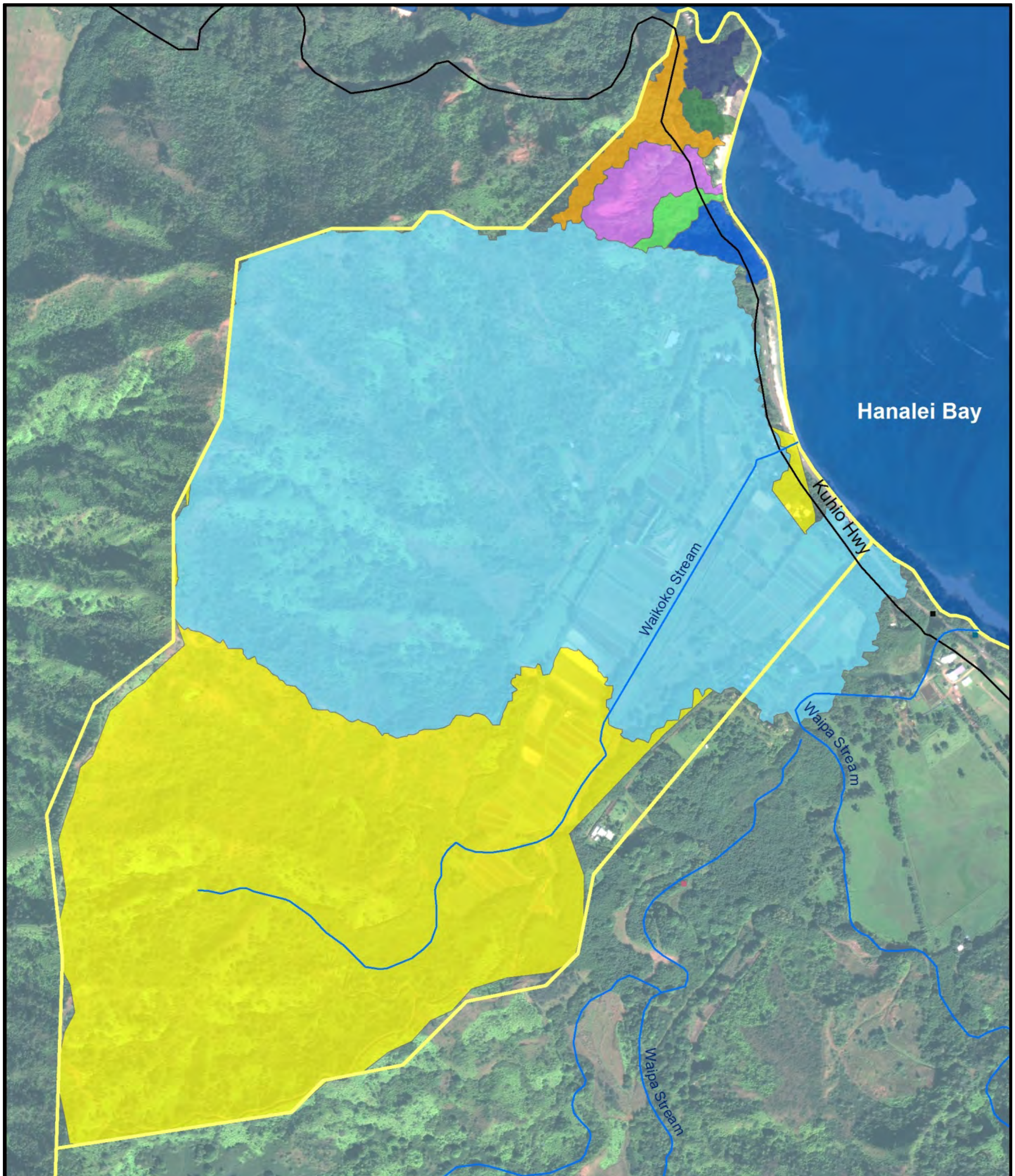


Figure 12.
Waikoko Watershed with Subwatersheds

Source: State of Hawaii Data Repository, NOAA
Satellite image, 1.10.2010

Hanalei Bay Watershed Management Plan
October 2012

1

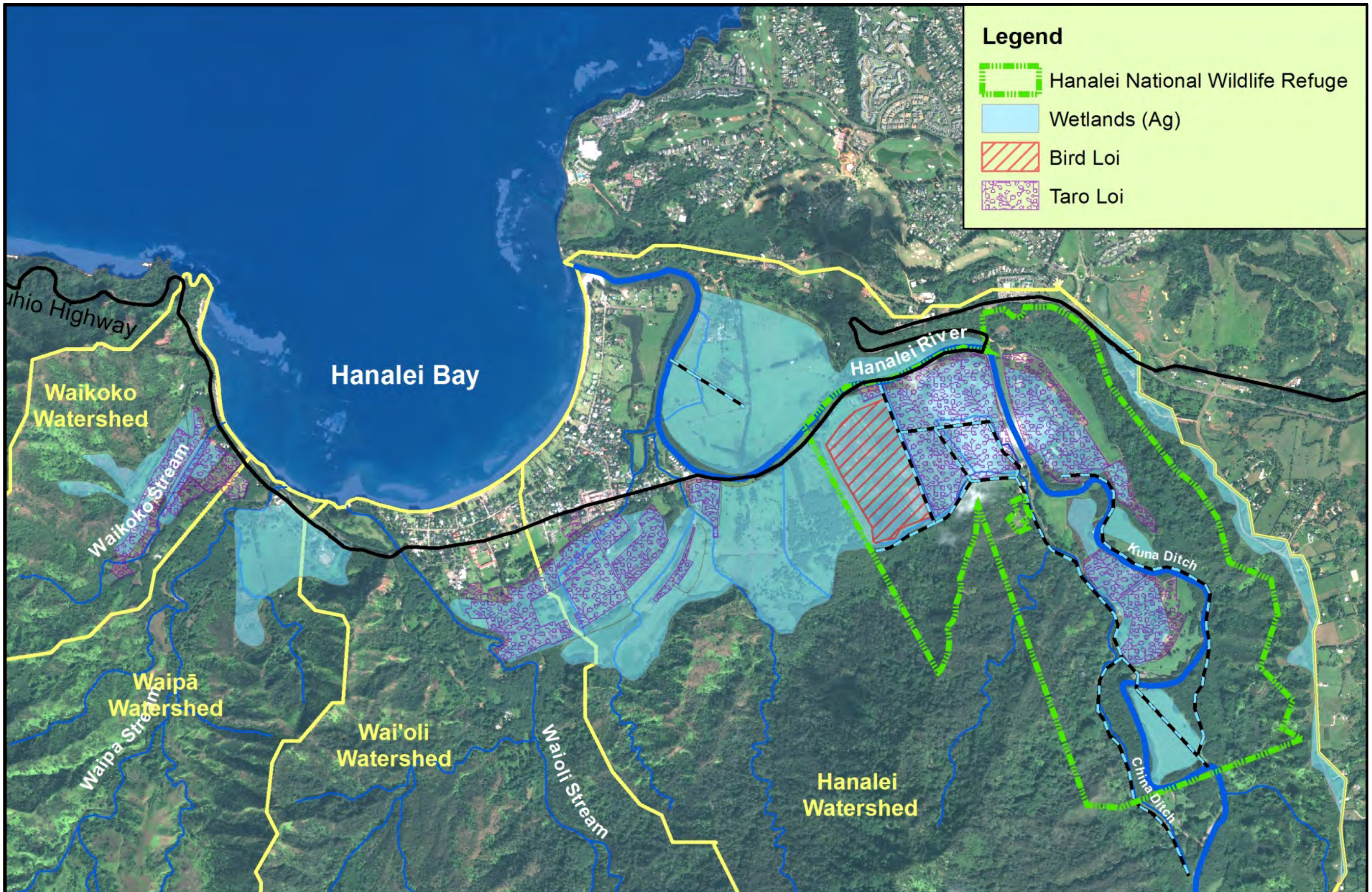


Figure 13.
Water Features ('auwai-ditches-lo'i)

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

1

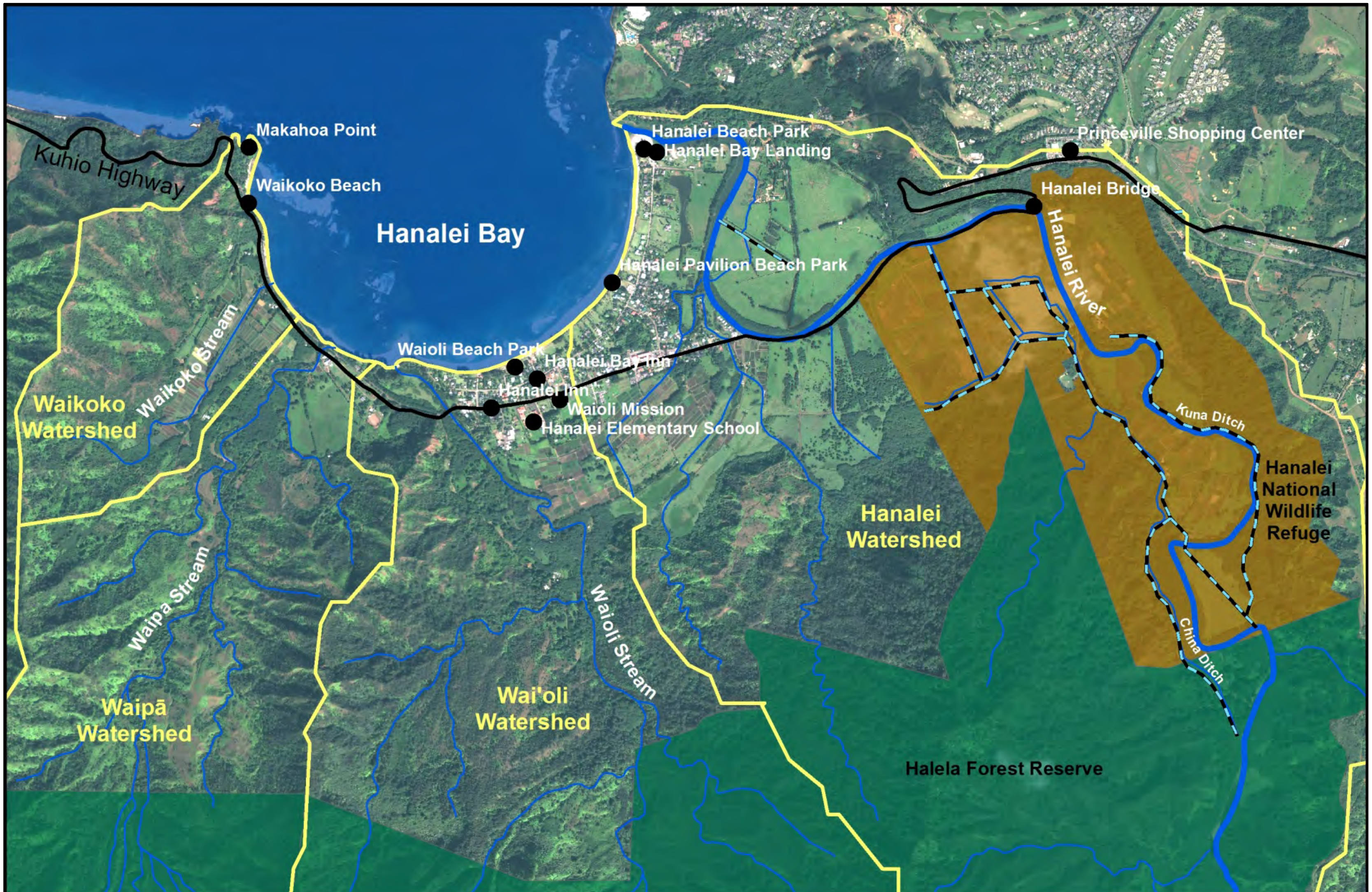


Figure 14.
Infrastructure, Parks, Beaches and Points of Interest

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.3 0.6 1.2 Miles

1

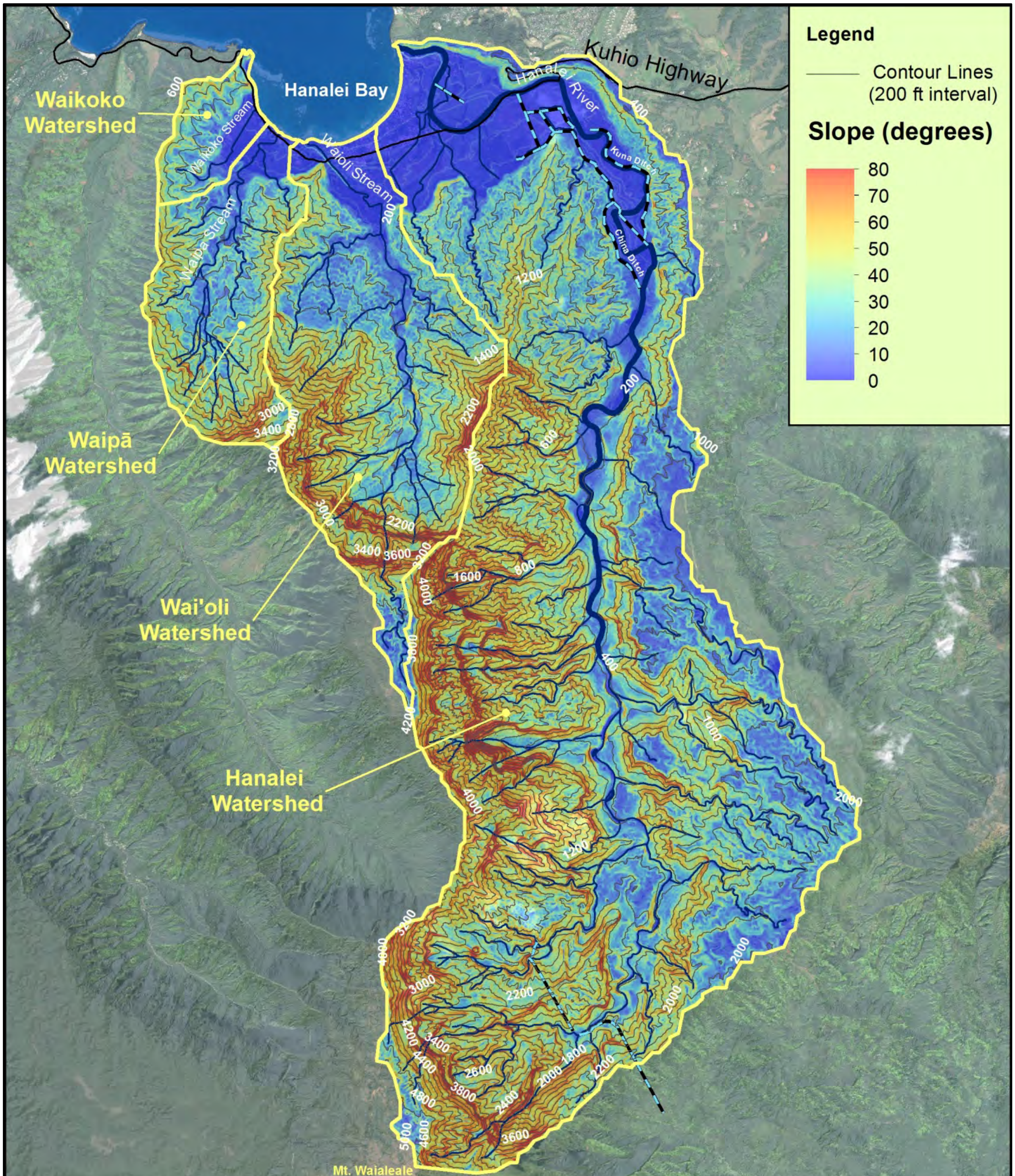


Figure 15.
Topography

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.5 1 2 Miles

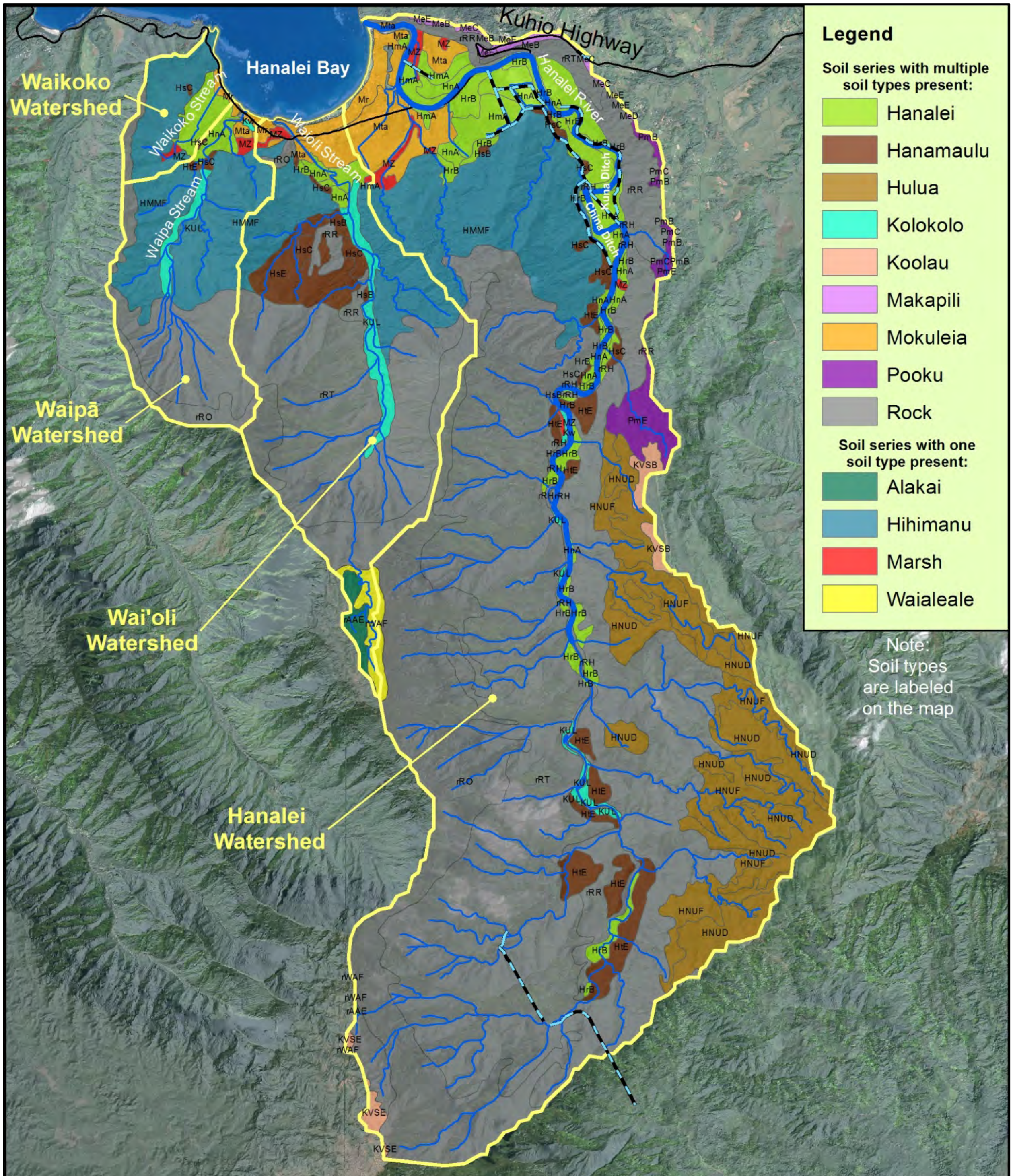


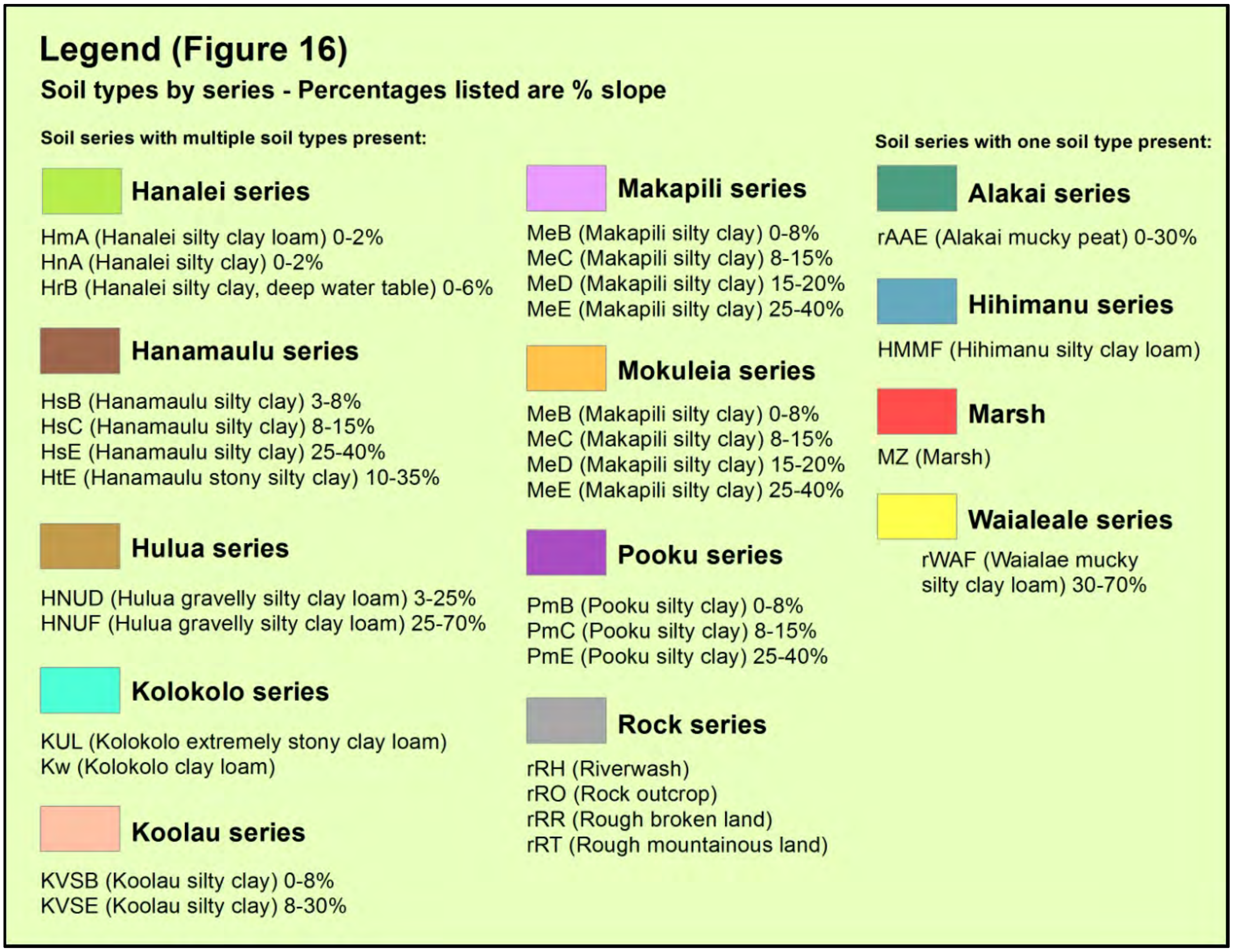
Figure 16.
Soils

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

Hanalei Bay Watershed Management Plan
October 2012

0 0.5 1 2 Miles


Legend (Figure 16)
Soil types by series - Percentages listed are % slope
Soil series with multiple soil types present:
Hanalei series
HmA (Hanalei silty clay loam) 0-2%
HnA (Hanalei silty clay) 0-2%
HrB (Hanalei silty clay, deep water table) 0-6%
Hanamaulu series
HsB (Hanamaulu silty clay) 3-8%
HsC (Hanamaulu silty clay) 8-15%
HsE (Hanamaulu silty clay) 25-40%
HtE (Hanamaulu stony silty clay) 10-35%
Hulua series
HNUD (Hulua gravelly silty clay loam) 3-25%
HNUF (Hulua gravelly silty clay loam) 25-70%
Kolokolo series
KUL (Kolokolo extremely stony clay loam)
Kw (Kolokolo clay loam)
Koolau series
KVSB (Koolau silty clay) 0-8%
KVSE (Koolau silty clay) 8-30%
Makapili series
MeB (Makapili silty clay) 0-8%
MeC (Makapili silty clay) 8-15%
MeD (Makapili silty clay) 15-20%
MeE (Makapili silty clay) 25-40%
Mokuleia series
MeB (Makapili silty clay) 0-8%
MeC (Makapili silty clay) 8-15%
MeD (Makapili silty clay) 15-20%
MeE (Makapili silty clay) 25-40%
Pooku series
PmB (Pooku silty clay) 0-8%
PmC (Pooku silty clay) 8-15%
PmE (Pooku silty clay) 25-40%
Rock series
rRH (Riverwash)
rRO (Rock outcrop)
rRR (Rough broken land)
rRT (Rough mountainous land)
Soil series with one soil type present:
Alakai series
rAAE (Alakai mucky peat) 0-30%
Hihimanu series
HMMF (Hihimanu silty clay loam)
Marsh
MZ (Marsh)
Waialeale series
rWAF (Waialae mucky
silty clay loam) 30-70%

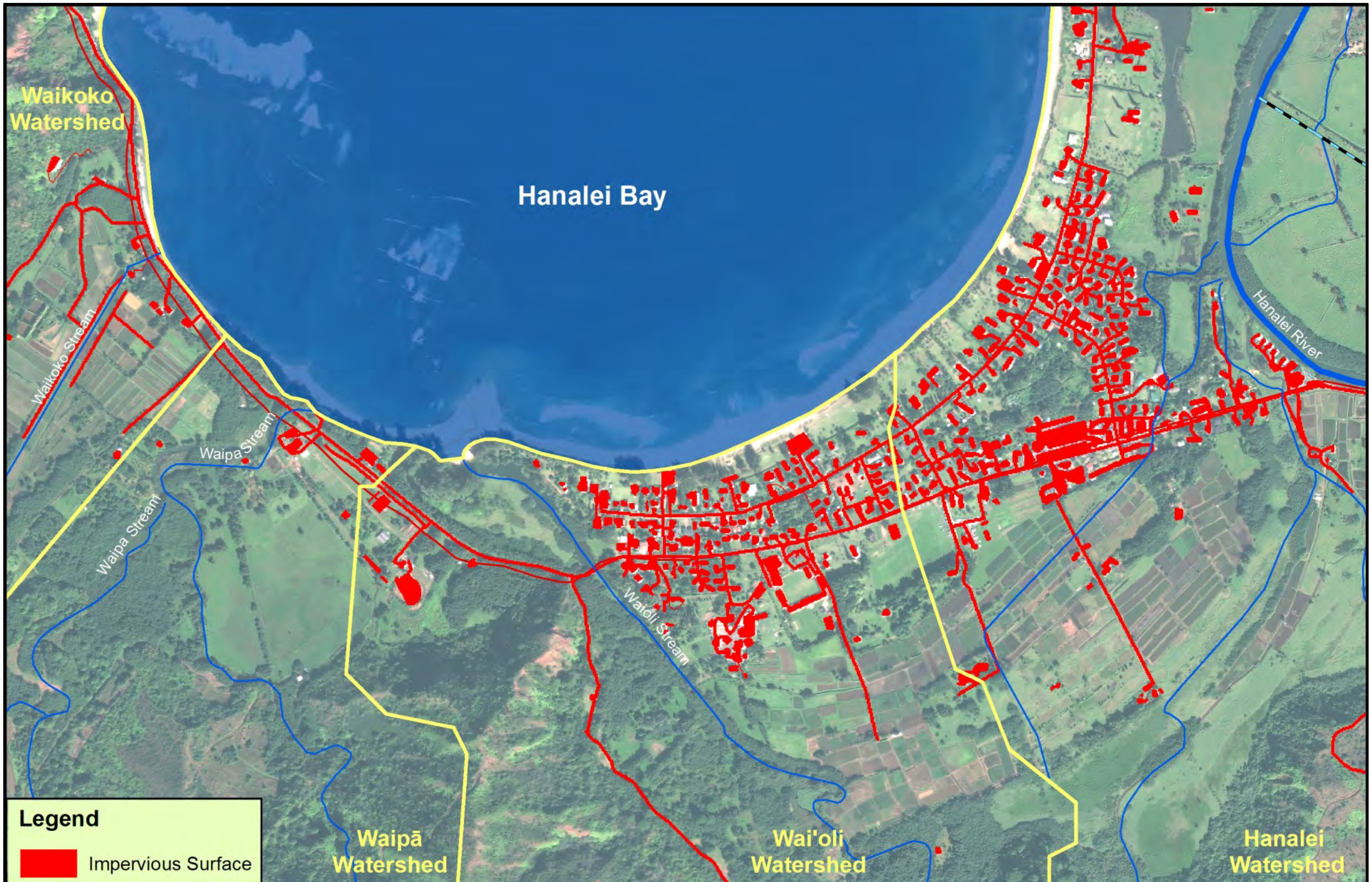


Figure 17.
Impervious Surfaces

Hanalei Bay Watershed Management Plan
October 2012

1

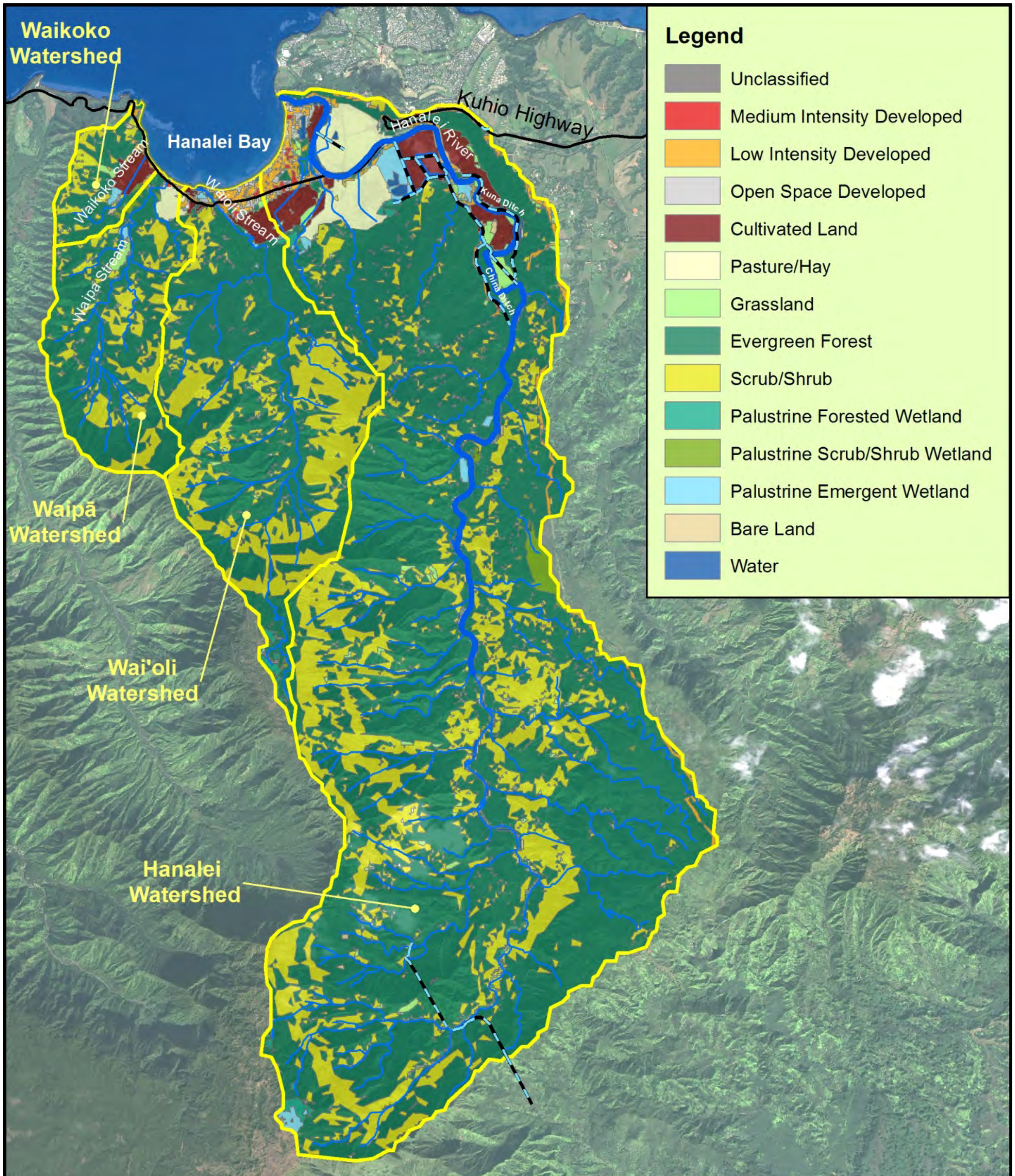


Figure 18.
Land Cover (C-CAP, 2001)

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository, NOAA (C-CAP)
Satellite image, 1.10.2010

N

0 0.5 1 2 Miles

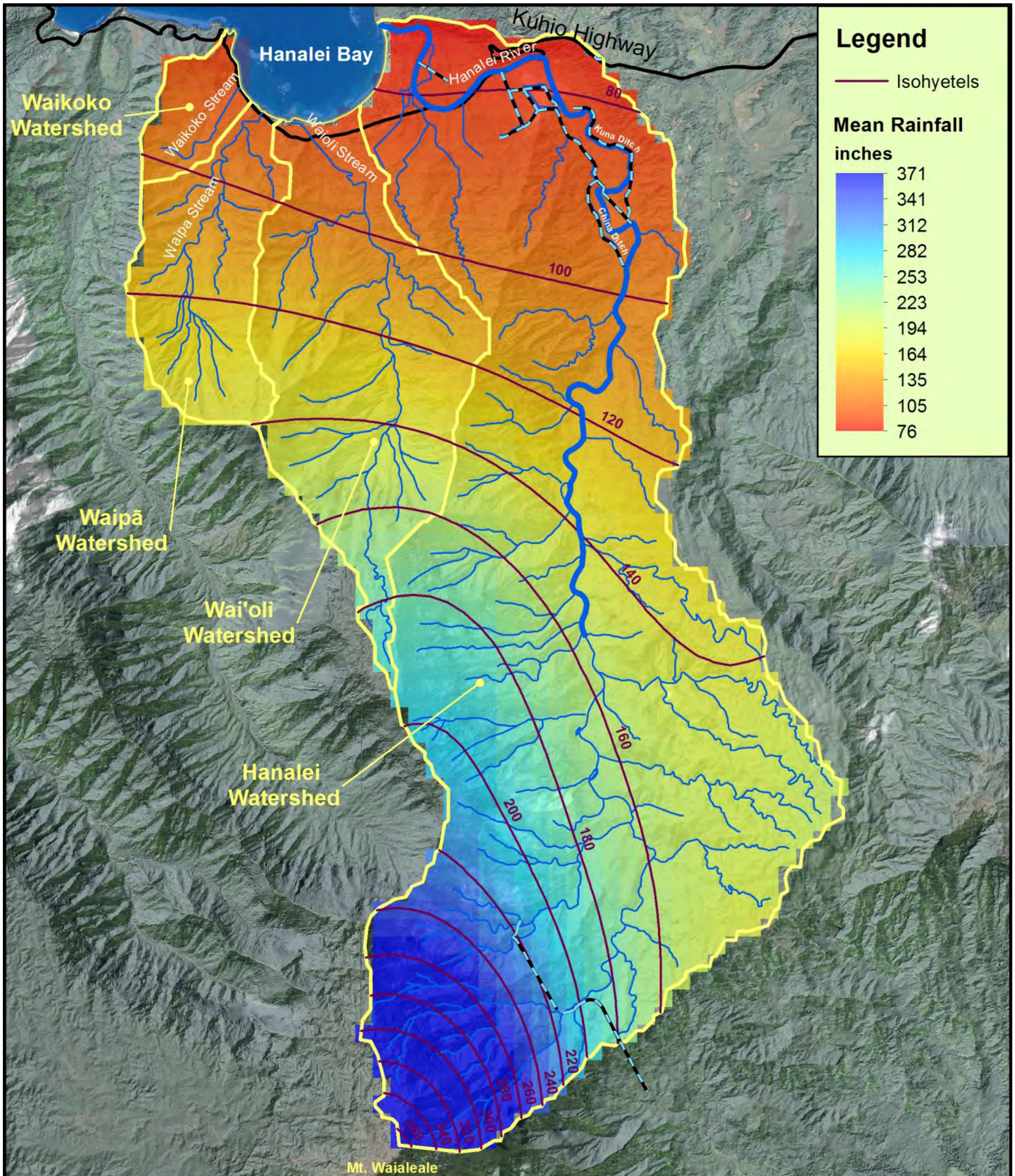


Figure 19.
Mean Annual Rainfall

Hanalei Bay Watershed Management Plan
2012

Source: State of Hawaii Data Repository,
Hawaii Rainfall Atlas

N

0 0.5 1 2
Miles

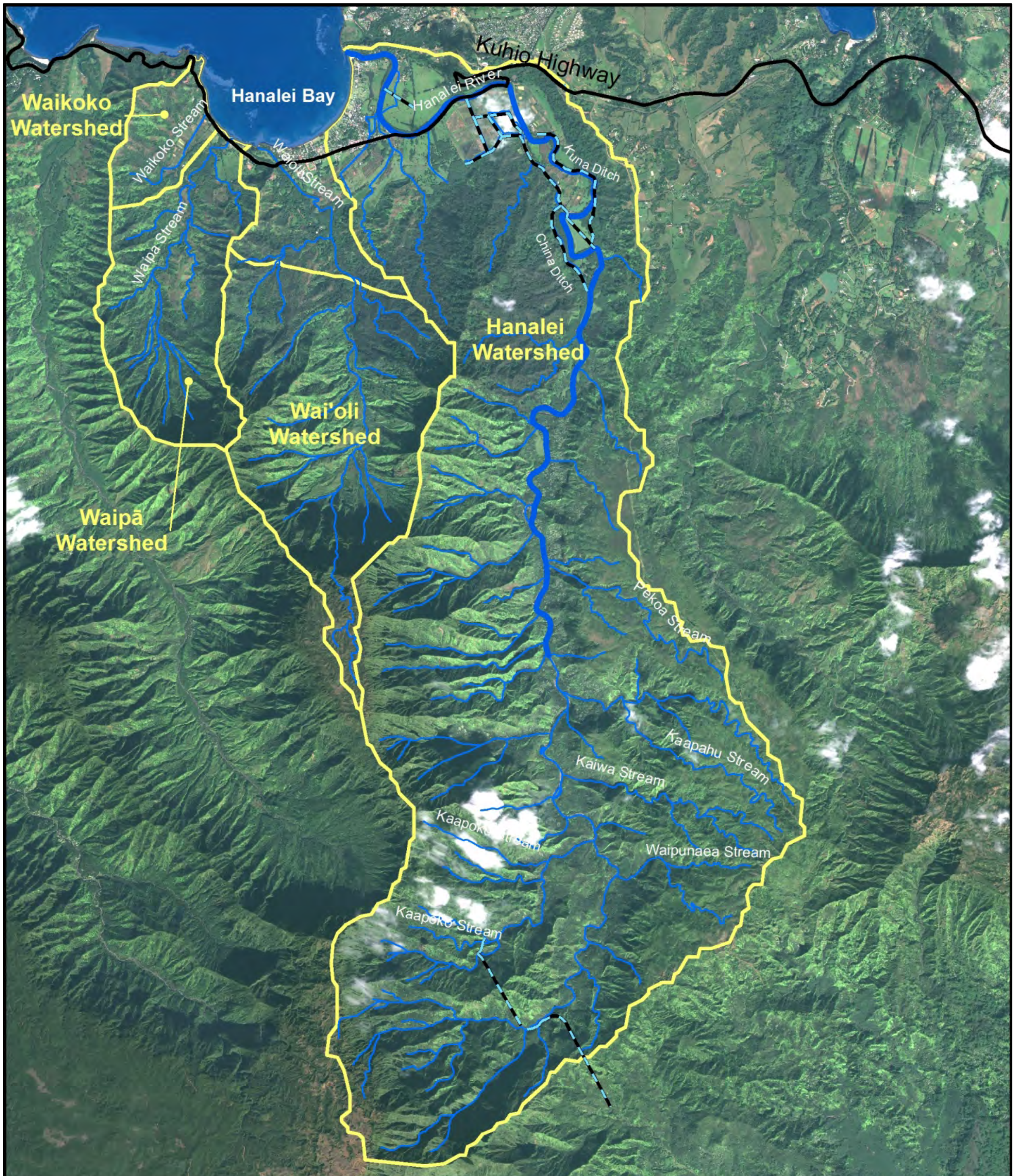


Figure 20.
Rivers and Streams

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.5 1 2 Miles

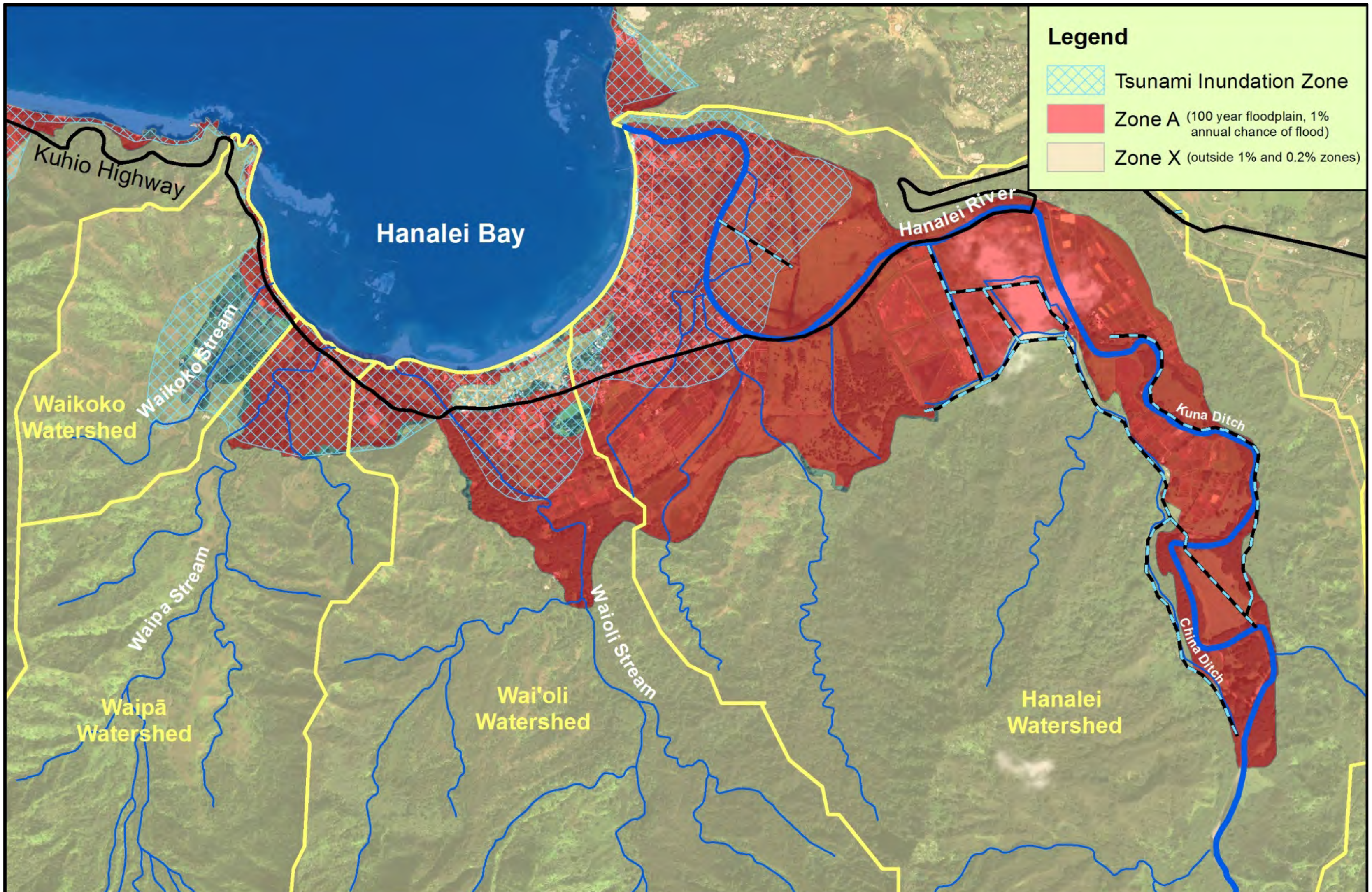


Figure 21.
Flood Insurance Rate Map

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.3 0.6 1.2 Miles

Hanalei Bay Watershed Management Plan
October 2012

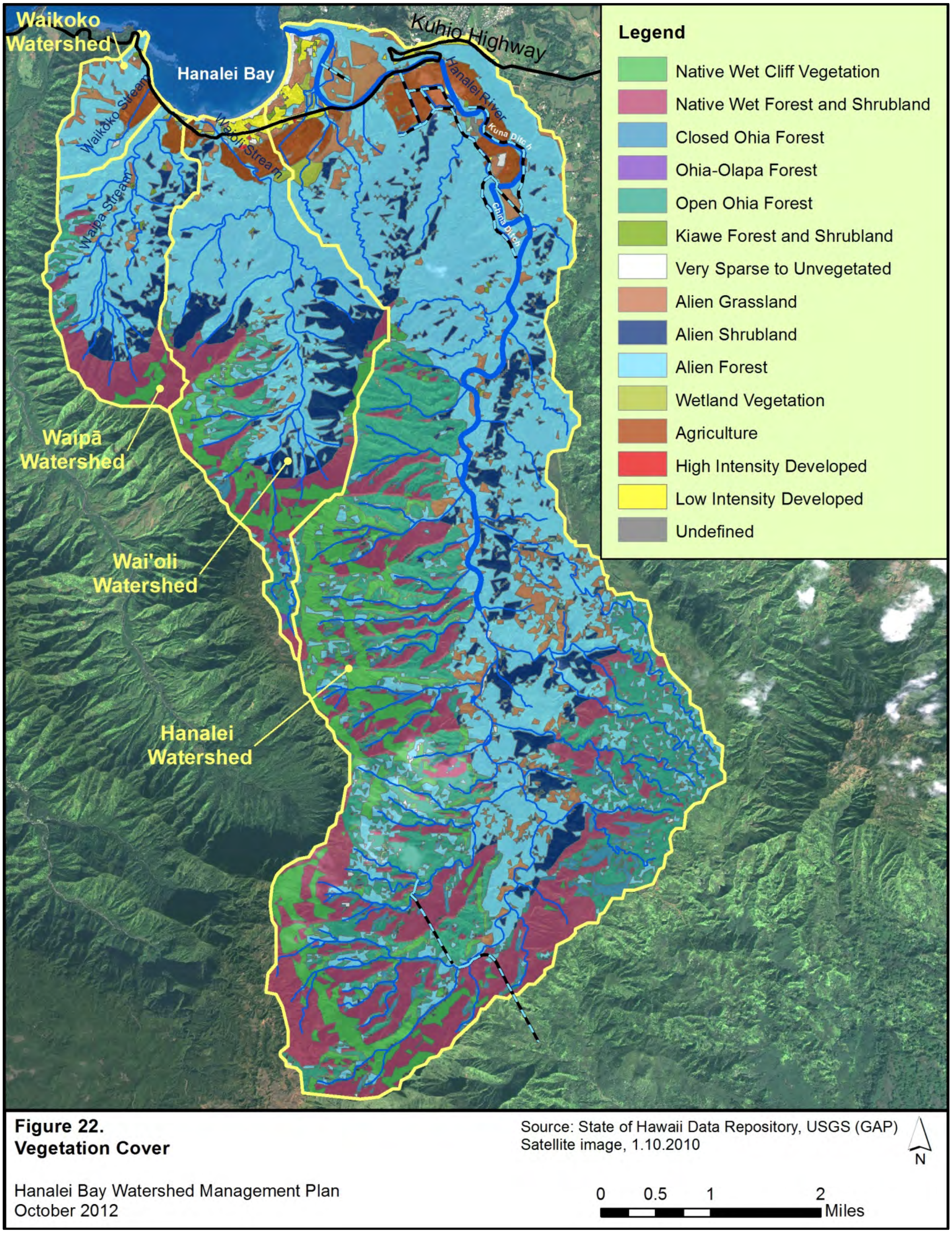
1 

Figure 22.
Vegetation Cover

Hanalei Bay Watershed Management Plan
October 2012

2

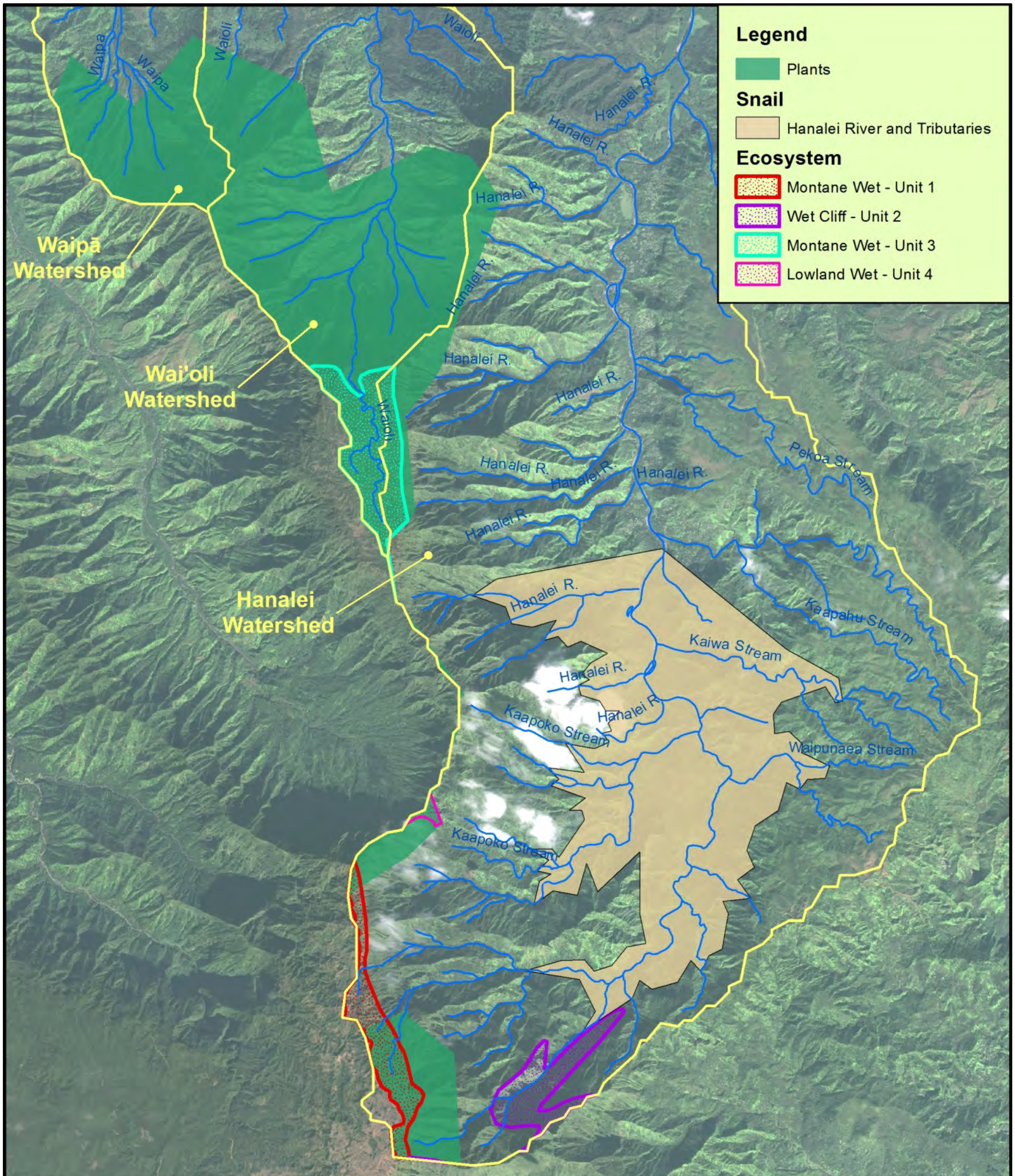


Figure 23.
Critical Habitat

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.5 1 2 Miles

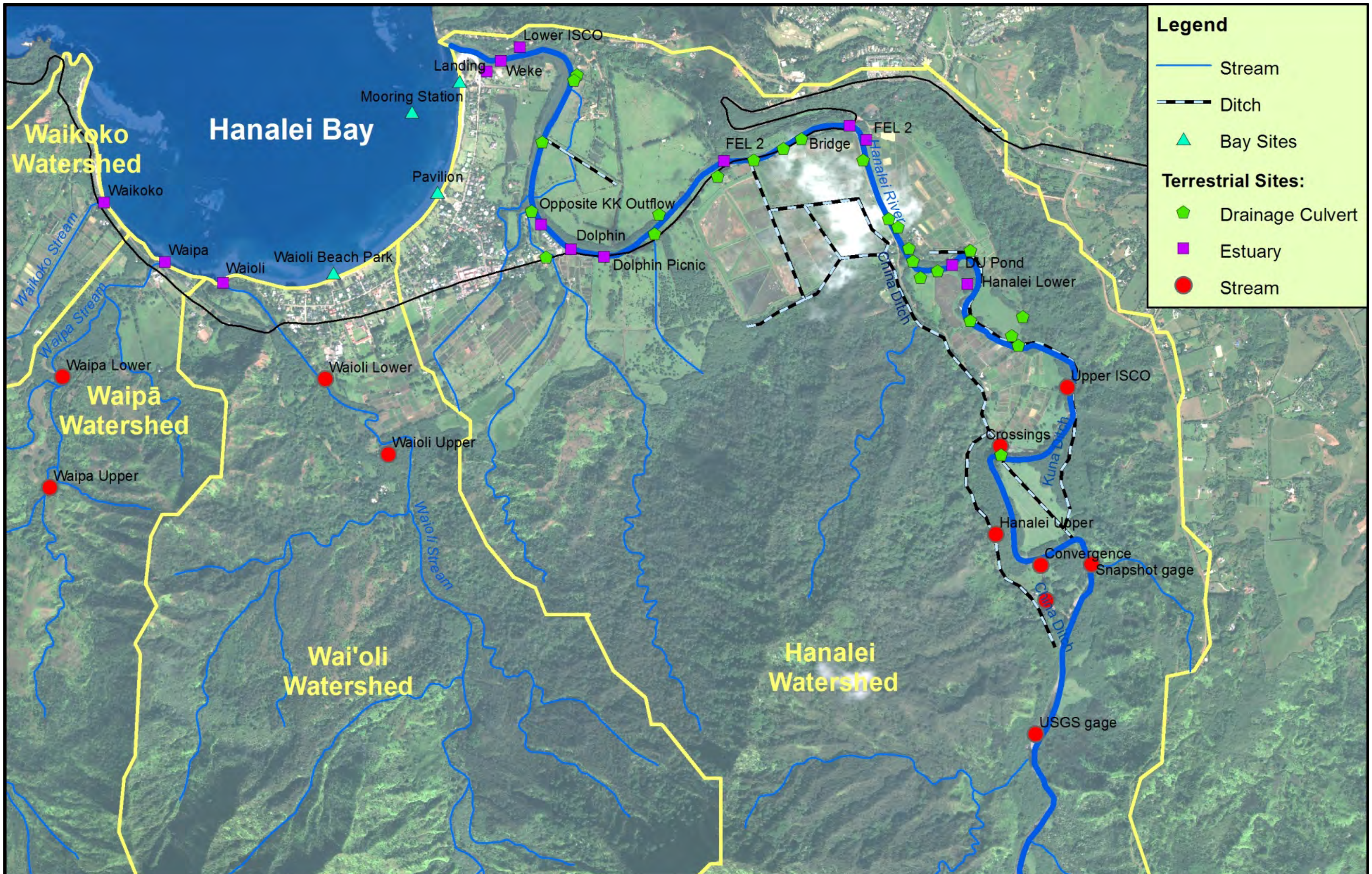


Figure 24.
TMDL Sampling Sites

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository, Phase 1 &2 TMDL
Satellite image, 1.10.2010

0 0.25 0.5 1 Mile

N

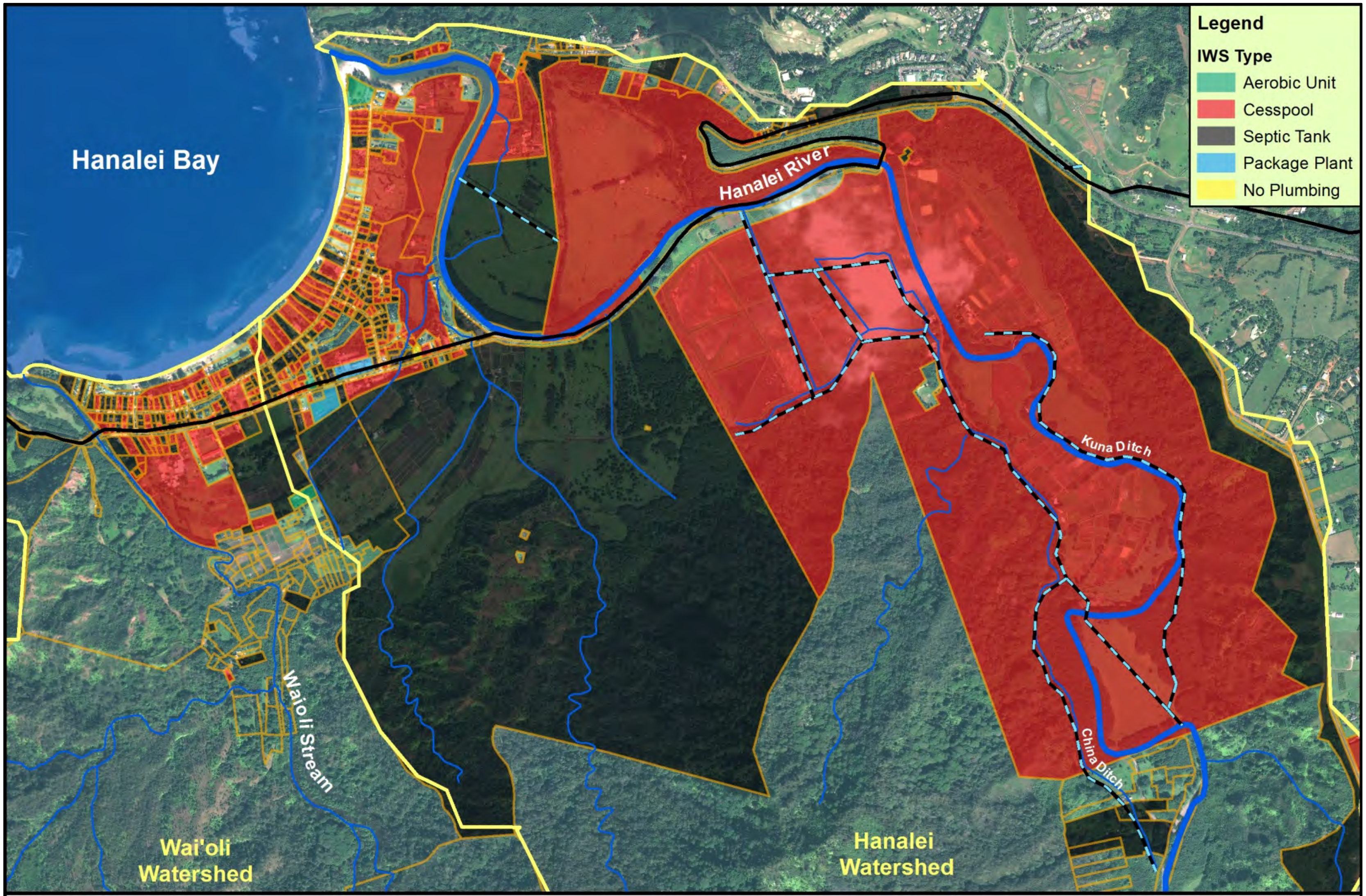


Figure 25.
Individual Wastewater Systems - Hanalei Watershed

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

Hanalei Bay Watershed Management Plan
October 2012

1

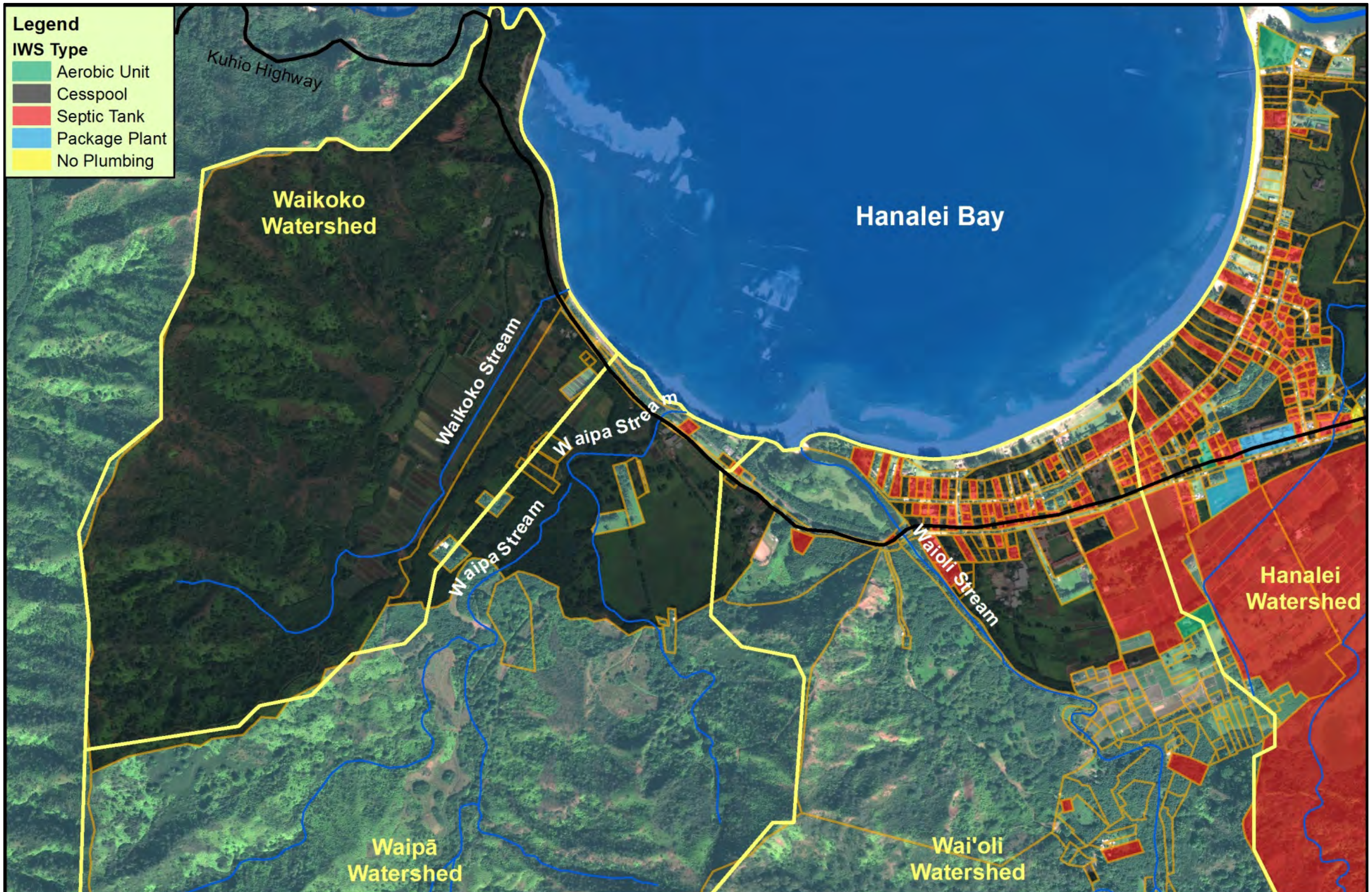


Figure 26.
Individual Wastewater Systems - Waikoko, Waipā & Wai'oli Watersheds

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

Hanalei Bay Watershed Management Plan
October 2012

1

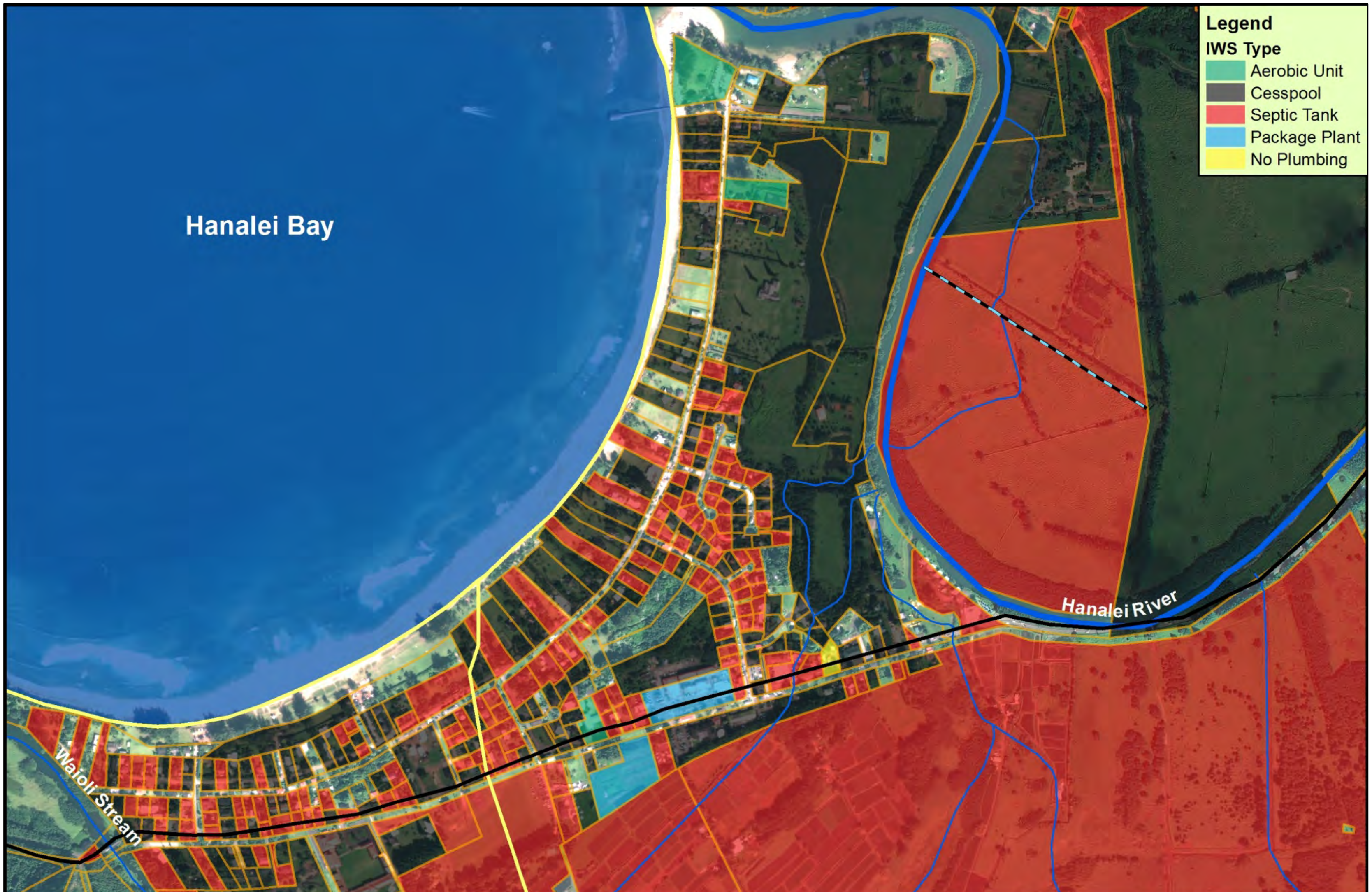


Figure 27.
Individual Wastewater Systems - Hanalei Town

Hanalei Bay Watershed Management Plan
October 2012

Source: State of Hawaii Data Repository
Satellite image, 1.10.2010

N

0 0.05 0.1 0.2 Miles

1

Appendix B. Photographs

Photo 1. Hanalei Watershed - Middle and Upper Hanalei River

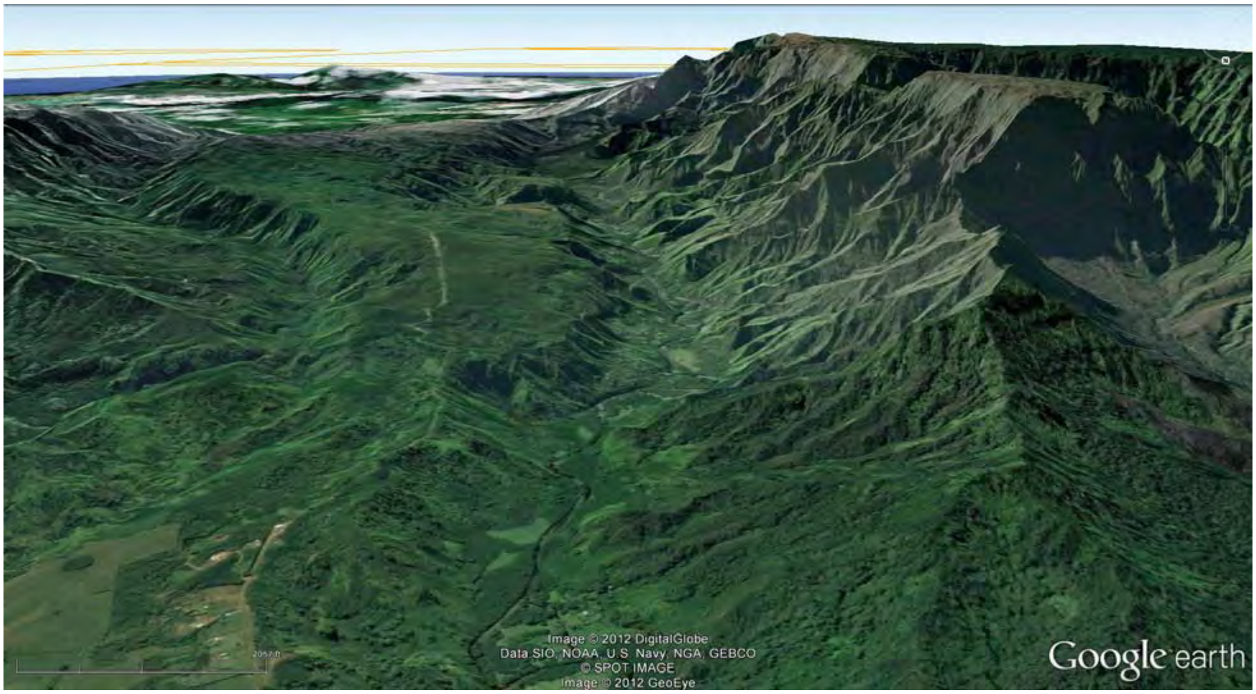


Photo 2. Wai'oli Watershed

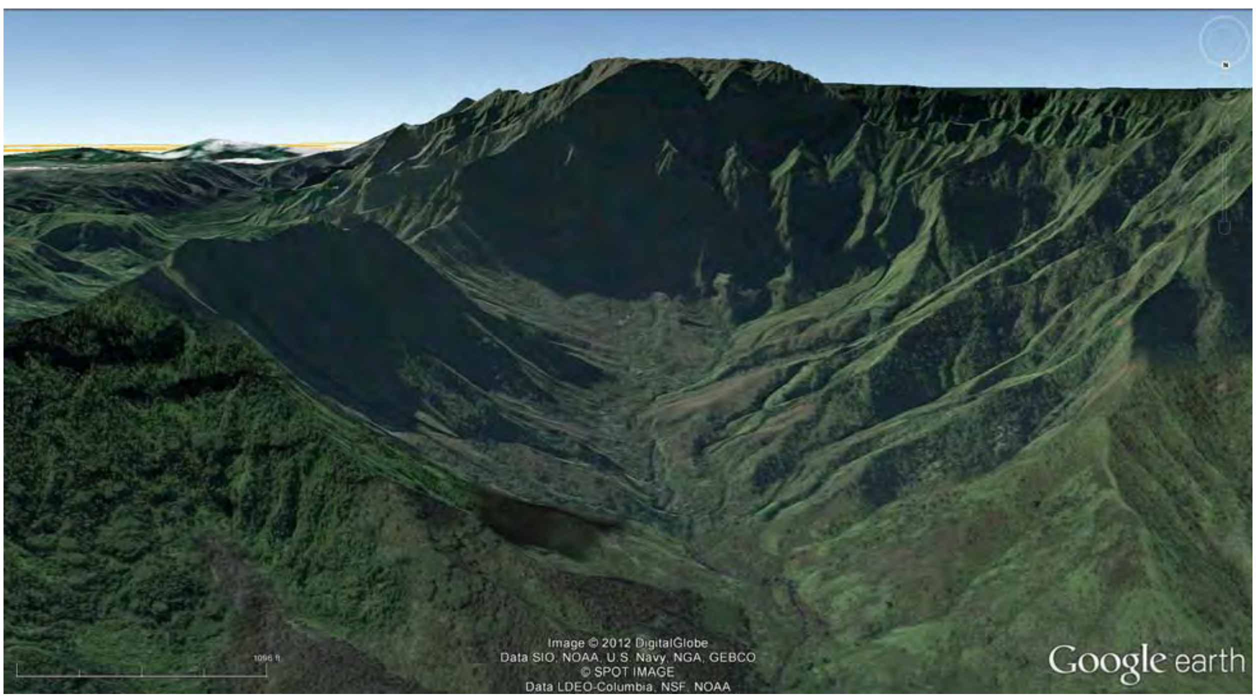


Photo 3. Waipā and Waikoko Watersheds

Photo 4. Hanalei Bay Looking East

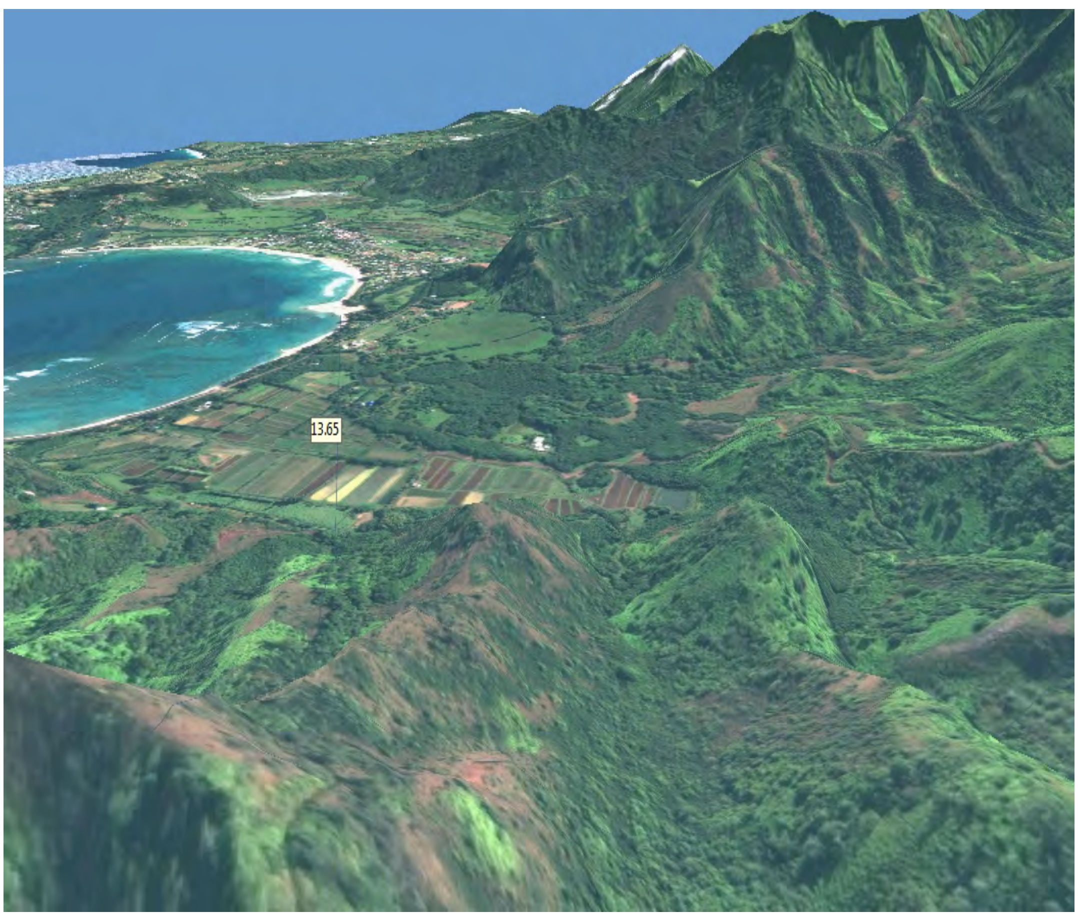


Photo 5. Hanalei Bay Looking West

Photo 6. Hanalei National Wildlife Refuge

Photo 7. Lower Hanalei River

Photo 8. Hanalei Town

Appendix C. Regulatory Environment

Understanding the regulatory environment is essential for establishing a clear picture of water quality issues and ultimately solutions. There are numerous Federal, State and county agencies that have responsibility related to implementing activities related to controlling polluted runoff and maintaining water quality (Table C1). Some of these entities have a role in promoting both regulatory and voluntary approaches. Implementation of management measures is most effectively done through economic incentives or by regulatory drivers. Regulatory approaches work best when adequate mechanisms are in place to provide oversight and enforcement. This section summarizes the key agencies and regulations that address point source and NPS pollutants. A comprehensive list of agencies, their roles in implementing management measures for NPS, and applicable regulatory authority was developed in association with the overall guidance for Hawai‘i (Stewart 2010a, b) (Table C1).

C.1. Coral Reef Conservation

At the Federal level coral reef conservation is primarily addressed by NOAA and the U.S. Coral Reef Task Force (USCRTF). NOAA administers the Coral Reef Conservation Program (CRCP). The CRCP brings together expertise from many NOAA programs and offices and works to reduce harm to and restore the health of, coral reefs by addressing national threats and local management priorities through the conservation activities. NOAA also maintains the Coral Reef Information System website.

The USCRTF was established in 1998 by Executive Order 13089 to lead U.S. efforts to preserve and protect coral reef ecosystems. The USCRTF accomplishes this by helping build partnerships, strategies and support for on-the-ground action to conserve coral reefs. In 2002 the task force called for the development of LAS to help focus action for the reduction of key threats to coral reefs to the local level. The goals and objectives of the Hawai‘i LAS (climate change and marine debris, lack of public awareness, coral reef fisheries, land-based pollution sources and recreational impacts to reefs and aquatic invasive species) were designed to be in line with those found in the U.S. National Action Plan to Conserve Coral Reefs. The Kā‘anapali-Kahekili Region has been selected by the USCRTF as a priority partnership site.

At the State level, the primary agency responsible for coordinating Hawai‘i’s coral reef management efforts in the main Hawaiian Islands is DLNR-DAR.[55] The Coral Reef Working Group (CRWG) was established to help provide guidance for DLNR-DAR’s coral program. The CRWG contains key members of Federal and State agencies involved in coral reef management. In order to provide a cohesive strategy for coral reef management in Hawai‘i, DLNR-DAR and the CRWG developed *The Hawai‘i Coral Reef Strategy for 2010-2020* (State of Hawai‘i 2010). This strategy incorporates the six multi-agency LAS and identifies four priority goals and five priority objectives for coral reef management.

The Kā‘anapali-Kahekili region is one of two priority sites (M-7) identified by the CRWG for funding and technical assistance to fulfill the priority objective “Reduce key anthropogenic threats to two

[55] http://www.hawaiicoralreefstrategy.com/

priority nearshore coral reef sites by 2015 using *ahupuaʻa*-based management".[56] This assists in obtaining Goal #1: "Coral reefs undamaged by pollution, invasive species, marine construction and marine debris"; Goal #2: "Productive and sustainable coral reef fisheries and habitat"; Goal #3: "Coral reef ecosystems resilient to climate change, invasive species and marine disease"; and Goal #4: "Increased public stewardship of coral reef ecosystems." It also correlates to NOAA CRCP's National Goals and Objectives for Coral Reef Conservation: Land-Based Sources of Pollution Impacts Objective 1.3: "Implement watershed management plans and relevant LAS within priority coral reef ecosystems and associated watersheds to improve water quality and enhance coral reef ecosystem resilience. Where needed, develop (or update) watershed management plans that incorporate coral reef protection measures." This WMP supports these goals and objectives.

C.2. Overview of Clean Water Act in Regulating Water Pollution

The first major breakthrough in controlling water pollution came with the Federal Water Pollution Control Act of 1948. With the growing awareness and the evolving environmental movement of the 1960s, it was extensively amended in 1972 and thereafter known as the Clean Water Act. Further major amendments came in 1977. The CWA regulates pollution discharges into navigable waters of the United States and sets water quality standards for surface waters with the goal of making them swimmable and fishable and "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters". The first phase of the Act was aimed specifically at point source pollutants. It prohibits the discharge of any pollutant from a point source into navigable waters, unless special permits are obtained under the National Pollutant Discharge Elimination System (Appendix C.4). At the Federal level, the CWA is administered by the EPA. In Hawaiʻi State and local governments are responsible for the day-to-day implementation of programs designed to meet the requirements of the CWA.

A big challenge, however, is the regulation of NPS because they cannot be specifically identified. This was partially addressed in the amendment known as the Water Quality Act of 1987, which essentially made one big NPS, stormwater, a regulated point source by regulating industrial and urban stormwater systems via NPDES permits. Other NPS pollution issues are addressed via projects and grants given to states to address agricultural runoff and other NPS problems.

Under CWA Section 305(b), states are required to periodically report to EPA on the quality of all water resources in the state and whether these waters are fully supporting water supply use, recreation activities and aquatic life. Section 303(d) requires states to identify waters of the state where water quality standards are not met and where uses are not supported. Surface waters that do not meet water quality standards after technology and regulation-based control measures are applied are listed on each state's 303(d) list, also known as the "list of impaired waters" (Section 2.4.1). The Section 303(d) List includes those waters (and associated pollutants) that do not support uses, and which require development of a TMDL strategy.[57] Studies or projects aimed at addressing sources and reducing NPS pollutants qualify for Federal funding under CWA Section

[56] *Ahupuaʻa*. A land division usually extending from the uplands to the sea (Pukui and Elbert 1986). As used by the ancient Hawaiians, an *ahupuaʻa* includes the entire watershed and also tidepools and ponds, near-shore waters along the beach, and the sea out to and including the coral reef (Parham et al. 2008).

[57] A TMDL is a calculation of a pollutant budget that generates the maximum load of a pollutant that a waterbody can receive per day and still safely meet water quality standards.

319, provided these recommendations are part of a watershed plan or comprehensive implementation that addresses EPA's nine elements (Box C1).

C.3. Point Source Pollution Regulations

Point sources are primarily controlled using regulatory approaches. Amendments to the CWA in 1972 (Section 402) introduced a permit system for regulating point sources of pollution that discharge pollutants into the ocean and other water bodies. Point source pollutants have identifiable sources and discharge locations such as the outfall of a wastewater treatment plant (WWTP), or industrial facility. The amendments provided the statutory basis for the NPDES permit program, which prohibits the discharge of any pollutant from a point source into navigable waters, unless special permits are obtained. This applies to industrial and municipal polluters and excludes homes on cesspools and septic systems. In 1987, Congress added Section 402(p) to the CWA, requiring the regulation of storm water discharges. In 1990, Phase I of the NPDES storm water program was established, requiring a NPDES permit to discharge storm water runoff from MS4s in large or medium municipalities that had populations of 100,000 or more. A ruling in 1999 created Phase II, which expanded the NPDES program to apply to all urbanized MS4. The Stormwater NPDES Permitting Program is managed by EPA and the implementation has been delegated to State agencies in most parts of the country, including Hawai'i. In Hawai'i, DOH is the permitting authority for the NPDES program. Although Phase II of the stormwater regulation program under the CWA requires small municipalities with an MS4 to obtain an NPDES permit, the storm sewer system on Kaua'i has not been designated as an MS4. There are no NPDES regulated discharges in the Hanalei Watershed.

C.4. Non-Point Source Pollution Regulations

NPS pollutants, such as excessive amounts of sediment, nutrients, and bacteria, come from a variety of diffuse sources such as stormwater, agricultural and urban runoff, erosion, feral animals, and leaking septic tanks and cesspools. NPS pollutants are the focus of this WMP. The hydrologic cycle moves these pollutants through watersheds and ultimately into the ocean. A watershed-based approach is necessary as the Hanalei Bay waters are impaired by land-based pollutants. According to EPA, NPS pollution is the nation's largest source of water quality problems. At present, about 40% of freshwater surface waters in the country are not meeting standards of swimmability and fishability, mostly due to the challenges of remediating NPS pollution. Regulating NPS pollutants via permits is impossible due to their diffuse nature, so alternative methods such as enlisting communities to take responsibility are used. Since MS4s are now under permitting programs, stormwater problems have been reduced on a nationwide basis (Appendix C.3). However, there is no designated MS4 in Hanalei, so stormwater is a NPS pollutant for the area.

The NPS pollutants that are impairing water quality in Hanalei are the result of the condition of the landscape, natural processes, and the activities that occur on it. As a result of the 303(d) listing for sediment and pathogen impairment, TMDLs have been calculated for the streams and estuaries (Phase 1) and are in process for Hanalei Bay (Phase 2) (Tetra Tech and DOH 2008; 2011). The objective is to stimulate action after the creation of these TMDLs. Projects eligible for CWA Section 319 funding must be part of a watershed based plan or comprehensive implementation that addresses EPA's nine elements (Box C1). DOH is responsible for allocating the TMDLs between point and non-point sources. However, since there are no point sources in Hanalei, the entire TMDL plan is focused on NPS pollution.

Federal agencies involved in funding NPS pollution reduction programs are EPA via grants and various programs under the CWA; NOAA under the Coastal Zone Management Act (CZMA); USDA via incentive-based conservation programs; DOT for Federal roads, and Department of the Interior via technical and financial assistance. States also have their own polluted runoff control programs. In Hawaiʻi, two programs exist specifically to implement polluted runoff controls. The Polluted Runoff Control Program[58], administered by the DOH-CWB and funded under CWA Section 319, and the Coastal Nonpoint Pollution Control Program, funded under Coastal Zone Act Reauthorization Amendments (CZARA) Section 6217 (Appendix C.5.1). To meet the program components required under Section 6217, the State developed the *Hawaiʻi's Coastal Nonpoint Pollution Control Program Management Plan* (CZMP 1996). In an effort to guide coordination between the DOH and Coastal Zone Management (CZM) pollution control programs, the State established a plan entitled *Hawaiʻi's Implementation Plan for Polluted Runoff Control* (DOH and CZMP 2000). More recent documents addressing NPS pollutants control include: *Hawaiʻi's Management Measures for the Coastal Nonpoint Source Pollution Control Program* (Stewart 2010a) and *Agency Programs, Projects, and Funding Opportunities that Support Ahupuaʻa, Watershed, and Ecosystem-based Management* (CZMP 2009). There is also a comprehensive document covering the agencies that can help implement management measures, *Responsible Agencies and Authorities - A Supplemental for Hawaii Management Measures* (Stewart 2010b).

Box C1. EPA's Nine Key Components for Watershed-Based

1. Identification of causes of impairment and pollutant sources or groups of similar sources that need to be controlled to achieve needed load reductions, and any other goals identified in the watershed plan.
2. An estimate of the load reductions expected from management measures.
3. A description of the nonpoint source management measures that will need to be implemented to achieve load reductions, and a description of the critical areas in which those measures will be needed to implement this plan.
4. Estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan.
5. An information and education component used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the nonpoint source management measures that will be implemented.
6. Schedule for implementing the nonpoint source management measures identified in this plan that is reasonably expeditious.
7. A description of interim measurable milestones for determining whether nonpoint source management measures or other control actions are being implemented.
8. A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made toward attaining water quality standards.
9. A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established.

[58] Formerly known as the Nonpoint Source Pollution Control Program.

C.5. Other Regulations

C.5.1. Coastal Zone Management Act

In 1990, while reauthorizing the CZMA, Congress enacted Section 6217 of CZARA entitled "Protecting Coastal Waters". Section 6217 requires States with approved CZM programs, including Hawaiʻi, to develop programs to implement NPS pollutant controls. CZM programs have been developed pursuant to Federal requirements by States with coastal lands in order to manage their coastal and ocean resources. States with approved CZM Programs are eligible for Federal funds.

At the Federal level, the CZM Program is administered by NOAA's Office of Ocean and Coastal Resource Management. State and local governments are responsible for the day-to-day implementation of programs designed to meet the requirements of the CZARA. The Coastal Nonpoint Pollution Control Program is part of the State CZM Program and is administered jointly by the DBEDT Office of Planning and DOH-CWB. The Hawaiʻi CZM Program is a broad management framework incorporating regulatory authorities of state and county agencies to provide greater coordination of existing laws. County governments play a crucial role in implementing the Hawaiʻi CZM Program by regulating development in geographically designated SMA. Through their respective SMA permit systems, the Counties assess and regulate development proposals in the SMA for compliance with the CZM objectives and policies and SMA guidelines set forth in Chapter 205A, HRS. No development can occur in the SMA unless the appropriate agency first issues an approval. Development is defined to include most uses, activities and operations on land and in the water.[59]

The Hawaiʻi CZM Program also has jurisdiction over the State's ORMP. The ORMP is a statewide plan mandated by Chapter 205A, HRS that focuses on facilitating comprehensive ocean resources management throughout the State. The network of government (Federal, State, County), academic and community partners is working across physical and jurisdictional boundaries to improve management of activities affecting Hawaiʻi's ocean and coastal resources. The West Maui Watershed Plan is an example of on-the-ground implementation efforts coordinated in part through this program.

C.5.2. Safe Drinking Water Act

The Safe Drinking Water Act (SDWA), enacted in 1974, regulates all current and potential drinking water sources, above and below ground. EPA is responsible for determining minimum quality standards to protect tap waters from contaminants that are detrimental to human health. Underground injection is used for many industrial discharges. Since underground injection wells have the potential to contaminate aquifers, injection wells are regulated under the SDWA. Under this legislation, EPA established the UIC Program that federally mandates minimum standards that must be adopted by each state's individual UIC program. In Hawaiʻi, the implementation of SDWA standards has not been delegated to the State, however the DOH Safe Drinking Water Branch has

[59] http://hawaii.gov/dbedt/czm/program/sma.php

developed a program to address many sources of UIC that are permitted by rule by EPA. There are multiple statutory requirements, both Federal and State, which regulate the implementation.[60]

The State UIC program was established under HAR §11-23 and 23A, with the intent of:

- Protecting the quality of Hawai'i's underground sources of drinking water from chemical, physical, radioactive, and biological contamination that could originate from injection well activity.
- Processing permits and project reviews for new and renewal permits, modifications, and abandonment of injection wells.
- Evaluating geologic logs of soil and rock, injectivity tests, geologic maps, and groundwater quality profiles to determine the viability of subsurface injection.
- Maintaining inventory and database of all injection well files.
- Organizing and conducting site inspections to verify the location and performance of injection wells and to verify compliance with all testing or well closure plans.
- Conducting site investigations to identify problems such as unpermitted facilities and correction of deficiencies.
- Enforcing Underground Injection Control rules and permit conditions.
- Serving the public by providing information and technical assistance.

According to HAR §11-23 and 23A, injection well operators are required to obtain a UIC permit from Hawai'i DOH and comply with the conditions of the permits. According to §11-23, Section 18A ("Monitoring and Reporting Requirements"), "the operator of any injection well or wells shall keep detailed records of the operation of the well or wells, including, but not limited to, the type and quantity of injected fluids, and the method and rate of injection for each well". According to the Code of Federal Regulations §144.51, the conditions for each permit shall be written into the permit either expressly, or by reference. Conditions are specified for each permit and include explicit monitoring and reporting requirements.

The Hawai'i DOH, Environmental Management Division, Wastewater Branch formulates and enforces all wastewater rules and regulations in Hawai'i. HAR §11-62 'Wastewater Systems' is the codification of these regulations and covers all public wastewater treatment and disposal systems as well as private WWTPs and Onsite Wastewater Treatment Systems throughout the State, from individual cesspools to major municipal WWTPs.

C.5.3. HAR Title 13, Chapter 5, Conservation District

HAR Title 13, Chapter 5 regulates land use in the state's Conservation District for the purpose of conserving, protecting, and preserving the important natural resources of the state through appropriate management and use, to promote their long-term sustainability and the public health, safety and welfare. The chapter establishes five subzones within the Conservation District: protective, limited, resource, general, or special. For each subzone, the chapter describes the

[60] **Federal**: Safe Drinking Water Act of 1974, 92-523; Safe Drinking Water Act Amendments of 1986, 99-339; Lead Contamination Control Act of 1988; Safe Drinking Water Act Amendments of 1996, 104-182; 40 Code of Federal Regulations (CFR) Parts 35, 124, 141, 142, 144, 145, 146, and 148; **Hawai'i Revised Statues**: Chapter 340 E, Chapter 340 F; **Hawai'i Administrative Rules**: HAR Title 11, Chapter 19, Emergency Plan for Safe Drinking Water; HAR Title 11, Chapter 20, Potable Water Systems; HAR Title 11, Chapter 21, Backflow and Cross-Connection Control; HAR Title 11, Chapter 23, Underground Injection Control, 1991; HAR Title 11, Chapter 23a, 12/21/2000 Amendment, Underground Injection Control; HAR Title 11, Chapter 25, Certification of Operating Personnel in Water Treatment Plants.

objective of the level of protection and identifies permitted uses along with the procedures necessary to obtain permission to engage in that use. Each use is assigned to one of four categories. The first category does not require a permit from the DLNR or BLNR. The second category requires a site plan, to be approved by the DLNR. The third category requires a departmental permit from DLNR permit. The fourth category requires a BLNR permit, and, where specified, an accompanying management plan.

Conservation lands within the Hanalei Bay Watershed fall into the protective, limited, resource and general subzones.

The objective of the protective subzone is to protect valuable resources in designated areas such as restricted watersheds, marine, plant and wildlife sanctuaries, significant historic, archaeological, geological, and volcanological features and sites, and other designated unique areas. To that end, many of the identified uses in this subzone fall under the third or fourth categories of land use and require, at minimum, a permit from the DLNR or BLNR. This includes: data collection that involves installation of equipment or ground disturbance; restoration or repair of fishponds; certain *kuleana* land uses; alteration of plant cover that involves ground disturbance; land use for public purposes such as recreational facilities; sanctuaries (plant and wildlife sanctuaries, natural area reserves, and wilderness and scenic areas); alteration of existing structures and topographic features; consolidation or subdivision of property; and certain types of tree removal.

The objective of the limited subzone is to limit uses where natural conditions suggest constraints on human activities. This includes land susceptible to floods and soil erosion, lands undergoing major erosion damage and requiring corrective attention by the by the county, state, or federal governments. To that end, some of the identified uses in this subzone fall under the third or fourth categories of land use and require, at minimum, a permit from the DLNR or BLNR. This includes: agricultural activities; botanical gardens and private parks; erosion control, flood control and other hazard prevention devices; alteration of plant cover; and single family residences in a flood plain or coastal high hazard area.

The objective of the resource subzone is to develop areas using management that ensures that the natural resources of those areas are sustained. To that end, a few of the identified uses in this subzone fall under the third or fourth categories of land use and require, at minimum, a permit from the DLNR or BLNR. This includes: commercial forestry; alteration of plant cover in an area over 10,000 sq. ft.; mining and extraction of any material or natural resource; and single family residences.

The objective of the general subzone is to designate open space where specific conservation uses may not be defined, but where urban use would be premature. In this subzone the land use that requires a permit from DLNR or BLNR are: land uses promoting natural open space and scenic value including those with accessory structures; provided that no new golf structures shall be developed; and land uses not previous identified under HAR sections for other subzones which are consistent with the objectives of the general subzone.

C.5.4. County of Kauaʻi Planning and Zoning

C.5.4.1. Kauaʻi General Plan

At the county level the *Kauaʻi General Plan* provides guidance for land use regulations, the location and character of new development and facilities, and planning for County and State facilities and services. The General Plan is given the effect of law through adoption of an ordinance by the County Council. HRS Chapter 46 grants the counties the power to regulate land development through zoning, though zoning must be based on a general plan. Chapter 5 addresses land use and development, for Open, Agriculture, and Urban designations. The overarching theme is to preserve Kauaʻi's rural character.

As detailed in Section 5.2 of the General Plan, lands within the Agriculture designation are to be used now or in the future for agricultural activities. The primary intent of the Agriculture designation is to conserve land and water resources in order to: (1) insure an excellent resource base for existing and potential agricultural uses; (2) assure a sufficient supply of land available for sale or lease at a cost that is economically feasible for agricultural enterprise; and (3) promote and preserve open agricultural lands as a key element of Kauaʻi's rural character and lifestyle, essential to its image as "The Garden Island" and to the continued viability and development of Kauaʻi's visitor industry. The secondary intent of the Agriculture designation is to provide an opportunity for people to reside in an agricultural community.

The Open designation is detailed in Section 5.3 of the General Plan. The intent of the Open designation is to preserve, maintain or improve the natural characteristics of non-urban land and water areas that: (1) are of significant value to the public as scenic or recreation resources; (2) perform essential physical and ecologic functions important to the welfare of surrounding lands, waters, and biological resources; (3) have the potential to create or exacerbate soil erosion or flooding on adjacent lands; (4) are potentially susceptible to natural hazards such as flood, hurricane, tsunami, coastal erosion, landslide or subsidence; or (5) form a cultural, historic or archaeological resource of significant public value. As provided for in the General Plan, lands designated Open shall remain predominantly free of development involving buildings, paving and other construction.

Section 5.4 of the *Kauaʻi General Plan* sets forth policy for the six county urban land use designations (i.e. Urban Center, Resort, Residential Community, Transportation, Military, and Parks), of which only Residential Community and Parks occur within the Hanalei Bay Region. In addition, Hanalei Town has a designated 'Town Center', which is used to concentrate shopping, commercial development, and residential uses. The General Plan contains policies related to development in urban areas with a key component of promoting growth and development in compact urban areas. Land use policies are in place to prevent sprawl and commercial strip development and encourage residential development within urban and town centers and in residential communities contiguous to them. Section 5.5 is also relevant to the Hanalei region as it sets forth the policy for Scenic Roadway Corridors including the Hanalei-Hāʻena Highway.

C.5.4.2. Kauaʻi County Comprehensive Zoning Ordinance

While the General Plan is a direction setting policy document, the County of Kauaʻi has multiple zoning provisions that are regulated by Chapter 8 of the *Kauaʻi County Comprehensive Zoning*

Ordinance (CZO). These provisions govern zoning issues within six major use districts and two special districts on a case by case basis. Similar to the State Land Use Districts, the County CZO regulates the type of land uses permitted on the island and their locations. The CZO is much more specific and detailed in its regulation of permitted uses, design standards, and building requirements.

C.5.4.3. North Shore Development Plan Ordinance

Further provisions are detailed in the *North Shore Development Plan Ordinance* (NSDPO), which is part of the *Kaua'i General Plan*. The NSDPO applies to the North Shore Special Planning Area, including the District of Hanalei and portions of other watersheds between Moloaa Stream and the Nā Pali Coast. This ordinance establishes development plans, zoning maps and design criteria to guide and regulate future development and protect physical and social characteristics that are found to be of particular public value. The ordinance supplements the CZO and Subdivision Ordinances in regulating use and development. Modifications to provisions of the CZO are made to the Residential, Commercial, Agriculture, and Open Districts that address items including subdivisions, type of dwelling in a district, number of dwellings per lot, facility use. Additional special regulations applicable to all districts cover structure height, setbacks, access locations, subdivisions, utility structures, recreational uses, and design standards for commercial districts.

C.5.4.4. Agricultural District

In accordance with HRS §205-4.5, all lands within the Agricultural District with the two highest categories of productivity rating (A or B) of the Land Study Bureau's classification system, shall be restricted to certain uses. CZO Chapter 8, Article 7 provides details on the permitted uses and structures for the Agricultural District. The purpose of Article 7 "is to protect the agricultural potential of lands within the County of Kaua'i to insure a resource base adequate to meet the needs and activities of the present and future" (County of Kaua'i 1972). CZO's Agriculture District regulations incorporate measures that are designed to carry out the purpose of limiting subdivision of agricultural lands and restricting the number of units that could be built.[61] Subdivision of parcels is permitted, based on size and date of ownership. Contiguous parcels up to 300 acres may be subdivided with the minimum size for each based on overall parcel size. For example, parcels between 50 and 300 acres may be subdivided into parcels with a minimum size of 25 acres each. However, per the NSDPO, if the land is zoned Open District by the County, no parcel may be subdivided into more than ten lots. The NSDPO establishes the minimum lot size for subdivisions in the Agricultural District to five acres.[62] Permitted structures and permitted residential densities are one dwelling unit per each parcel one acre or larger. Additional dwellings are permitted at one per each additional three acres with a maximum of five dwellings per parcel. However, the NSDP states that no more than one dwelling unit may be permitted on any parcel smaller than five acres. Setbacks from the property line are required in accordance with Section 8-3.5 of the CZO.

[61] As described in the General Plan (Section 5.2.4.1): "The key regulation is a sliding scale limiting the number of lots that can be created in subdividing a parcel of Agriculture land. The sliding scale is structured to allow some residential development on each existing parcel, but to discourage wholesale development of large acreages. Under the sliding scale, the ratio of residences to land area decreases as the land area increases. This preserves large areas of the larger lots for agricultural use. It favors the subdivision of smaller parcels (30 acres or less) by allowing smaller lot sizes of one to three acres.

[62] The CZO states that parcels of 10 acres or less may be subdivided into parcels with a minimum size of one acre each.

C.5.4.5. Urban Lands

The General Plan, CZO, and NSDPO set forth specific policies for Urban lands regarding density, development of commercial and recreational facilities, residential dwellings and urban services (e.g. wastewater treatment facilities), and the maintenance of open space and scenic roadway corridors. Policies provide specifics on uses, structures, parcel and lot area, setback requirements, minimum distance between buildings, parcel dimension requirements, access/driveways, building height, utilities and service, public access, and permit requirements. Specific requirements may be written into permits.

C.5.5. County of Kaua'i Best Management Practices Maintenance

The "Stormwater Permanent Best Management Practices Manual" (Hawai'i DOT 2007), developed for the O'ahu MS4s, is used statewide for managing stormwater.[63] It covers specific hydraulic design criteria and drainage conditions on catch basins, inlets, culverts, gutters and ditches, as well as permanent management practices to control polluted runoff, among other things. Which management practices are chosen is site-specific and should be managed by the Kaua'i District DOT office which, according to the DOT website, is responsible for: 1) engineering services and field inspections of transportation construction projects in conformance with approved plans and specifications; and 2) maintenance, alteration and repair of State roads, highways, and related structures.

Conversations with Kaua'i District DOT staff confirmed that although there is no MS4 and there are no NPDES permits, they use the consent decree and manual as guidance. The district DOT has no official or routine schedule for the maintenance activities of manholes and storm drains along Kuhio Highway. The amount of debris clogging varies based on conditions and if inspections show any clogging, debris is removed. There is no record of the amount of debris found or removed. Inspections are conducted about once a week and debris is removed about once a month depending on water flow conditions. Since the State baseyard is located in Lihue, it is difficult to get big equipment to the area.

County roads and storm drains are regulated and maintained by the Kaua'i County Department of Public Works (DPW). The Kaua'i District DOT suspects they use a maintenance schedule similar to the district's, however their baseyard is close by, so it might be easier for them to bring big equipment.

Kaua'i DPW has an internal publication on construction projects with the following relevant wording:

> "In accordance with Chapter 11-55, Water Pollution Control and Chapter 11-54, Water Quality Standards, Title 11, State Administrative Rules, the contractor shall be responsible

[63] A lawsuit by the EPA against the Hawai'i DOT in 2005 for violations against the CWA related to improper management of the O'ahu Storm Sewer System, including permitted MS4s, resulted in a Consent Decree that bound the involved parties to abide by certain provisions and the development of the BMP manual. [United States of America Department of Health, State of Hawaii (Plaintiff) vs. Department of Transportation, State of Hawaii (Defendant). Civil Action No. CV05 00636. Consent Decree. January 30, 2006.]

for ensuring that the BMP [Best Management Practice] to minimize or prevent the discharge of sediments, debris and other water pollutant into state waters are provided at all times".

"National Pollution Discharge Elimination System (NPDES) Requirements:

A. The contractor shall obtain and comply with the National Pollutant Discharge Elimination System (NPDES) requirements for Kauai District permit projects. This is available at the Kauai District Office at 3060 Eiwa St., Suite 205. Due to potential cost impacts, the contractors needs to be aware of these requirements.
B. The contractor shall complete and submit a contractor's certification of NPDES compliance, including completion of Best Management Practice (BMP) checklist and submittal of a written BMP Plan and drawings, prior to issuance of the permit to perform work upon county roadways."

C.6. Community-Based Initiatives

Parallel to Federal and State programs, and often supported by available funding, voluntary initiatives are an important mechanism for both preventive and treatment control of NPS pollutants. There are numerous stakeholders that are affected by NPS pollutants since ultimately they impact water quality of ocean waters. The HWH has taken a leadership role in the watersheds that drain into Hanalei Bay, and has identified actions and strategies to reduce NPS pollutants (Section 0). Community engagement, education, and volunteer programs (including voluntary installation of green infrastructure) are an integral part of a comprehensive solution to reduce NPS pollutants.

Table C1. Agencies with Responsibility for Controlling Polluted Runoff and Monitoring and Maintaining Water Quality

Federal Agencies
National Oceanic and Atmospheric Administration (NOAA) Jointly administers Coastal Nonpoint Pollution Control Program, which falls under CZARA Section 6217, with EPA. Administers Coral Reef Conservation Program to address threats to coral reef ecosystems, including land-based pollutants.
U.S. Army Corps of Engineers (USACE) Charged with protection of the Nation's aquatic resources which is accomplished by: implementing the Nationwide Permits system for certain activities; regulating construction activities in navigable waters and dredging of harbors; regulating the discharge of fill material in wetlands and other U.S. waters; and conducting ecosystem restoration, flood damage reduction, water control projects and various water quality studies. Administers CWA Section 404.
U.S. Coast Guard Responsible for administration of a maritime protection program to prevent and control pollution in U.S. navigable waters. Enforces laws against individuals and companies that pollute marine waters.
USDA Farm Services Agency Responsible for most of the Federal financial support regarding farming activities such as farm plans to reduce erosion or control animal impacts on water.

USDA Natural Resources Conservation Service (NRCS) Provides technical assistance for agricultural production and cultivation, conservation activities, and economic management. Advocates proper agricultural production methods and the use of management practices to minimize adverse environmental impacts. Works closely with the 16 Soil and Water Conservation Districts (SWCD) in Hawaiʻi. Assists in developing conservation plans to treat existing and potential resource problems and has funding to assist with the installation of best management practices. Provides permitting expertise and coordination with permitting agencies. Sponsors the Environmental Quality Incentives Program (EQIP), a voluntary program that provides financial and technical assistance to agricultural producers through contracts up to a maximum term of ten years. These contracts help plan and implement conservation practices that address natural resource concerns and for opportunities to improve soil, water, plant, animal, air and related resources on agricultural land and non-industrial private forestland.
U.S. Environmental Protection Agency (EPA) (Region 9) Responsible for providing clean and safe surface water, ground water, and drinking water and protecting and restoring aquatic ecosystems (Office of Water). Provides funding and technical support for implementation of the Hawaiʻi Polluted Runoff Control Program through CWA Section 319. For Hawaiʻi, permitting activities have been delegated to the State. Jointly administers Coastal Nonpoint Pollution Control Program, which falls under CZARA Section 6217, with NOAA. Has prohibited the construction of new large capacity cesspools and required all existing large capacity cesspools to be replaced with alternative wastewater systems by April 2005.
USGS Pacific Islands Water Science Center Collects information needed to understand U.S. water resources and provide access to water data, publications and maps. Collect, analyze, and interpret water-quality data and information on the transport, fate and remediation of contaminants.
State Agencies
DOH Environmental Planning Office Water Quality Management Program: Responsible for setting the State's water quality goals (Water Quality Standards), evaluating the progress in achieving these goals, and long-range planning to solve water quality problems. Planning Review Program: Reviews development projects with potential environmental impacts and coordinates departmental evaluations on mitigative measures. Implements environmental policies and standards at the earliest stages of the planning process for statewide project developments.
DOH Environmental Management Division: Clean Water Branch Responsible for enforcing and revising water quality standards. Water quality standards are maintained through monitoring and enforcement, sponsorship of polluted runoff control projects, review of permit issuance and public education. Administers Section 319 grants programs and NPDES permit process, regulates sewage treatment and disposal, hazardous waste and solid waste, and reviews and issues permits for industrial storm water discharge, construction storm water discharge, MS4 permits and NPDES.
DOH Environmental Management Division: Safe Drinking Water Branch Responsible for enforcing the Federal Safe Drinking Water Act, which covers waters that are potential sources of drinking water, both surface and underground. Administers UIC Program as required by SDWA and directed by EPA. Administers Ground Water Protection Program, which is a non-regulatory program whose goal is to protect human health and sensitive ecosystems by protecting ground water resources. Its focus is on water quality assessment, and on developing pollution prevention and protection measures.
DOH Environmental Management Division: Wastewater Branch Administers engineering and financial functions related to water pollution and municipal and private wastewater treatment. In charge of reviewing/approving and monitoring of all sewage and wastewater treatment systems including septic tanks and cesspools. Provides engineering, design, facility approval/audit, environmental assessment, grant/loan award, inspection of new facilities. Implements Statewide Wastewater Operator Training Center and supports the State board Operating Personnel in Wastewater Treatment Facilities. The three sections within the Wastewater Branch are: Planning/Design, Construction/Operations and Grants Management.
Department of Transportation (DOT) Responsible for the developing and implementing strategies to control polluted runoff from transportation facilities (i.e. public highways and trails, airports, and commercial harbors). Authorized to enforce polluted runoff control mechanisms for commercial harbors, highways, roads and bridges, including through NPDES permits.

DBEDT Office of Planning Oversees the Hawai'i CZM Program. This program guides appropriate land and water uses and activities through coordination of State and county agencies and ensuring compliance with laws, regulations and management policies, including the requirements of the CZMA. The CZM Program employs a variety of regulatory and non-regulatory techniques to address coastal issues and uphold environmental laws.	
Department of Land and Natural Resources (DLNR) Manages State-owned terrestrial and submerged lands and regulates uses in the designated conservation districts. Administers the State's designated marine life conservation districts, marine and freshwater fisheries management areas, wildlife sanctuaries, and natural area reserves. Provides funding to the 16 local SWCDs through the Hawai'i Association of Conservation Districts.	
DLNR Commission on Water Resource Management (CWRM) The Commission's staff is comprised of the Surveying, Planning, Ground-Water Regulation, and Stream Protection and Management Branches. Oversees the instream use protection program, which recommends appropriate interim and final instream flow standards. Issues permits for well construction, modification of existing well or pump installation, and alterations of stream channels and diversions.	
DLNR Engineering Division Oversees the flood and dam safety program. Provides for the inspection and regulation of construction, enlargement, repair, alteration, maintenance, operation, and removal of dams or reservoirs to protect the health, safety, and welfare of the citizens of the State by reducing the risk of failure of the dams or reservoirs.	
DLNR Division of Aquatic Resources Manages the state's aquatic resources and ecosystems through programs in commercial fisheries and resource enhancement; aquatic resources protection, habitat enhancement, and education; and recreational fisheries. Sets overall water conservation, quality and use policies; defines beneficial and reasonable uses; protects ground and surface water resources, watersheds and natural stream environments; establishes criteria for water use priorities while assuring appurtenant rights and existing correlative and riparian uses and establishes procedures for regulating all uses of Hawai'i's water resources.	
DLNR Division of Forestry and Wildlife Responsible for the management of State-owned forests, natural areas, public hunting areas, and plant and wildlife sanctuaries. Program areas cover watershed protection; native resources protection, including unique ecosystems and endangered species of plants and wildlife; outdoor recreation; and commercial forestry. Manages State Forest Reserve System and Natural Area Reserves System in part to protect upper watershed areas.	
DLNR Land Division Responsible for managing State-owned lands in ways that will promote the social, environmental and economic well-being of Hawai'i's people and for ensuring that these lands are used in accordance with the goals, policies and plans of the State. Responsible for leasing State agricultural lands to agricultural operators under Chapter 171, HRS. One of the lease conditions is that the operators work with the local soil and water conservation districts to develop and implement a conservation plan.	
Department of Agriculture Regulates activities to protect agricultural industries and natural resources against insects, diseases and pests. Controls all eradication services directed against weed and insect pests, and controls the sale and use of pesticides. Pursuant to Act 90, SLH 2003, beginning on January 1, 2010, the authority to manage, administer, and exercise control over any public lands that are designated important agricultural lands pursuant to Section 205-44.5, HRS, was transferred from DLNR to the State Department of Agriculture (DOA) (Section 171-3(b), HRS).	
Soil and Water Conservation Districts (SWCD) Conducts soil and water conservation activities within their respective boundaries. Works closely with the USDA NRCS to assist the needs of agricultural producers and the community through conservation planning, and technical assistance with management or conservation practices.	
County Agencies	
East Kaua'i Soil Conservation District State entity affiliated with NRCS. This district is managed by unpaid volunteers. Mission is to promote stewardship and conservation of natural resources by advocating the use of management practices by land users and public. Review and approve resource conservation plans for erosion control and water conservation on agricultural lands. Involved in Kaua'i County Sediment and Erosion Control permitting process. Participate in DOH/EPA NPS pollutants programs. Participate and support initiatives that seek to protect and maintain irrigation systems. Natural resource protection and conservation outreach.	

County of Kaua'i Municipal government with executive authority in form of the Mayor. Includes County Council. The County of Kaua'i is responsible for planning and zoning activities and has several departments and divisions dealing with issues related to water quality.
Kaua'i Department of Planning Advises executive branch on land use matters and administers zoning/subdivision ordinances. Follows the *Kaua'i General Plan* as its policy and guidance document to plan and improve the physical environment and quality of life for the people of Kaua'i and to address the overall development of the island. Issues permits: building, clearing, stockpiling, grading, and construction dewatering. Assesses the need for construction of permanent detention/retention and other engineering control structures in developments. Takes enforcement action against illegal grading or construction.
Kaua'i Department of Water Local authority responsible for enforcement of Safe Drinking Water Act. Deals with drinking water quality. Manages municipal water resources and distribution system. Develops Watershed Management Plans that are used to meet the requirements of preparing a county water use and development plan under the State Water Code and County ordinances.
Kaua'i Department of Public Works (DPW) Responsible for planning, design, construction and maintenance of county-owned facilities. In charge of garbage collection, sewage treatment and review and enforcement of various construction codes, inspection and management of construction projects. Each project untaken by the department requires consideration of erosion and sediment control, nutrient management and road construction/ reconstruction. Manages sanitary sewage facilities and landfills. Various divisions within DPW are relevant to water quality.
Kaua'i DPW – Engineering Division Provides engineering and surveying services for DPW. Provides recommendations and technical support to other County departments. Administers Storm Water Management Program, reviews building permits and zoning issues, and conducts field survey and mapping projects. Three divisions within Engineering are: Construction Management & Inspection, Design & Permitting and Survey & Mapping.
Kaua'i DPW – Wastewater Management Division Responsible for developing and operating the County's wastewater infrastructure. Contains two programs: 1. Wastewater Administration and Engineering Program – manages objectives of Wastewater Division and administers sewer user charge system. Responds to requests for information and complaints. Reviews construction and building permit plans. 2. Wastewater Treatment Facilities Program – responsible for operation, maintenance and repair of all County wastewater collection, treatment and disposal facilities to protect health and the environment. Conducts preventative maintenance, treatment processes control, solids management, safety and training, and laboratory monitoring for regulatory compliance.

Appendix D. Background Information on Water Quality, Pollutants, and Treatments

D.1. Understanding Water Quality

The impacts of pollutants on water quality and ultimately coral reef health, is a driving force behind this WMP. This section provides readers basic information about water quality to support their understanding of pollutant sources and how they affect various water quality parameters and watershed resources.

D.1.1. Water Quality Standards

As defined by the Federal Water Quality Standards Regulation (40 CFR §131.2) a water quality standard defines the water quality goals for a water body, or portion thereof, by designating the use or uses to be made of the water, by setting criteria necessary to protect the uses, and by protecting water quality through antidegradation provisions (EPA 1994). States adopt water quality standards to protect public health or welfare, enhance the quality of water, and serve the purposes of the CWA. The Regulation describes State requirements and procedures for developing, reviewing, revising, and adopting water quality standards, and EPA requirements and procedures for reviewing, approving, disapproving, and promulgating water quality standards as authorized by CWA Section 303(c).

HAR Chapter §11-54 defines the general policy of water quality antidegradation, as well as the state standards for particular pollutants for Hawaiʻi waters. The state standards for pollutants are defined by both narrative and numerical criteria (Appendix D.2). §11-54-1.1 defines a general policy of water quality antidegradation for all water types:

a) Existing uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

b) Where the quality of fish, shellfish, and wildlife and recreation in and on the water, that quality shall be maintained and protected unless the director finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the state's continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the director shall assure water quality adequate to protect existing uses fully. Further, the director shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control.

c) Where high quality waters constitute an outstanding national resource, such as waters of national and state parks, and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected.

State waters are classified as either inland waters or marine waters with specific water quality criteria set forth for streams, estuaries, embayments, open coastal waters and oceanic waters. For the Hanalei region, criteria for all are potentially applicable. "Streams" means seasonal or continuous water flowing unidirectionally down altitudinal gradients in all or part of natural or modified channels as a result of either surface water runoff or ground water influx, or both. Streams may be either perennial or intermittent and include all natural or modified watercourses. “Estuaries” means characteristically brackish coastal waters in well-defined basins with a continuous or seasonal surface connection to the ocean that allows entry of marine fauna. Estuaries may be either natural or developed. "Embayments" means land-confined and physically-protected marine waters with restricted openings to open coastal waters, defined by the ratio of total bay volume to the cross-sectional entrance area of seven hundred to one or greater. "Total bay volume" is measured in cubic meters and "cross-sectional entrance area" is measured in square meters, and both are determined at mean lower low water. “Open coastal waters” means marine waters bounded by the 183 meter or 600 foot (100 fathom) depth contour and the shoreline, excluding bays named in subsection (a) of HAR Chapter §11-54-6. “Oceanic waters” means all other marine waters outside of the 180 meter or 600 foot (100 fathom) depth contour.

The format of Hawai‘i’s water quality standards differs from other states’ standards in that many of the criteria are expressed as geometric means of a representative data set, and are not intended for comparison with single sample values. The geometric mean indicates the central tendency or typical value of a set of numbers. The geometric mean normalizes the range being averaged so that no range dominates the weighting.

The criteria also contain allowances for rainfall events in the form of less strict “10 percent” and “2 percent” criteria. The “not to exceed the given value 10% of the time” means that the standard is exceeded if greater than 10% of the samples are higher than the appropriate standard for the season of interest. A sample size of 50 to 90 to show exceedance of the corresponding “10% of the time” criterion is preferred by DOH. The “not to exceed the given value 2% of the time” means that the standard is exceeded if greater than 2% of the samples are higher than the appropriate standard for the season of interest. A sample size of 250 to 450 to show exceedance of the corresponding “2% of the time” criterion is preferred.

Hawai‘i’s water quality standard categories are further refined by inclusion of a wet or dry criterion, defined either by calendar date by levels of freshwater input. Inland waters including springs and seeps, ditches and flumes, natural freshwater lakes, reservoirs, low wetlands, coastal wetlands, saline lakes, and anchialine pools, define wet and dry season based on the calendar date. “wet” season is November 1 through April 30 and “dry” season is May 1 through October 31. For estuaries, there is no specification for “wet” and “dry” season. For embayments “wet” criteria apply when the average fresh water inflow from the land equals or exceeds one per cent of the embayment volume per day. “Dry” criteria apply when the average fresh water inflow from the land is less than one percent of the embayment volume per day. For open coastal waters, “wet” criteria apply when the open coastal waters receive more than three million gallons per day of fresh water discharge per shoreline mile. “Dry” criteria apply when the open coastal waters receive less than three million gallons per day of fresh water discharge per shoreline mile.

D.1.2. Background versus Above Background Levels

Investigations and studies involving water quality of the Hanalei Bay Watershed have usually had one common objective: identify the presence of and/or quantify the amount of a target substance (e.g. bacteria). Quantifying the amount of a substance, often reported as a concentration and expressed as mass per volume, is necessary to determine if its concentration is polluting the waters. In many instances it is necessary to sample a substance over time to determine if the level of the substance is increasing, and/or if it is higher than natural background levels. Background levels, often referred to as ambient conditions, exist for living and non-living substances in, and phenomena occurring on, the watershed. Background inherently implies reference to a time frame that may be difficult to quantify. Above background levels are simply levels of a substance that are higher than background.

Issues concerning the comparison and reporting of background versus above background levels occur when background levels are unknown or vary with time and space across the watershed. Water quality in the Hanalei Bay Watershed has been sampled from a variety of sites over the last two decades. When compared to water quality standards, the concentrations of several parameters (i.e. indicator bacteria) have often exceeded these standards. In the case of indicator bacteria, *E. coli* and *enterococci* samples collected from water and soils are used to indicate the presence of waste from humans and animals. These bacteria have been found to reproduce and occur naturally in the environment (Fujioka and Hardina 1991), and as result it is difficult to determine if the bacteria contained in samples are from humans and animals or naturally occurring. In the case of bacteria, new sampling analysis techniques have been developed that can refine the source of waste found in the watershed and reduce and remove the ambiguity that indicator bacteria create (Boehm 2010) (Section 5.3.3.2).

D.1.3. Physical Water Quality

There are various physical parameters that are tested when water quality monitoring is performed. These are not necessarily introduced contaminants, but normal parameters that are a function of the hydrologic cycle and biogeochemical processes taking place in the watershed. Parameters may fluctuate naturally with time and space or due to human alterations and activities in the watershed. Physical parameters such as pH, TSS, and temperature are tested to assess whether levels are normal or unusual, for either natural or unnatural reasons. Results of such testing are looked at holistically because combinations of factors and types of pollutants can cause certain problems due to synergistic effects.[64] For example, if there is an influx of agricultural runoff into a waterbody, the excess nutrients may result in an algal bloom. This causes an increase in plant biomass and then plant die-off and decomposition, leading to higher levels of suspended solids. The decomposing bacteria in turn increase the biological oxygen demand (BOD) and reduce the amount of DO in the water column, making it difficult for other aquatic organisms to survive. Physical water quality parameters typically tested for are shown in Box D1.

Box D1. Physical Water Quality Parameters

pH: pH is a measurement of Hydrogen ions and refers to a liquid's level of acidity or alkalinity. It is presented on a logarithmic scale of 0-14, with levels lower than 7 meaning acidic and levels higher than 7 meaning alkaline. pH has a direct effect on the solubility and biological availability of nutrients and toxic metals. Lower pH levels make toxic metals more soluble. pH is extremely important in water quality due to these synergistic effects.

Dissolved oxygen (DO): This is the amount of oxygen in the water column. In order for an aquatic ecosystem to be balanced, there are certain DO levels required to sustain aquatic organisms. If the level of DO is unusually low, this could indicate an unbalanced state such as eutrophication, where excess plant matter and its decomposition has caused a hypoxic environment.

[64] Synergy: the interaction of elements that when combined produce a total effect that is greater than the sum of the individual elements, contributions, etc. (source: dictionary.com)

Biological oxygen demand (BOD): BOD is an indirect measure of organic pollution. It measures the amount of DO needed for aerobic bacteria to decompose the organic material in a given water sample. If the BOD is high, this can point towards an increase in plant matter so this is an indirect indicator of eutrophication.

Temperature: Temperature varies naturally based on daytime and season. However, there are certain temperature ranges that are healthy for an aquatic ecosystem. If the temperature falls below or above that range, it affects the biological activity in that ecosystem. Wastewater effluent, runoff and other discharges can affect the temperature of a waterbody.

Total suspended solids (TSS): This is a measurement of particulate matter in the water. Water samples are filtered and the weight of the remaining particulates provides a measurement of particulate matter in the water column.

Turbidity: This parameter is linked to many things, e.g. directly to the amount of TSS in the water. Turbidity is a measure of water clarity. It is measured in "Nephelometric Turbidity Units" or NTU which is a measurement of how light is scattered by particulates in the water. Turbid waters can be caused by sediments, phytoplankton and other particulates. High turbidity reduces light penetration which affects plant photosynthesis. Settling particulates can also kill hatching larvae and clog fish gills.

Total dissolved solids: These are minerals or salts and trace elements that occur naturally, as well as plant nutrients such as Nitrogen and Phosphorus. The former generally affect the taste and clarity of water without having negative ecological impacts. The latter can cause ecological problems.

Salinity: This measures the amount of salt in the water and is generally used in estuaries and coastal waters. There are certain salinity levels that are healthy for certain ecosystems and an influx of freshwater into estuaries or the ocean can have a negative impact on the aquatic organisms. Even treated wastewater, when directly released into the ocean, is sometimes considered pollution not just because of the nutrients and bacteria, but because of the dilution it causes in the seawater.

Electrical conductivity: This measurement is an estimate of the total dissolved ions/minerals in the water and varies naturally depending on the geology and other factors in a watershed. Electrical conductivity measurements can help determine possible pollution problems in the water as various pollutants from wastewater, agricultural and urban runoff may cause an increase in electrical conductivity.

Chlorophyll a: This measures the amount of chlorophyll, the cell component of plants that makes them green. This measurement is an indirect way of estimating plant (algae) biomass in the water.

Stream flow: Stream flow is a measure of water velocity. It is subject to seasonal variation. Stream flow has a direct effect on several water quality parameters as it affects temperature, DO and the distribution of various substances. It can also potentially alter habitat. Problems can arise during storm events when heavy rainfall causes high velocity and streambank erosion, which in turn affects the amount of TSS and turbidity. It can also physically damage habitat. Stormwater runoff is a contributor to variable flows that can negatively impact aquatic ecosystems.

D.1.4. Chemical Water Quality

Nutrients such as Nitrogen and Phosphorus are used as chemical water quality parameters since nutrient pollution can lead to disturbances in fresh and saltwater ecosystems. Nitrogen and Phosphorus are natural elements with their own respective biogeochemical cycles.

Nitrogen is naturally present in the environment, in soil, in the atmosphere and all living things. It makes up 78% of air. It is present in multiple organic and inorganic forms such as ammonium, nitrite and nitrate and Nitrogen gas. The Nitrogen cycle is a complex sequence of conversions of various Nitrogen states to other states as it moves through the environment, the ground, water, and atmosphere (Box D2). Nitrogen is an important source of food for plants and in order for them to use it, bacteria "fix" the Nitrogen, i.e. convert it to a usable form. For example, ammonium (NH_4^+) present in the soil from decomposed animal excretions gets converted to nitrite and later nitrate, which can be absorbed by plants. These ionic forms later get converted back into Nitrogen gases that enter the atmosphere, completing the cycle.

Box D2. Understanding Nitrogen

The Forms of Nitrogen

Nitrogen load inputs into Hanalei Bay are of concern due to their potential to adversely impact the Bay by stimulating primary productivity of the food chain and triggering harmful algal blooms. Excess Nitrogen from fertilizers, human and animal waste, and decomposing vegetation (including food waste) are all sources of Nitrogen found in the waters of the Hanalei Bay Watershed.

Organic Nitrogen in Living Things

Nitrogen is a component of amino acids and urea. Amino acids are the building blocks of all proteins. Proteins comprise not only structural components such as muscle, tissue and organs, but also enzymes and hormones essential for the functioning of all living things. Urea is a byproduct of protein digestion. The term "organic Nitrogen" is used to describe a Nitrogen compound that had its origin in living material. The Nitrogen in protein and urea is organic Nitrogen. Organic Nitrogen can be introduced to the environment from sanitary waste systems including wastewater treatment plants, septic and cesspool systems, from humans and animals, as discarded food material, or as ingredients of cleaning agents.

Ammonification

Many of the transformations of Nitrogen in both soluble and particulate forms are mediated by bacteria that use different forms of Nitrogen. During the processes of decomposition, the Nitrogen in proteins is transformed eventually to ammonia (NH_3) or ammonium (NH_4^+) by certain kinds of bacteria. These processes are called ammonification. Nitrogen in the liquid or leachate from wastewater systems is primarily ammonium. Some of the leachate discharged into the ground becomes adsorbed (stuck) to soil particles and is effectively immobilized from further transport.

Nitrification

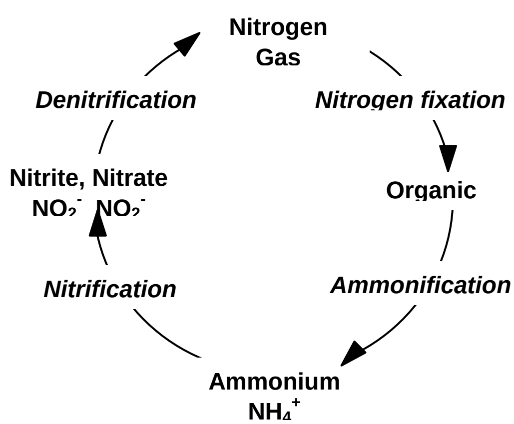
Some kinds of bacteria change ammonia to nitrite or nitrite to nitrate. These processes are called nitrification. Nitrification is an aerobic process and can occur only in the presence of oxygen. The nitrate form of Nitrogen is the one most used for plant growth, and is the most mobilized form in groundwater. Nitrate in ocean waters is often the primary reason for triggering algal blooms, which can create nuisance mats of floating algae in and on the water, and lead to stress on fishes and other aquatic organisms due to the use of oxygen in the water by bacteria that "feed" on the algae. The ammonium form of Nitrogen is also used by plants, but is not as mobile in water and therefore not as problematic with respect to triggering algal blooms in the ocean.

Denitrification

Some bacteria species in soils can take nitrate and change it back to Nitrogen gas through a process called denitrification. Denitrification is an anaerobic process. This means it only takes place when no oxygen or extremely low concentrations of oxygen are available and a source of carbon for the bacteria is present in the soil. The amount of nitrate in ground water that is denitrified prior to entering the Bay is unknown, as is the amount in nitrate form. In general, denitrification probably lowers some of the nitrate reaching the Bay, which reduces the potential threat of algal blooms.

Simplified Nitrogen Cycle

In summary, Nitrogen cycles through the air, water, and soils, with many transformations controlled by the actions of specialized bacteria. Some of these transformations require aerobic conditions while others occur only under anaerobic conditions. Under the best case scenario bacteria will regulate the amount of Nitrogen in forms transported in surface and ground water discharged in the Bay that can potentially disrupt the food chain and trigger algal blooms.



Simplified Nitrogen cycle, *italics* denote processes and **bold** the different forms of Nitrogen.

Phosphorus is a mineral that is present in the terrestrial environment in water, soil, and sediments and whose biogeochemical cycle excludes any atmospheric stage. Phosphorus is most commonly found in rocks and ocean sediments in the form of phosphate salts. The phosphate salts are released through weathering of rocks and move through the system tightly bound to soil molecules and delivered with sediments because Phosphorus is not highly soluble. Phosphorus drains from the land to the ocean, but a considerable amount is deposited in ocean sediment from the shells and bones of marine organisms and by precipitation and settling of phosphates. In most soils the Phosphorus absorbed by plants comes from organic molecules that undergo decomposition and release Phosphorus in plant-available inorganic forms. Phosphorus is an important nutrient for plants.

Nutrients become a problem in the environment when excess amounts are present in watersheds and are eventually delivered to the ocean. While Nitrogen and Phosphorus are extremely important nutrients for terrestrial and aquatic plants, excess concentrations disrupt the ecological balance of aquatic ecosystems. Nutrients support the growth of aquatic plants, including algae, which provide a food source for other aquatic organisms and produce oxygen via photosynthesis. However, when nutrient levels are high, they can lead to eutrophication, which is an excessive production of plant biomass in the water, leading to decomposition and a hypoxic environment. An example is the stimulation of algae growth that can block sunlight from reaching other aquatic organisms and leads to a die-off of larger amounts of algae, which is decomposed by bacteria in a natural process. These bacteria use more oxygen than under normal conditions, reducing the amount of oxygen available to other aquatic organisms. The reduction in sunlight and oxygen makes it difficult for other aquatic organisms to survive.

Because Nitrogen and Phosphorus stimulate plant growth, they are used as chemical fertilizers in agricultural production to increase yield. Agricultural runoff is a significant contributor of nutrients to the Nation's waterbodies. The EPA has ranked Nitrogen and Phosphorus pollution as one of the top causes of degradation in U.S. waters for over a decade. Sources of these nutrients are agricultural runoff as well as wastewater from leaking septic tanks and wastewater treatment effluent.

For water quality measurements, different forms of Nitrogen are taken into consideration and water quality standards are set for NH_4^+ (Ammonium), NO_x (Nitrate plus Nitrite) and Total Nitrogen (which combines the two). Phosphorus measurements identify Total Phosphorus.

D.1.5. Biological Water Quality

Microbes in fresh and salt water can come from a variety of sources within a watershed, and be contained in both surface and ground water. Suspected sources are feral ungulates contributing fecal matter, birds, livestock, and human sewage via leaking septic tanks or wastewater seepage. Some bacteria strains occur naturally in the environment. Microbial contamination is an environmental health concern as different types of bacteria and other microorganisms such as *Giardia, Cryptosporidium and Staphylococcus* can transmit disease and cause infections in humans. Transmission of water borne diseases is through contact with contaminated water (i.e. during surfing or swimming), or ingesting contaminated water. According to EPA, pathogens are the second most frequent cause of water quality impairments under the CWA. The increased interaction of humans and domestic and feral animals is stimulating the evolution of new pathogens. Several microorganisms that used to live only within animals have evolved to infect humans (e.g. avian flu).

D.1.5.1. Enterococci

Pollutants from sewage-related sources are both an environmental issue and a public health concern, since sewage can contain harmful pathogens that cause a variety of illnesses in humans. Sewage can affect ocean and freshwater systems through point and non-point sources (i.e. sewage treatment facilities (point source) and cesspools (non-point source)) (Hartz et al. 2008). To decide whether coastal waters are safe for swimmers, Hawai'i DOH monitors bacteria levels in ocean waters. There are multiple disease-causing agents that can be present in sewage and it is unfeasible to test for each one. Therefore, agencies throughout the world, including the World Health Organization, EPA, and DOH, use fecal indicator bacteria to determine if sewage contamination is present. Past indicators include fecal coliform and *Escherichia coli* (*E. coli*). In 1988, the Federal standard for assessing marine water health risks officially became bacteria of the genus *Enterococcus* (Hartz et al. 2008). Indicator bacteria are not pathogens themselves, but rather they are bacteria naturally present in the feces of warm-blooded birds and mammals. Finding high levels of *enterococci* in water is an indicator that fecal contamination may have occurred near the testing site. EPA established *enterococci* as an indicator because studies over many years have shown a positive correlation between high levels of *enterococci* and gastrointestinal illnesses caused by sewage-related bacteria and viruses. *Enterococci* is also used due to it being a good indicator in saltwater. *Enterococci* die off in the water column at about the same rate, making it a useful tool in determining when waters are swimmable.

The Federal standard for *enterococci* is set at 35 CFU/100ml for marine waters and 33 CFU/100ml for fresh waters. The current standards used to determine safe swimming conditions in Hawai'i are: Inland waters – 33 CFU/100ml in five or more samples, single sample maximum 89 CFU/100ml; Coastal waters within 300m of the shore – 35 CFU/100 ml in five or more samples, single sample maximum 104 CFU/100ml (HAR §11-54). One important consideration is that *enterococci* have also been found to naturally occur in Hawaiian soils where they are able to survive longer than in water (up to 28 days in laboratory conditions) (Craig et al. 2002; Fujioka and Hardina 1991). In the event of heavy rains, streambank erosion can cause increased levels of *enterococci* in streams and the ocean that are not from a sewage-related source. Therefore, *enterococci* is not an ideal indicator to use in Hawai'i and DOH is working on identifying other indicator organisms.[65] To address the issues of soil presence, DOH has developed a "toolbox approach" to further narrow down whether elevated levels of *enterococci* are related to sewage. To do this, they test for additional organisms (i.e. *Clostridium perfringens*) when *enterococci* levels are high. Although these organisms are not officially recognized by EPA as indicators, DOH-CWB is allowed to use them as a secondary indicator to trace human sewage. Other modern tools used by scientists in the past few years have been DNA markers to trace contaminated waters by their fecal source, e.g. pig, human or ruminant. Studies like this have been conducted in Hanalei streams and the bay and have confirmed contamination of certain areas with human fecal material (Boehm 2010).

[65] http://hawaii.gov/health/about/reports/bacteriatestingquestions.pdf

D.2. State of Hawai‘i Water Quality Standards[66]

Source: Department of Health - Amendment and Compilation of HAR Chapter 11-54, May 27 2009)

Toxic Pollutants (micrograms per liter) - Applicable to ALL WATERS

	Freshwater		Saltwater		
Pollutant	Acute	Chronic	Acute	Chronic	Fish Consumption
Acenapthene	570	ns	320	ns	ns
Acrolein	23	ns	18	ns	250
Acrylonitrile*	2,500	ns	ns	ns	0.21
Aldrin	3	ns	1.3	ns	0.000026
Aluminum	750	260	ns	ns	ns
Antimony	3,000	ns	ns	ns	15,000
Arsenic	360	190	69	36	ns
Benzene*	1,800	ns	1,700	ns	13
Benzidine*	800	ns	ns	ns	0.00017
Beryllium*	43	ns	ns	ns	0.038
Cadmium	3+	3+	43	9.3	ns
Carbon tetrachloride*	12,000	ns	16,000	ns	2.3
Chlordane*	2.4	0.0043	0.09	0.004	0.00016
Chlorine	19	11	13	7.5	ns
Chloroethers-					
ethy (bis-2)*	ns	ns	ns	ns	0.44
isopropyl	ns	ns	ns	ns	1,400
methyl (bis)*	ns	ns	ns	ns	0.0006
Chloroform*	9,600	ns	ns	ns	5.1
Chlorophenol (2)	1,400	ns	ns	ns	ns
Chlorpyrifos	0.083	0.041	0.011	0.0056	ns
Chromium (VI)	16	11	1,100	50	ns
Copper	6+	6+	2.9	2.9	ns
Cyanide	22	5.2	1	1	ns
DDT*	1.1	0.001	0.013	0.001	0.000008
metabolite TDE*	0.03	ns	1.2	ns	ns
Demeton		0.1	ns	0.1	ns
Dichloro-					
benzenes*	370	ns	660	ns	850
benzidine*	ns	ns	ns	ns	0.007
ethane (1,2)*	39,000	ns	38,000	ns	79
ehenol (2,4)	670	ns	ns	ns	ns
propanes	7,700	ns	3,400	ns	ns
propene (1,3)	2,000	ns	260	ns	4.6
Dieldrin*	2.5	0.0019	0.71	0.0019	0.000025
Dinitro-					
o-cresol (2,4)	ns	ns	ns	ns	250

[66] Although the State standards for most parameters are presented in micrograms per liter (μg/L), the tables (except for Toxic Pollutants) have been converted to milligrams per liter (mg/L) to be consistent with how data are presented in scientific publications and the TMDL documents.

	Freshwater		Saltwater		
Pollutant	Acute	Chronic	Acute	Chronic	Fish Consumption
toluenes*	110	ns	200	ns	3
Dioxin	0.003	ns	ns	ns	$5.0x10^{-9}$
Diphenyl-hydrazine (1,2)	ns	ns	ns	ns	0.018
Endosulfan	0.22	0.056	0.034	0.0087	52
Endrin	0.18	0.0023	0.037	0.0023	ns
Ethylbenzene	11,000	ns	140	ns	1,070
Fluoranthene	1,300	ns	13	ns	18
Guthion	ns	0.01	ns	0.01	ns
Heptachlor*	0.52	0.0038	0.053	0.0036	0.00009
Hexachloro-					
benzene*	ns	ns	ns	ns	0.00024
butadiene*	30	ns	11	ns	16
Cyclohexane-					
alpha*	ns	ns	ns	ns	0.01
beta*	ns	ns	ns	ns	0.018
technical*	ns	ns	ns	ns	0.014
cyclopentadiene	2	ns	2	ns	ns
ethane*	330	ns	310	ns	2.9
Isophorone	39,000	ns	4,300	ns	170,000
Lead	29+	29+	140	5.6	ns
Lindane*	2	0.08	0.16	ns	0.02
Malathion	ns	0.1	ns	0.1	ns
Mercury	2.4	0.55	2.1	0.025	0.047
Methoxychlor	ns	0.03	ns	0.03	ns
Mirex	ns	0.001	ns	0.001	ns
Napthalene	770	ns	780	ns	ns
Nickel	5+	5+	75	8.3	33
Nitrobenzene	9,000	ns	2,200	ns	ns
Nitrophenols*	77	ns	1,600	ns	ns
Nitrosamines*	1,950	ns	ns	ns	0.41
Nitroso-					
dibutylamine-N*	ns	ns	ns	ns	0.19
diethylamine-N*	ns	ns	ns	ns	0.41
dimethylamine-N*	ns	ns	ns	ns	5.3
diphenylamine-N*	ns	ns	ns	ns	5.3
Pyrrolidine-N*	ns	ns	ns	ns	30
Parathion	0.065	0.013	ns	ns	ns
Pentachloro-					
ethanes	2,400	ns	130	ns	ns
benzene	ns	ns	ns	ns	28
phenol	20	13	13	ns	ns
Phenol	3,400	ns	170	ns	ns
2,4-dimethyl	700	ns	ns	ns	ns
Phthalate esters					
dibutyl	ns	ns	ns	ns	50,000

	Freshwater		Saltwater		
Pollutant	**Acute**	**Chronic**	**Acute**	**Chronic**	**Fish Consumption**
diethyl	ns	ns	ns	ns	590,000
di-2-ethylhexyl	ns	ns	ns	ns	16,000
dimethyl	ns	ns	ns	ns	950,000
Polychlorinated biphenyls*	2	0.014	10	0.03	0.000079
Polynuclear aromatic hydrocarbons*	ns	ns	ns	ns	0.01
Selenium	20	5	300	71	ns
Silver	1+	1+	2.3	ns	ns
Tetrachloro-					
Ethanes	3,100	ns	ns	ns	ns
benzene (1,2,4,5)	ns	ns	ns	ns	16
ethane (1,1,2,2)*	ns	ns	3,000	ns	3.5
ethylene*	1,800	ns	3,400	145	2.9
phenol (2,3,5,6)	ns	ns	ns	440	ns
Thallium	470	ns	710	ns	16
Toluene	5,800	ns	2,100	ns	140,000
Toxaphene*	0.73	0.0002	0	0.0002	0.00024
Tributylin	ns	0.026	ns	0.01	ns
Trichloro-					
ethane (1,1,1)	6,000	ns	10,400	ns	340,000
ethane (1,1,2)	6,000	ns	ns	ns	14
ethylene*	15,000	ns	700	ns	26
phenol (2,4,6)	ns	ns	ns	ns	1.2
Vinylchloride*	ns	ns	ns	ns	170
Zinc	22+	22+	95	86	Ns

ns - No standard has been developed

* - Carcinogen

\+ - The value listed is the minimum standard. Depending on hardness of receiving waters ($CaCO_3$), higher standards may be calculated using formula from EPA Water Quality Criteria (EPA 440/5-86-001)

Compounds listed in plural are mixtures of isomers. Numbers listed refer to total allowable concentration of any combination of isomers in compound.

Criteria for All Streams

Parameter	Geometric Mean not to exceed given value	Not to exceed given value more than 10% of the time	Not to exceed given value more than 2% of the time
Total Nitrogen (mg/L)			
Wet season*	0.25	0.52	0.8
Dry season*	0.18	0.38	0.6
Nitrate + Nitrite Nitrogen (mg/L)			
Wet season	0.07	0.18	0.3
Dry season	0.03	0.09	0.17
Total Phosphorus (mg/L)			
Wet season	0.05	0.1	0.15
Dry season	0.03	0.06	0.08
Total Suspended Solids (mg/L)			
Wet season	20.0	50.0	80.0
Dry season	10.0	30.0	55.0
Turbidity (N.T.U.)			
Wet season	5.0	15.0	25.0
Dry season	2.0	5.5	10.0

*	-	Wet season: November 1 - April 30
**	-	Dry season: May 1 – October 31
L	-	Liter
N.T.U.	-	Nephelometric Turbidity Units. Comparison of intensity of light scattered by sample under equal conditions. Higher intensity = higher turbidity
mg	-	Milligram or 0.001 grams

Additional stream water quality parameters:

Enterococci	33 CFU/100ml in 5 or more samples, 89 CFU/100ml in single sample
pH Units	Not to deviate more than 0.5 units from ambient conditions; not to be lower than 5.5 or higher than 8.0
Dissolved Oxygen	Not less than 80%, determined as a function of water temperature
Temperature	Not to vary more than one degree Celsius from ambient conditions
Specific Conductance	Not to exceed 300 micromhos/centimeter

Criteria for All Estuaries (except Pearl Harbor)

Parameter	Geometric Mean not to exceed given value	Not to exceed given value more than 10% of the time	Not to exceed given value more than 2% of the time
Total Nitrogen (mg/L)	0.2	0.35	0.5
Ammonia Nitrogen (mg/L)	0.006	0.01	0.02
Nitrate + Nitrite Nitrogen (mg/L)	0.08	0.025	0.035
Total Phosphorus (mg/L)	0.025	0.05	0.075
Chlorophyll a (mg/L)	0.002	0.005	0.001
Total Suspended Solids (mg/L)	10.00	30.00	55.00
Turbidity (N.T.U.)	1.5	3.00	5.00

L - Liter

N.T.U. - Nephelometric Turbidity Units. Comparison of intensity of light scattered by sample under equal conditions. Higher intensity = higher turbidity

mg - Milligram or 0.001 grams

Additional estuary water quality parameters:

Enterococci	33 CFU/100ml in 5 or more samples, 89 CFU/100ml in single sample
pH Units	Not to deviate more than 0.5 units from ambient conditions; not to be lower than 7.0 or higher than 8.6
Dissolved Oxygen	Not less than 75%, determined as a function of water temperature and salinity
Temperature	Not to vary more than one degree Celsius from ambient conditions
Salinity	Not to vary more than 10% from ambient conditions
Oxidation	Reduction potential (EH) – not to fall under 100 millivolts in upper 10 centimeters of sediment

Criteria for Embayments (Hanalei Bay)

Parameter	Geometric Mean not to exceed given value	Not to exceed given value more than 10% of the time	Not to exceed given value more than 2% of the time
Total Nitrogen (mg/L)			
Wet season*	0.2	0.35	0.5
Dry season*	0.15	0.25	0.35
Ammonia Nitrogen (mg/L)			
Wet season	0.006	0.013	0.02
Dry season	0.0035	0.008	0.015
Nitrate + Nitrite Nitrogen (mg/L)			
Wet season	0.008	0.02	0.035
Dry season	0.005	0.014	0.025
Total Phosphorus (mg/L)			
Wet season	0.025	0.05	0.075
Dry season	0.02	0.04	0.06
Chlorophyll a (mg/L)			
Wet season	0.0015	0.0045	0.0085
Dry season	0.0005	0.0015	0.003
Turbidity (N.T.U.)			
Wet season	1.50	3.00	5.00
Dry season	0.40	1.00	1.50

* - Wet season criteria apply when average freshwater inflow from land equals or exceeds 1% of embayment volume per day

** - Dry season criteria apply when average freshwater inflow from land is less than 1% of embayment volume per day

L - Liter

N.T.U. - Nephelometric Turbidity Units. Comparison of intensity of light scattered by sample under equal conditions. Higher intensity = higher turbidity

mg - Milligram or 0.001 grams

Additional water quality parameters:

Enterococci	35 CFU/100ml in 5 or more samples, 104 CFU/100ml in single sample
pH Units	Not to deviate more than 0.5 units from a value of 8.1, except at coastal locations where and when freshwater from stream, storm drain or groundwater discharge may decrease pH to 7.0
Dissolved Oxygen	Not less than 75%, determined as a function of water temperature and salinity
Temperature	Not to vary more than one degree Celsius from ambient conditions
Salinity	Not to vary more than 10% from natural or seasonal changes considering hydrologic input and oceanographic factors

State of Hawai‘i Effluent Monitoring Standards

(Source: Department of Health - Amendment and Compilation of Title 11, Chapter 62 of Hawai‘i Administrative Rules, January 14, 2004)

Parameter	Standard	Sampling Schedule
BOD	Not to exceed 30 mg/L for arithmetic mean of composite samples Not to exceed 60 mg/L for grab sample	Large facilities**: Composite sampling at least weekly Small Facilities: Grab sampling at least monthly
TSS	Not to exceed 30 mg/L for arithmetic mean of composite samples Not to exceed 60 mg/L for grab sample	Large facilities: Composite sampling at least weekly Small Facilities: Grab sampling at least monthly
Total Daily Flow	Specified in permit	Monitored weekly
Pathogens in sludge: Fecal coliform OR *Salmonella sp.*	Not to exceed 1000 MPN/g of total solids (based on dry weight) Not to exceed 3 MPN/g of total solids (based on dry weight)	Seven samples must be analyzed before sludge is used, disposed, etc.

*Composite sample results are based on one or more analyses in a 30-day period. For this, at least eight samples are required. They have to be done under flow proportional conditions (i.e. either the time interval between each aliquot or the volume of each aliquot must be proportional to either the stream flow at the time of sampling or the total stream flow since the collection of the previous aliquot).

**Large facilities have a design flow higher than 100,000 gallons per day. Small facilities have a design flow of less than 100,000 gallons per day.

D.3. Effects of Erosion and Vegetation on Hydrology

D.3.1. Erosion and Sedimentation

Soil is formed by chemical weathering and to a lesser degree, physical weathering of rock material. Soils are generally found in the location where they formed and develop horizons or layers that contain different levels of organic material, chemical concentrations, texture, colors and thickness.

Sediment is material that includes soils and fragments of rocks and other debris that were transported from their original locations via wind and water. Thus, sediments are a depositional feature. After long periods, some sediment can weather and develop into soils. Sediments generally do not contain horizons but may contain graded zones or layers differentiated by particle sizes.

This distinction between soil and sediment is critical when designing restoration and erosion control bioengineering strategies. For example, installing vegetative cover to an area that has a developed soil profile may only require planting of either seed or container stock and supplemental water, while an area that has sediments would require soil amendments such as fertilizers and physical site preparation to support plant establishment. Additionally, the volume of sediments and their locations can yield clues as to the condition of a watershed and can lead to diagnosing or discovering the location of sediment source.

Box D2. Impervious Surfaces

Buildings, rooftops, parking lots, roads, and other impervious surfaces generate surface runoff under all rainfall events except for the very smallest events. Impervious surfaces affect storm water runoff quantity and quality in two primary ways. Impervious surfaces do not allow rainfall to infiltrate into the ground, preventing water from recharging soil and the aquifer and slow release to streams and the ocean. Rain falling on impervious surfaces begins to pond almost immediately at the onset of rains, generating rapid runoff with higher volumes than compared to a pervious surface. This rapid transport of runoff reduces detention time of water on the watershed and the amount of rainfall that infiltrates into the ground. This, in turn, diminishes the capture and remediation of pollutants by microbes in the soils and plant roots and results in the direct delivery of contaminants to the ocean.

D.3.2. Non-native (Introduced) Vegetation

Non-native plants, introduced either on purpose or inadvertently, have displaced native plants that evolved on the island over millions of years. Some scientists hypothesize that non-native forest canopy structure and plant types are less effective than a forest covered with native vegetation in controlling erosion rates, capturing rainfall, and maintaining recharge to high level aquifers. However, publications supporting this hypothesis were not found during a literature search. Recent research has shown that non-native forest trees use more water compared to native trees, resulting in a decrease of ground water recharge and other alterations to the hydrologic cycle (T. Giambelluca, pers. comm.).

In many areas the removal of vegetation and the physical damage to the ground surface changes the ratio of rainfall to runoff. In forested areas dominated by native plants the canopy structure and ground cover is often dense and multi-storied. The vegetation in native forests plays a significant role in the hydrologic cycle by directly intercepting rain, which protects the ground surface from raindrop erosion; temporarily storing water on its surfaces; and facilitating infiltration of water into the ground and recharge of high level aquifers. Removal of native forest and encroachment by non-native plants reduce these functions, and often leads to increases in surface erosion, reduction of ground water recharge, and increases in surface water runoff.

D.3.3. Climatic Controls on Plants and Erosion

Weather patterns and the climate regime that affect the project area have a significant impact on the erosion process. For most of the year trade winds dominant the weather pattern and rainfall amounts from individual trade showers is often low (<0.01 inch). During dry periods between the brief trade showers evapotranspiration often exceeds rainfall. This causes soil moisture to drop to levels that make it difficult for plants to pull water from the soil. This may cause plants to become stressed, and dormancy and die off may occur. Plants that evolved in this type of climatic regime developed growth strategies to accommodate dry periods in order to maintain vigor and root tensional strength. Following the dry period, winter rains frequent the island chain. Plants such as annual invasive grasses that have died off and lost stems have a reduced canopy, which exposes ground surfaces surrounding the plants. Additionally, roots lose tensional strength and their ability to hold soil particles is reduced. The winter rainfall events that occur in the early part of the rainy season occur the when soil is most vulnerable and erodibility is high.[67] The frontal winter storms differ from the summer trade wind dominated showers in that precipitation intensity and amounts are higher and more erosive.

D.3.4. Effects of Fire on Plants and Erosion

Subsequent to fire the landscape is often bare and exposed, which increases the vulnerability to accelerated erosion and, in steep areas, landslides. This scenario is exacerbated by non-native vegetation that is not drought tolerant and dies back during the dry summer months or periods of drought. In watersheds where this scenario has played out, erosion rates and sediment loads carried in runoff have been observed to be extreme (A. Hood, pers. comm.).

The potential indirect adverse effects are a consequence of the alteration of the natural fire regime. This includes the alteration of the vegetation at the local ecosystem and landscape levels of the affected watersheds. Combined with the direct effects on soil and its biota, the result could be the overall degradation of watershed health and native biodiversity. These indirect effects could also include reduced water quality and available water resources, and of the loss of ecosystem level watershed services, such as ground water infiltration, aquifer recharge, flood control, nutrient cycling, and others.

D.4. NPS Pollutant Transport

Transport of NPS pollutants and their delivery to receiving waters is a function of several variables that ultimately determine their fate and condition. The distance between the NPS pollutant source and the receiving water body as measured along the pathway the NPS pollutant is carried plays a major role in determining the travel time and condition of the NPS pollutant. For example, Nitrogen discharged in effluent water at the LWRF in its Nitrate form (NO_3^-) is denitrified due to the relatively long travel time it takes for water to flow from the LWRF to the ocean.

Sediment load is not only a function of the area of erodible soil, but other factors such as proximity of the source to drainage courses, rainfall patterns, and condition of the flow path it is transported along. Therefore, a single moderately sized hotspot sediment source that is located in immediate proximity to a receiving water can contribute a significant load compared to multiple or larger sites

[67] Erodibility is a term used to describe a soil's susceptibility to erosion.

that are farther from the receiving water or that are attenuated[68] during transport over the watershed.

Many NPS pollutants are associated with sediments that are transported primarily in surface water. Thus sediment laden runoff from a farm field likely is likely transporting a portion of chemicals applied to fields (e.g. fertilizers and pesticides). Several forms of Phosphorus attach directly onto sediment particles and sediment movement is the primary transport mechanism.

Nutrients migrate into the soils via ground water infiltration and surface water runoff. During rainfall events, nutrients, sediment, and bacterial pollutants are carried overland into the stream channels, where they are carried in runoff to the ocean.

Several classes of NPS pollutants, including nutrients, can be found in two forms: dissolved and particulate matter. Dissolved forms of pollutants are so small that they are in solution and move at the rate of the solution (water) they are dissolved in. The dissolved form is primarily associated with pollutant transfer through soils and contamination of ground water, though it can also be readily carried in surface runoff. Particulate matter is a mobile form of substrate and is the form most commonly transported in surface water runoff. Control and sequestration of NPS pollutants, whether they are dissolved or in particulate form, is a challenge. The most effective approach to reducing NPS loads to the ocean is to reduce their generation at the source.

D.4.1. Agricultural Activities

Farming activities can expose soil and change surface water flow patterns, both of which can increase rates of erosion and loads of sediments and other NPS pollutants delivered into the ocean. Application of fertilizers and pesticides introduces nutrients and chemicals to fields, which can be leached into ground water via irrigation water. Leaching occurs when irrigation rates are higher than plant uptake. Fertilizers that leach below the root zone are not available to the plants, are wasteful to the applicator, and costly to the ground water. It is unknown if fertilizer application rates in the project area are applied based on information such as soil nutrient levels, plant requirements, and irrigation applications.

Under certain weather conditions wind picks up dust and soil particles and carries them to downwind locations. In addition, fugitive dust generated by motorized vehicles can be transported from the ground into the air.

D.4.2. Urban Activities

Due to the S4 and impervious surfaces in the urban areas, NPS pollutants can be quickly routed off the landscape during rainfall and rapidly delivered to the ocean. A certain portion of NPS pollutants, such as the Ammonium and Nitrate forms of Nitrogen, are carried in ground water to the ocean. Runoff generated in the Conservation and Agricultural and Districts that makes its way to the Rural District is routed rapidly due the S4 system. The water received into the Rural District is not detained and NPS pollutants are not attenuated.

[68] Attenuation of sediment occurs as flow carrying the particles encounters vegetated areas where sediment can be filtered by plant material, and deposited along the flow paths in flat and depression areas, commonly referred to as sinks.

Large amounts of NPS pollutants are associated with a phenomenon referred to as the *first flush*. During dry periods, impervious surfaces accumulate NPS pollutants generated by human activities or from atmospheric dry fall. The time interval between runoff-generating rainfall events is referred to as the accumulation phase. The *first flush* is the first big rainfall event occurring after the accumulation phase. It contains the highest concentration of contaminants and generates the highest pollutant loads at its receiving waters (Scholze et al. 1993).

D.5. Causal Impacts of Land Based Pollutants on Selected Ocean Resources

Coral reef ecology is primarily based on processes of reproduction and recruitment, which are dependent on water and substratum quality. Pollutants and related synergistic[69] effects can cause mortality and disease in species; hinder ecological functions; impede growth, reproduction and larval development; and cause trophic structure and dynamic changes (NOAA CRCP 2009). The casual relationship between coral reef ecosystems and impacts from ocean based extractive and contact activities such as fishing, swimming and diving and the deposition of land based activities in ocean waters is complex. Research by scientists and anecdotal observations by persons who utilize the ocean for economic gain and/or recreational opportunities are in agreement that policies to prevent overfishing and protection of key fish resources, limit inputs of land based pollutants, and minimize physical impacts to coral reef are necessary to protect and maintain healthy coral reefs (Davidson et al. 2003).

This section provides some specific examples of adverse impacts that land-based pollutants have on the ocean environment within the project area. While this is not a comprehensive list of pollutants and their impacts, it presents examples of the cause and effect relationship that activities within the watershed are currently having on the coastal environment in the Hanalei Region.

D.5.1. Sediment

Within the Main Hawaiian Islands, sediment is probably the leading pollutant from land based sources that causes the alteration of reef community structure (Friedlander et al. 2008). Sediment delivery to nearshore waters during runoff events has increased as coastal areas are developed, floodplains filled, storm drains constructed, and streams channelized (Friedlander et al. 2008). Studies conducted on the transport rate of suspended sediments carried in storm water runoff in Hawai'i have found that flows that occur 2% of the time are responsible for delivering up to 90% of the total annual load (S. Izuka, presentation). Suspended sediments carried in streams and gulches to the ocean is known locally as 'red dirt', and the resulting plumes can often be seen for days or weeks.

Fine terrigenous sediment entering the nearshore ocean affects corals in two ways: (1) suspended in seawater, the sediment drastically reduces the amount of light reaching coral reefs and other shallow benthic systems; and (2) as the sediment settles, it can bury corals or cause them to expend a large amount of energy keeping their surfaces clean (Piniak 2004). Sediment within the ocean environment induces mortality of coral polyps and limits coral colonization. Accumulated sediments prevent coral recovery through re-suspension and interference with fertilization, larval development and settlement in corals (NOAA CRCP 2009). In addition, sediment particles often

[69] Synergy is the interactions of two or more activities or materials that combine to create a single result.

carry nutrients attached via sorption[70], encouraging algal growth (Davidson et al. 2003) (Appendix D.5.2). Terrigenous sediments have also been found to act as flocculants, meaning they attract bacteria suspended in the water that attach to the sediment particles. When the sediment particles become weighted down by the bacteria, they sink to ocean floor where the bacteria can become concentrated and use up the available oxygen. This results in an anoxic layer along the floor of the ocean. The anoxic layer adversely impacts organisms that normally dwell on and just above the ocean floor (R. Richmond, presentation).

D.5.2. Nutrients

Nutrients, including Nitrogen and Phosphorus, are sourced from sewage, wastewater, and fertilizer runoff from agricultural fields (mainly taro *lo'i*) and landscaped areas. Research into the effects of nutrients on two ocean resources, coral reefs and green sea turtles, is discussed in this section.

D.5.2.1. Effects on Coral Reefs

Nutrient inputs from external sources must be very low in order to promote productive and species rich coral reefs (Global Coral Reef Alliance 2012). Nutrient loading has been cited as a main cause of reef health degradation (Derse et al. 2007, Cole et al. 2004, Umezawa et al. 2002). In a study performed on the Great Barrier Reef, Kinsey and Davies (1979) estimated that long term Nitrogen and Phosphate enrichment caused a greater than 50% rate of suppression of coral reef calcification, inhibiting coral growth.

Derse et al. (2007) determined that the relatively low δ15N values observed in algae collected in Hanalei Bay implicates fertilizer, rather than domestic sewage, as an important external source of nitrogen to the coastal water around Hanalei. "The N:P ratio in the algae compared to the ratio in the Bay waters imply that the Hanalei Bay coastal ecosystem is nitrogen limited and thus, increased nitrogen input may potentially impact this coastal ecosystem and specifically the coral reefs in the Bay".

Excessive amounts of nutrients, particularly Nitrogen and Phosphorus, promote the rapid growth of algae that compete with juvenile and adult corals for space on benthic reef surfaces, can affect success of coral settlement, and in extreme cases can result in eutrophication of reef waters (Global Coral Reef Alliance 2012, NOAA CRCP 2009, McClanahan et al. 2002).

The results of the study conducted by Derse et al. (2007) in Hanalei Bay indicate:

> *…it is probable that all excess anthropogenic N input into the bay is utilized immediately for macroalgae (and other primary producers) growth. This implies that the macroalgae might be growing as fast as the nutrients can be supplied, and such macroalgae growth could possibly have an alarming impact on the surrounding reef environment if input will increase in the future. This evidence, combined with the implications that fertilizer runoff is flowing into the bay in large amounts, suggests that the reef in Hanalei Bay could be in crisis if nutrient loads increase in the future. The suggestion that increased fertilizer use and subsequent fertilizer-rich runoff and groundwater input to the bay may result in a large-scale impact on the nutrient dynamics in the bay and possibly on the surrounding reef environment has severe*

[70] Sorption is a process by which one substance attaches to another through either chemical or physical bonding.

implications for the impact of future increased agriculture and tourism development in the region and in Hawai'i in general.

D.5.2.2. Effects on Green Sea Turtles

A study of 3,939 stranded Hawaiian green sea turtles over a 28 year period found that the rate of incidence of fibropapilloma, a tumor-forming disease linked to a herpesvirus, increases in watersheds with high eutrophication levels, and in particular watersheds with high Nitrogen footprints (Van Houtan et al. 2010). Further analysis revealed "strong epidemiological links" between disease rates and presence of invasive macroalgae that the turtles feed on.

D.5.3. Effect of Chemical Pollutants on Coral Reefs

There are a wide range of anthropogenically derived chemical pollutants that may affect coral reef ecosystems. The range of compounds includes: pesticides, trace metals, petroleum hydrocarbons and pharmaceuticals. van Dam et al. (2011) conclude that while short-term pulse-like pollution, such as an oil spill, can have a direct and severe impact on a coral reef system, recurring pollution may exert subtle effects on lower trophic levels of the system, affecting species fitness and adaptation.

van Dam et al. (2011) collated and assessed available information on different chemical stressors in the marine environment and the effects on reef-building corals. Using that information they summarized the main contaminant groups, sources, and concerns in regards to tropical coral reefs (Table D1).

Table D1. Potential Effects of Chemical Pollutants on Coral Reefs[71]

Contaminant Group	Sources	Main Concerns
Insecticides	Agricultural and urban runoff	Survival, reproduction, early life transitions and genetic effects. (Bioaccumulation for persistent OC pesticides)
Herbicides	Agricultural and urban runoff, antifouling applications, ballast water discharge	Photosynthesis and calcification
Metals	Agricultural runoff, various urban and industrial sources, and antifouling applications	Bioaccumulation, survival, reproduction, growth and behavior

Pesticides (insecticides, herbicides and fungicides) interfere with coral reproduction and growth (NOAA 2006). Markey et al. (2007) studied the effects of four classes of insecticides on corals and determined that even at very low levels, insecticides inhibited the settlement and metamorphosis stages of corals. Lewis et al. (2009) contend that exposure to herbicides reduces productivity of coral reefs. A study conducted by Råberg et al. (2003) confirms that in laboratory experiments *Porities cylindrica* exposed to low levels of 2,4-D and diuron, two commonly used herbicides, demonstrated reduced primary production rates.

[71] Excerpted from van Dam et al. (2011).

Most scientists agree that although more studies on the effects of long term exposure of coral reefs to chemical pollutants are needed, prolonged low level exposure to this type of pollution reduces the resilience of coral reef organisms to other forms of environmental stress (van Dam et al. 2011, Lewis et al. 2009).

D.5.4. Pathogens

Land-based inputs may both directly contribute land-derived pathogens and/or exacerbate the effect of in situ pathogens on coral reef ecosystems. Land-based runoff that discharges from streams to coastal waters is a source of pathogens (Viau et al. 2011). Runoff may contain pathogens from NPS such as leaking sewage infrastructure, wild and domestic animal excreta, and other poorly understood environmental reservoirs. As coral reefs become stressed, they are more susceptible to viral and bacterial infections. The presence of bacteria in ocean waters poses serious threats to human health.

D.5.5. Sunscreens

The tourism industry brings recreational ocean users to the north shore of Kaua'i and exposes the sensitive coastal habitat to sunscreen that has been applied to the skin. Sunscreen has been documented as a contributor to bleaching of hard corals in areas where there is a high level of human recreational use, by promoting viral infections (Danovaro et al. 2008). During laboratory tests, sunscreen even in low quantities caused large amounts of coral mucous (zooxanthellae and coral tissue) release within 18-48 hours, with complete coral bleaching within 96 hours. Four typical sunscreen ingredients were found to cause complete coral bleaching at very low concentrations: butylparaben, ethylhexylmethoxycinnamate, benzophenone-3, and 4-methylbenzylidene camphor (Danovaro et al. 2008).

D.6. Wastewater Systems

This section provides background information on various types of wastewater systems. Fact sheets from DOH on cesspools, septic tanks, aerobic treatment units, and absorption fields are included.

D.6.1. Wastewater Treatment Plants

WWTP systems collect non-storm water waste from buildings that house retailers, restaurants, and offices. The wastewater is collected and treated to secondary treatment levels. The treated effluent is discharged below ground via injection wells. Upstream of the WWTP there are a number of grease traps fitted to the pipes conveying waste from restaurants. A grease trap is essentially a box that collects grease and other food products and allows liquids to flow through. The traps must be cleaned frequently and the grease is transported offsite for disposal. When the wastewater outflow from restaurant is maximized for prolonged periods, the trap can be filled and exceed capacity, allowing grease to flow through the trap and be delivered to the WWTP. Grease causes disruptions to the bacteria in the WWTP and reduces the treatment efficiency, quality of the effluent, and increases the amount of maintenance required.

D.6.2. Cesspools

Cesspools, also known as drywells, are old-fashioned decentralized sewage disposal systems frequently used for individual homes before the availability of septic tanks. Cesspools are more widely used in Hawai‘i than in any other state in the country. They are essentially holes in the ground that directly receive raw, untreated sewage. They used to be made of stone or bricks, allowing liquids to slowly seep into the soil and solids to collect and decay at the bottom. Modern residential cesspools are rudimentary septic systems with concrete linings and other safety measures. Typical cesspools are cylindrical holes deep in the soil, lined with a porous inner stone or concrete material. The outer surface is filled with gravel and soil covers the lid. Raw sewage flows into the chamber, which partially digests some of the solid material before the effluent seeps into the surrounding soil. A biofilm is created in the soil around the cesspool that helps attenuate pollutants, however, depending on the location of the cesspool, there is potential for pollutants to seep into ground and surface waters. This is of particular concern during storm or flood events that can cause overflowing of the cesspool and for unmaintained cesspools that might get disturbed by tree roots and other underground disruptions. The effectiveness and risk of a cesspool depends on the porosity of the surrounding soil, its proximity to water sources and other criteria. Since cesspools do not actually treat sewage and natural attenuation by soils is insufficient, cesspools pose a hazard to surrounding water bodies.

D.6.3. Septic Tanks

Septic tanks are frequently used in homes that are not connected to large sewage treatment facilities and are the most frequently used individual wastewater treatment system in Hanalei. They are a safe option for domestic sewage treatment if properly maintained. A septic tank is a watertight container collecting wastewater underground from a home. The solids collect at the bottom, while grease and soap scum floats at the top. The organic matter is partially decomposed through anaerobic digestion if it stays in the tank long enough, providing partial treatment of the wastewater. The use of a septic tank can drastically reduce the pollutant load of effluent. A well-designed tank can result in effluent containing a TSS concentration of 75mg/L, biochemical oxygen demand of 150 mg/L, Total Nitrogen of 53 mg/L and a 95% chance of the LOG10 of the Fecal Coliform Colony forming units per 100 ml being less than or equal to 8.[72] The effluent liquid goes into a leach field, where it percolates into the soil, which further attenuates it by filtering out pathogens.

The size of the tank depends on the water use of a household. Adequate time must be allowed for water treatment to take place to avoid pumping suspended organic matter into the leach field. The settled solid material stays at the bottom of the tank until it gets pumped out, which must be done periodically to keep the system functioning. Many homeowners forget to do this because the septic tank is not visible, causing problems with effectiveness of the system due to leaks, and soap and oil residue and organic matter flowing into the leach field. Septic tanks can be potential threats to water quality if poorly designed and/or maintained. Failure is caused by increased influent volumes and lower retention times, which reduces treatment and can flood the leach field.

[72] The water quality standards for treated wastewater effluent from treatment facilities are 60mg/L of TSS and 60mg/L of BOD.

D.6.4. Injection Wells

Injection wells are an alternative to discharging effluent water into the ocean. They are drilled into the earth surface above, below, or adjacent to underground sources of drinking water. After treatment, wastewater is pumped into injection wells and discharged into the ground. Care must be taken to avoid seepage into underground sources of drinking water, as regulated by the SDWA (Dong et al. 2002). The EPA UIC Program defines an injection well as: a bored, drilled, or driven shaft, or a dug hole that is deeper than it is wide; an improved sinkhole; or a subsurface fluid distribution system.[73] The construction of injection wells depends on the individual injection site and its hydrogeology, as well as the type of fluids to be injected.

There are six different well classes as defined by EPA. Classes I-IV relate mainly to the injection of hazardous and non-hazardous municipal wastewater, oil and gas related liquids, fluids from mining activities, radioactive waste, and carbon dioxide. Only one of these classes, Class V, which involves injection of nonhazardous fluids into or above USDW, is permitted in Hawai‘i. Class V wells are usually shallow on-site, sink/floor drains that discharge to dry wells, septic systems or drainage wells, though some deep wells exist. Hawai‘i DOH has further divided these wells into six subclasses (Table D2). These wells are classified as point sources under the CWA, however a NPDES permit to discharge pollutants is not required as these ground water inputs are regulated under the Safe Water Drinking Act (Appendix C.5.2).

Domestic Wastewater Treatment Plant Effluent Wells (Code 5W12) are designated as High-Low risk of contaminating groundwater, with possible contamination by pathogenic bacteria/viruses, nitrates, ammonia, chlorides, sulfates, sodium, and calcium.[74] They are considered lower risk than other septic systems for organics and bacteria.

Table D2. Class V Injection Wells: Subclasses as defined by Hawai‘i DOH

Well Subclasses	Use	Notes
Subclass A	Injection of fluids into an USDW including sewage wells and industrial disposal wells not classified under subclasses AB or B.	
Subclass AB	Injection of sewage and industrial waste into exempted aquifers via wells not classified under subclass B; example brine disposal wells used in desalinization.	
Subclass B	Injection of non-polluting fluids into any geohydrologic formation, including USDW.	Includes air conditioning return flow wells, cooling water return flow wells, recharge wells to replenish aquifers, salt water intrusion barrier wells, wells for aquaculture if water receiving formation has either an equal or greater chloride concentration than that of the injected fluid, OR a total dissolved solids concentration in excess of 5,000 mg/L, wells for experimental technology; all wells not included in Class V subclasses A, AB, C, D, E, or in Classes I-IV.

[73] http://water.epa.gov/type/groundwater/uic/index.cfm

[74] The subclass of well coded 5W12 by the EPA refers to *Domestic Wastewater Treatment Plant Effluent Disposal Wells* that function to dispose of treated sewage or domestic effluent from small package plants up to large municipal treatment plants.

Well Subclasses	Use	Notes
Subclass C	Injection of surface fluids, i.e., storm runoff, into any geohydrologic formation.	
Subclass D	Injection of overflows, or relief flows, from potable water systems into any geohydrologic formation.	
Subclass E	Injection of geothermal effluents provided it is injected deep enough to not have detrimental effects on USDW, Brine injection wells for the disposal of excess water from the steam-flashing process; Condensate injection wells for the disposal of condensate from electric generators; and Gas injection wells for the disposal of non-condensible gases entrained in an aqueous solution.	If effluent is discharged below the basal water table, the receiving formation water shall be tested and injection allowed if the receiving water has, either: A. An equal or greater chloride concentration as that of the injected fluid; B. total dissolved solids concentration in excess of five thousand mg/l; An equivalent or lesser water quality than the injected fluid.

Source: HAR Title 11 (§11-23-06)

D.6.5. Homeowner’s Guide Fact Sheets

Following are informative fact sheets on cesspools, septic tanks, aerobic treatment units, and absorption fields developed by the Department of Health and the University of Hawai‘i Manoa Water Resources Research Center.

Department of Health
Kinau Hale
1250 Punchbowl St.
Honolulu, HI 96813
Phone – (808) 586-4400
Fax – (808) 123-1234

CESSPOOLS

Homeowners Guide: Fact Sheet #1

How Does Your Cesspool Work?

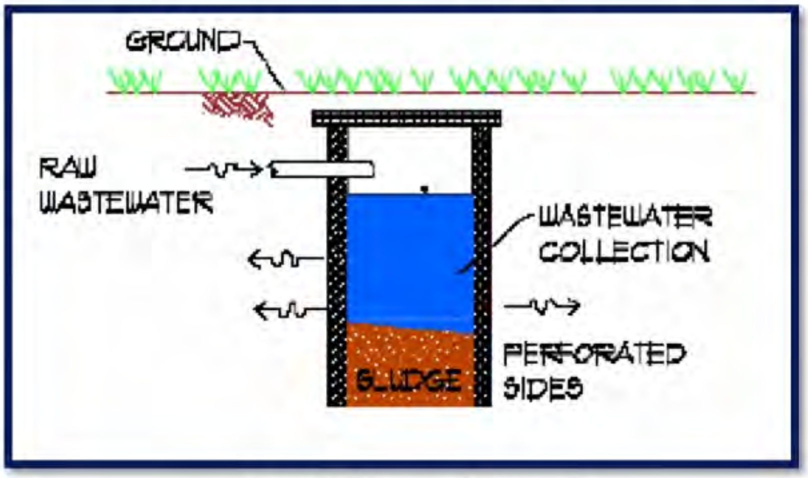


Figure 1. Diagram of a cesspool.

A cesspool is lined excavation in the ground typically constructed of perforated stone or concrete. Raw wastewater is discharged directly into the cesspool where solids known as sludge is allowed to settle and the liquid portion of the wastewater known as effluent exits through the perforated sides. Effluent may also exit through the bottom of the cesspool, however the collection of sludge limits this process. Sludge retained in the cesspool may be degraded through microbial digestion, however removal of sludge through this process is minimal.

Over time, biological growth known as a biomat forms along the sides of the cesspool. When a biomat forms, side openings may become clogged (which frequently happens). In the event of clogging, the cesspool would need to be pumped and physically cleaned, or chemically treated to unclog the openings. Chemical treatment is often the preferred process to unclog the openings (since it is easier and cheaper), however, chemicals are not as effective as pumping and will not work on heavy clogs.

Pumping is an inevitable occurrence as sludge is continuously collected in the bottom of the cesspool, therefore cesspools typically require annual pumping. In many cases, pumping or other procedures to unclog the cesspool may become dangerous as cesspools deteriorate. Structural deterioration may lead to cesspool cave-ins or collapse.

Typical Signs of a Failing System

Cesspools are generally substandard and typically older systems. This means it is extremely important to identify any warning signs of a failing system. Should any of the following signs appear, notify a certified service provider immediately to prevent further dangers.

1. **Sewage backed up or odors present.** This may be attributed to too much water entering the system or a clog in the piping or cesspool itself.
2. **Ground subsidence over cesspool area.** This is a dangerous sign of a potential cave-in. Do not approach the area and notify a service provider.
3. **Ponding or abnormal lush/burnt growth over cesspool area.** This is likely a sign of overflow of an overloaded or clogged cesspool.

Cesspools in Hawaii

Cesspools are currently regarded as substandard and outdated systems in terms of wastewater treatment and disposal. They do very little in the treatment of raw wastewater and are considered disposal systems as opposed to treatment systems. However, there are over 170,000 cesspools used in Hawaii, and they are used in Hawaii more then any other state in the US. Unfortunately, many of these cesspools are often neglected, ageing, or no longer functioning as designed. This poses a serious threat to Hawaii's precious groundwater resources.

Many restrictions have been placed on cesspools by the state and the EPA. Large capacity cesspools have been banned nationally and new cesspools are no longer allowed. In fact, failing cesspools are required to be removed and replaced as opposed to being fixed or altered. However, if cesspools are constructed in the right conditions and with proper maintenance and operation, cesspools are capable of providing adequate onsite wastewater disposal.

Figure 2. Uncovered cesspool.

Produced by: The Hawaii State Department of Health & the University of Hawaii, Manoa Water Resources Research Center

Figure 3. Newly installed cesspool.

Figure 4. Collapsed cesspool.

Cesspool Safety

As with all subsurface onsite wastewater treatment systems, collapse is a major hazard associated with ageing or structurally compromised systems. Cesspools are generally older systems and therefore more prone to collapse then other systems. If you own an older system, or even a new system, the following are a few safety precautions that should be followed.

- **Walking over or around the cover of the cesspool**. Cesspool covers may not be able to sustain the additional weight and should never be stood on.
- **Pumping out the contents of old cesspools may be dangerous if the cesspool is not able to withstand the exterior pressures as its contents are removed.** Always have a professional pumper remove the contents of your cesspool.
- **Chemically treating or aerating the sludge.** Chemical treatment and aeration is sometimes used to improve cesspool efficiency or unclog the cesspool, however similar to pumping; disturbing the solids has been known to cause cesspool collapse.
- **Driving over a cesspool.** Never drive over a cesspool. They are not designed to withstand the weight of a vehicle, unless designed specifically to do so.

Maintenance and Inspections

Cesspools are relatively low maintenance systems. Maintaining your cesspool is mainly limited to monitoring what goes down the drain and identifying warning signs. Annual pumping of solids is highly recommended and annual inspections by a licensed professional should be conducted as stipulated in your operating permit. Due to the fact that cesspools are typically older systems and commonly past their designed lifetimes, cesspools are more at risk of collapse then other treatment system. Self-inspections should be limited to visual inspections of above ground components and the general area above and around the cesspool. Many health hazards exist when maintaining and inspecting cesspools, so be extremely careful.

Maintenance Tips

- **Annually inspect and pump your cesspool.** Solids will always build up in cesspools and will require pumping at certain levels. To ensure a proper functioning system, have your cesspool annually inspected by a professional and pumped if deemed necessary.
- **Avoid using garbage disposals.** Garbage disposals place an additional load of solids on your cesspool and increases the frequency of necessary pumping. Try to limit or avoid using your garbage disposal
- **Conserve water.** Reducing the amount of water received by your cesspool will improve its disposal efficiency and prolong its health.
- **Avoid shockloads.** Try to avoid activities that create large water flows such as consecutive large loads of laundry or large parties. Large inflows of wastewater into cesspools will overload the system and could cause backups and overflows.
- **Don't throw trash down the drain.** No trash other then toilet paper should be allowed to enter your cesspool. Cesspools are not designed to handle most trash items and they will definitely clog your cesspool. Avoid flushing items such as paper towels, tampons, condoms, cigarette butts etc. as these items will increase the frequency of pumping.

For More Information

For more information see "*Septic System Checkup: The Rhode Island Handbook for Inspection*" by the RI Department of Environmental Management. Available at: www.uri.edu/ce/wq/owtc/html/owtc.html

More Fact Sheets and information may be found on the Hawaii State Department of Health OSDS website: www.doh.com/TBD

Department of Health
Kinau Hale
1250 Punchbowl St.
Honolulu, HI 96813
Phone – (808) 586-4400
Fax – (808) 123-1234

SEPTIC TANKS

Homeowners Guide: Fact Sheet #2

How Does Your Septic Tank Work?

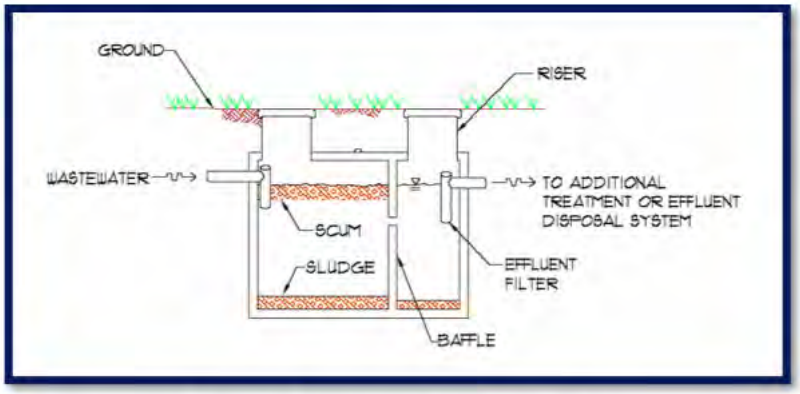


Figure 1. Two compartment septic tank.

The septic tank is commonly known as a conventional wastewater treatment system and is typically accompanied by a subsurface wastewater infiltration system (SWIS) or drainfield. The primary purpose of a septic tank is to remove settable solids and floatable scum from wastewater so that wastewater may be safely disposed of into the soil.

Septic tanks operate by receiving wastewater discharged directly from your home where it is stored for a period of time, known as the hydraulic retention time. By retaining the wastewater and providing quiescent conditions, solid material is allowed to settle to the bottom of the tank (sludge) and oils/floatables are allowed to rise to the top (scum). Baffles, as seen in Figure 1, allow the clarified wastewater to exit the septic tank while retaining the collected sludge and scum. Sludge and scum retained in the tank is degraded and broken down through microbial action. However, over time the volume of the sludge and scum will still build up and eventually require pumping to remove them.

An effluent filter is often installed to the outlet piping to further prevent solids from entering the drainfield, which will cause clogging. Some septic tanks may also have a second compartment to allow additional settling to prevent solids from entering the drainfield. Effluent received by the drainfield from the septic tank is then dispersed into the soil bed where it is allowed to percolate into the ground and is additional purified.

Typical Signs of a Failing System

The following are signs of a system failure and should any of these signs appear, notify a certified service provider immediately.

- Toilets, sinks, and drains are backed-up or not draining properly.
- Unusually lush growth or "burnt" growth over the absorption field.
- Sewage is surfacing or ponding over the absorption field or septic tank.
- Obnoxious odors originating from the septic system area.

Septic Tanks in Hawaii

Septic tanks are common alternatives to centralized public sewer systems and wastewater treatment. Over 4,500 homes in Hawaii utilize septic tanks, mainly in areas where public sewer systems are not available. However, research and surveys have found that septic tanks are not always maintained or monitored properly. Septic tanks are typically "out of sight, out of mind." It is not uncommon to find a homeowner who does not know the simple maintenance and workings of such an important fixture on their property.

In Hawaii, failing septic systems are a serious concern to the contamination of groundwater with infectious disease causing bacteria. With groundwater making up a large portion of the states potable water, maintaining your septic tanks is extremely important. Furthermore, backups or overflows and surfacing of wastewater, places anyone in the surrounding area of a failing septic tank at risk. Therefore for the protection of Hawaii's environment as well as anyone in the vicinity of a septic tank, it is imperative septic tanks are properly operated and maintained.

Figure 2. Installed septic tank.

Produced by: The Hawaii State Department of Health & the University of Hawaii, Manoa Water Resources Research Center

Figure 3. Newly installed septic tank.

Figure 4. Pumping of septic tank.

Septic Tank Maintenance and Inspection

Septic tanks are not maintenance intensive systems. In addition to being the most common type of onsite wastewater system, they are one of the easiest to maintain and operate. Nonetheless, improper care and neglected maintenance may still lead to a system failure. Septic tanks require periodical professional inspections and pumping to ensure functionality and avoid clogging of the drainfield. Generally, inspections should occur at least once every three years and should be pumped routinely according to the time-table presented in Figure 5. However, inspection and pumping frequency depend largely on the size of the septic tank and facility water use. The required pumping and inspection frequencies should be stipulated in the required operating permit issued by the Department of Health for every operating septic system. Always use a DOH Certified Inspector/Service Provider for any professional inspections or pumping. A list of certified inspectors/service providers is available from the DOH.

In addition to professional inspections and pumping, homeowner inspection and maintenance are equally important tasks. Controlling the materials entering your septic tank and identifying warning signs is the everyday maintenance necessary to maintain your system. With the proper training and knowledge, self-inspections allow the homeowner to greatly reduce the risk of costly failures by identifying problems sooner rather then later. Information on homeowner inspection and maintenance can also be obtained from the DOH.

	Household size (number of people)								
	1	2	3	4	5	6	7	8	9+
Tank Size (gals)	Duration (in years) Between Pumpings and/or Inspections								
500	5.8	2.6	1.5	1.0	0.7	0.4	0.3	0.2	0.1
750	9.1	4.2	2.6	1.8	1.3	1.0	0.7	0.6	0.4
900	11.0	5.2	3.3	2.3	1.7	1.3	1.0	0.8	0.7
1000	12.4	5.9	3.7	2.6	2.0	1.5	1.2	1.0	0.8
1250	15.6	7.5	4.8	3.4	2.6	2.0	1.7	1.4	1.2
1500	18.9	9.1	5.9	4.2	3.3	2.6	2.1	1.8	1.5
1750	22.1	10.7	6.9	5.0	3.9	3.1	2.6	2.2	1.9
2000	25.4	12.4	8.1	5.9	4.5	3.7	3.1	2.6	2.2
2250	28.6	14.0	9.1	6.7	5.2	4.2	3.5	3.0	2.6
2500	31.9	15.6	10.2	7.5	5.9	4.8	4.0	3.5	3.0

Figure 5. Suggested pumping intervals for septic tanks.

Ten Simple Steps for Routine Maintenance as directed by the EPA

1. Locate your septic tank and drainfield. Keep a drawing of these locations in your records.
2. Have your septic system inspected at least every three years.
3. Pump your septic tank as needed (generally every three to five years) determined by a pumping table (see Figure 5) or as determined by inspection.
4. Don't dispose of household hazardous wastes in sinks or toilets.
5. Keep other household items, such as dental floss, feminine hygiene products, condoms, diapers, and cat litter out of your system. Minimize the use of the garbage disposal.
6. Use water efficiently.
7. Plant only grass over and near your septic system. Roots from nearby trees or shrubs might clog and damage the system. Also, do not apply manure or fertilizers over the drainfield.
8. Keep vehicles and livestock off your septic system. The weight can damage the pipes and tank, and your system may not drain properly under compacted soil.
9. Keep gutters and basement sump pumps from draining into or near your septic system.
10. Check with your local health department before using additives. Commercial septic tank additives do not eliminate the need for periodic pumping and can be harmful to your system.

More Information

For more information see "*A Homeowners Guide to Septic Systems*" by the U.S. Environmental Protection Agency. This may be found at: http://epa.gov/owm/septic/pubs/homeowner_guide_long.pdf

More Fact Sheets and information may be found on the Hawaii State Department of Health OSDS website: www.doh.com/TBD

Department of Health
Kinau Hale
1250 Punchbowl St.
Honolulu, HI 96813
Phone – (808) 586-4400
Fax – (808) 123-1234

AEROBIC TREATMENT UNITS

Homeowners Guide: Fact Sheet #3

How Does Your Aerobic Treatment Unit Work?

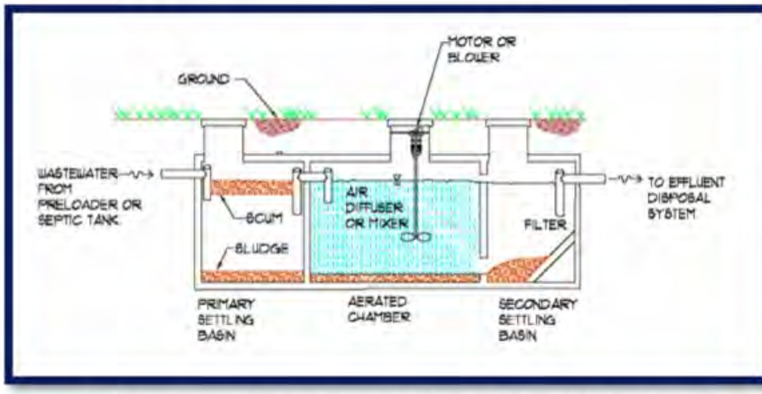


Figure 1. Three compartment suspended growth aerobic treatment unit.

Aerobic treatment units (ATUs) utilize aeration to enhance microbial degradation of sewage. In the presence of oxygen, microorganisms are able to break down organics and clarify wastewater more efficiently and effectively then in oxygen deficient systems such as septic tanks and cesspools. In the ATU, air is bubbled through the wastewater in the aeration chamber by a blower or mixer. This provides oxygen as well as thoroughly mixes the microbes and sewage. Here the microorganisms uptake oxygen and degrade organics to clarify the wastewater.

Preceding the aeration chamber, the wastewater may be pre-treated by a septic tank or a settling chamber. This separates and retains the larger solids, which take longer to be degraded by microorganisms. After the aeration chamber, another settling chamber often exists to allow remaining solids and microbes to settle out and be returned to the aeration chamber. This is extremely important as it maintains the microbe population in the aeration chamber and further clarifies the wastewater before it enters the disposal system..

There are different types of aerobic treatment units, however all ATUs function on the same basic principle, to provide an oxygenated environment for microbes to consume organic matter. Two common systems are the suspended growth aeration system, as described above, and the fixed-film growth system. The latter uses plastic, styrofoam, or gravel in the aeration chamber, which provide a medium for microorganism to grow on. In addition to the different types of systems, additional features such as disinfection units (such as chlorination) commonly accompany an ATU.

Typical Signs of a Failing System

1. Alarm triggered. The alarm signals any malfunction in the system. Know whom to call before the event of a triggered alarm. The faster a problem is fixed, the cheaper it will be.

2. Sewage back-up. If sewage is not draining properly or odors are present inside the home, a clog in the system is likely. Report immediately since contact with sewage is hazardous.

3. Unusual changes in ATU operation. Changes in sound, smell, or sewage characteristics are telltale signs of a failing system. Notify a service provider immediately.

ATU's in Hawaii

ATU's are an alternative and advanced form of onsite wastewater treatment and are used moderately in Hawaii. Compared to the conventional septic tank or cesspool, it is a much more complex operating system that produces a much higher degree of wastewater treatment. ATUs are generally implemented in environmentally sensitive areas where conventional septic systems cannot meet the required treatment criteria. This can occur where soil conditions are not suitable for conventional systems, underground water tables are high, or land slopes are too steep. As a result, ATU usage is continually increasing as septic tanks and cesspools fail to meet treatment standards in Hawaii.

Because of its complex mechanical and electrical design, ATUs are maintenance intensive systems and cost more money to operate then a conventional system. However, when properly maintained, an ATU will outperform most onsite sewage disposal systems in terms of effluent quality and are designed to function for a long time. In addition, ATUs are subject to ANSI/NSF Standard 40 certification, which verifies the functionality of the ATU. New ATUs are also typically required to include two years of maintenance by the manufacturer. Therefore, despite the higher costs and maintenance required by an ATU, they provide a much safer and effective form of onsite wastewater treatment to protect Hawaii's environment.

Figure 2. ATU in septic system.

Figure 3. Installed ATU.

Do's & Don'ts

Aerobic treatment units utilize biological processes and as an owner, there are things you need to do to ensure the health of your system. An important characteristic of ATUs is that improper care for the system will reveal itself faster then conventional systems. Follow these simple Do's and Don'ts to protect your ATU from harm and abuse.

Do this:

- **Do keep a service contract provided by the system manufacturer or a licensed service provider.** ATUs are maintenance intensive and its operation is highly dependent on proper maintenance.
- **Do become familiar with your ATU and how it works**. Know how your ATU sounds, smells like, and looks like when it is properly functioning, so that you may be able to recognize when it is not working properly.
- **Do conserve water in your household and divert other water sources such as roof drainage and sump pumps away from your ATU.** Overloading your unit with larger flows will hurt your ATU.
- **Do constantly be aware of your alarm system.** Alarm systems are put in place to notify you of any malfunctions. Know where your alarm system is located and what to do when it is activated.
- **Do keep all general information and detailed records of your ATU on hand.** Service contracts, system manuals, installation information, and past maintenance are just a few things you should always have readily available if called upon.
- **Do check before using chemical additives in your ATU.** Typically chemical additives are not proven to work and may actually harm your system. Check with the DOH or a certified service provider before using a chemical additive.

Don't do this:

- **Do not drive or park over any part of your ATU and its drainfield.** This can cause damage to piping, the ATU tank, and the drainfield.
- **Do not attempt self-repairs or allow unauthorized repairs or maintenance on your ATU.** Aerobic treatment units have many mechanical parts and should only be maintained by a professional.
- **Do not allow chemicals or poisons to enter your ATU.** Avoid flushing down household chemicals or pesticides/herbicides because they can kill the bacteria used in the ATU.
- **Do not overuse your garbage disposal.** Waste from garbage disposals can overload your ATU and increase clogging and require more frequent pumping.
- **Do not allow non-biodegradable items such as cigarette butts, disposable diapers, or coffee grounds to enter your system.**

Maintenance and Inspections

Aerobic treatment units have many mechanical parts and therefore require diligent inspections and maintenance. In an ATU, even the smallest of malfunctions can significantly inhibit the wastewater treatment. However, if properly maintained ATUs will produce a very high level of wastewater treatment and are designed to last for a long time.

There are many types and brands of ATUs on the market and each contains specific demands for its maintenance and upkeep, therefore it is not always possible for the owner to provide the required inspections, repairs, and maintenance. Newly installed ATUs are required to have a service contract provided by the manufacturer. Operating permits issued by the DOH are also required and will stipulate the frequency of inspections and maintenance. Professional inspections consist of inspecting wastewater quality, the mechanical parts, and overall system functions. If any maintenance is required, always hire a certified service provider. An up-to-date list of certified service providers may be obtained from the DOH.

Figure 4. Aeration in an ATU.

More Information

For more information see "*Decentralized Systems Technology Fact Sheet: Aerobic Treatment*" by the US EPA. Available at:
www.epa.gov/npds/pubs/aerobic_treatment.pdf

Additional information may also be found at:
http://nesc.wvu.edu/pdf/ww/publications/pipline/PL_SU05.pdf

More Fact Sheets and resources may be found on the Hawaii State Department of Health OSDS website: www.doh.com/TBD

Department of Health
Kinau Hale
1250 Punchbowl St.
Honolulu, HI 96813
Phone – (808) 586-4400
Fax – (808) 123-1234

ABSORPTION FIELDS

Homeowners Guide: Fact Sheet #4

Produced by the Hawaii State Department of Health & University of Hawaii Water Resources Research Center

Soil Absorption Fields

Soil absorption fields are onsite wastewater disposal systems commonly found at the backend of many septic systems. They typically consist of a distribution box and a subsurface, perforated piping system. The absorption field may also be referred to as the drainfield or soil absorption field, and two common types of absorption fields are the absorption bed and the absorption trench. Nevertheless, all absorption fields function on the same basic principle as they utilize the soil to treat and effectively dispose of wastewater effluent.

Absorption fields are designed and chosen based on the characteristics of the soil and groundwater, surrounding terrain, and climate conditions. High groundwater tables, steep slopes, and wet climates are typical factors that limit the use and effectiveness of absorption fields. Maintaining the field is very important and greatly affects the performance of the system. Maintenance begins with maintaining the preceding treatment unit and includes being able to identify obvious warning signs and following a few simple rules. The absorption field is a simply maintained yet extremely important component of your onsite sewage disposal system.

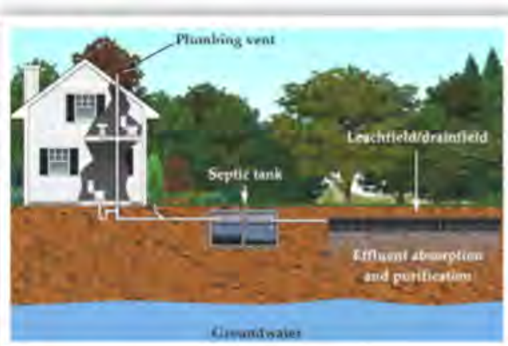


Figure 2. Conventional septic system with a soil absorption drainfield.

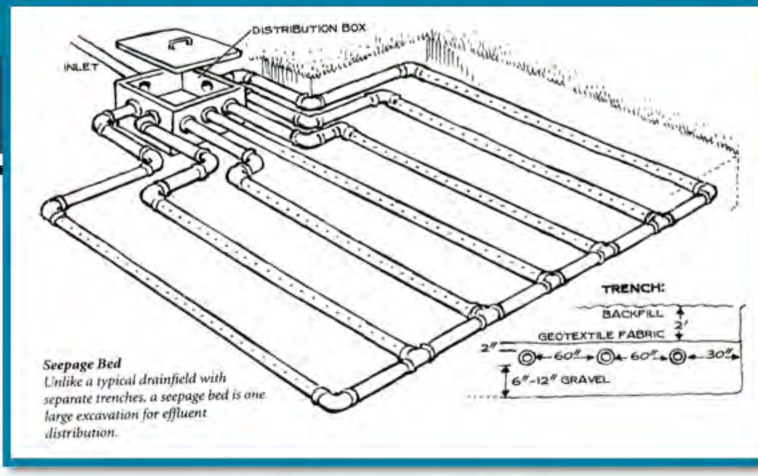


Figure 1. Soil absorption bed.

How Does It Work?

Absorption systems are a type of subsurface wastewater infiltration systems (SWIS). The main function of the absorption field is to receive treated wastewater effluent from the septic tank (or any preceding treatment unit) and distribute the effluent into the subsurface soil. As the effluent seeps through the soil, microbial actions and filtration further breaks down pollutant organics and removes infectious bacteria from the effluent. If properly designed and maintained, this allows the wastewater effluent to be safely disposed of onsite without contamination or pollution of the receiving groundwater table.

This first component of an absorption system is the distribution box (D-box). The D-box receives wastewater effluent from a wastewater treatment unit and evenly distributes the effluent into the piping system. The piping system is typically a network of subsurface, perforated pipes overlain by gravel and soil. The main job of the piping system is to evenly distribute the effluent into the surrounding soil where it can be further purified and finally incorporated into the groundwater. Commonly a biological mat of microorganisms may grow under the absorption field and this is beneficial to the continued treatment of the wastewater effluent as it leaches through the soil.

More Information

For more information on soil absorption systems see the "Septic Tank/Absorption Field Systems: A Homeowner's Guide to Installation and Maintenance" found at: http://extension.missouri.edu/publications/DisplayPub.aspx?P=EQ401

Additional fact sheets and resources may be found at the Department of Health OSDS website: www.doh.gov/TBA

Absorption Field Maintenance

The absorption field is the last component of your onsite sewage disposal system. It is essential to maintain your absorption field to ensure the proper disposal of your treated wastewater. A failing absorption field can lead to surfacing of wastewater or contamination of groundwater and pose health hazards to both your family and the public. The following are a few maintenance tips to keep your field running properly and safely.

1. **Have your absorption field inspected the same time your treatment unit is inspected.** This will ensure the proper functioning of your absorption field.
2. **Maintain your wastewater treatment unit.** The quality of effluent an absorption field receives is a direct factor to the health of the field. Maintaining a healthy treatment unit, whether it is a septic tank, aerobic treatment unit, or any other type of onsite wastewater treatment, will ensure the highest quality effluent possible and in turn protect your disposal field.
3. **Know where your absorption field is located.** By knowing where you septic system and absorption field is located, it will help you protect it from harmful activities and identify important warning signs.
4. **Avoid driving, digging, or construction over the field.** These activities may compact the soil or cave-in piping which will lead to system failures and safety hazards.
5. **Do not allow trees or large shrubs to grow on or near the field.** Roots can penetrate pipes causing leaks or clogs and prevent the proper distribution of effluent.
6. **Cover your disposal field with small vegetation.** Ground cover such as grass will protect your absorption field from erosion. However, do not plant trees or plants with invasive root systems.
7. **Divert surface water away from the disposal field.** Roof drains, sump pumps, or runoff should be kept away from the field as much as possible. Excessive water flowing over or into the absorption field may over saturate the soil and reduce the ability of the absorption field to properly dispose of the effluent.
8. **Use water efficiently.** Using less water will increase the treatment efficiency of your septic system and consequently prolong the health of your absorption field.

Common Failures and their Causes

Sewage ponding or evidence of ponding in yard. (See top pictures)

- Too much water is entering the septic system.
- Surrounding soil is over saturated due to rising groundwater tables or excessive rain.
- Solids are flowing into the absorption field.
- Lift-station pump failed or float switches incorrectly set.
- Pipes are clogged.

Obnoxious odors inside or outside the home.

- If inside, fixtures are likely backing up due to failure in the septic system.
- If outside, sewage may be surfacing and ponding.

Fixtures backed-up or draining slowly.

- Clogging is occurring somewhere in the septic system.
- Piping system improperly designed or constructed (if new).
- Broken piping system.
- Too much water is entering the septic system.
- Lift-station pump failed.

Surface or groundwater contaminated with bacteria.

- Septic system failing and improperly discharging wastewater into environment.
- Septic system imporperly constructed or placed.
- Source is other then homeowner's system.

Appendix E. Soils

E.1. Soil Series

Figure 16 illustrates the soil series in the Hanalei Bay Watershed as classified by the NRCS.[75] These series come from seven major soil orders: Alfisols, Andisols, Histosols, Inceptisols, Mollisols, Oxisols, and Spodosols.

Alfisols are well developed, fertile, noncalcic soils with an accumulation of clay in the subsoil. The Marsh series, of the Alfisols order, are moderately deep, well drained soils upland soils. The soil formed in colluvium or residuum from interbedded sandy limestone, siltstone, and shale. The Marsh series fine-loamy soils are found in small patches in the Agricultural District in each of the Hanalei, Waiʻoli, Waipā and Waikoko Watersheds.

Andisols are soils developing in parent material containing at least fifty percent volcanic ash. They are naturally fertile soils that can support dense vegetation in moist climates. The Koolau series, of the Andisols order, consists of deep, poorly drained soils that occur in areas with a mean annual rainfall of 160 inches (406 cm) and from 750 to 5,200 ft (229 to 1,585 m) elevation. Koolau series soils formed in material weathered from basic igneous rock. The Koolau series silty clays are upland soils found in small patches in the Hanalei Watershed.

Histosols are organic soils that develop when vegetation and decomposing letter alter young lava flows. Histosols form in places where organic matter is slow to decompose and accumulates over time. The Alakai series, of the Histosols order, are deep, very poorly drained soils that occur in areas where the mean annual rainfall is about 280 inches (711 cm) and from 3,000 to 5,000 ft (914 to 1,524 m) elevation. Alakai series soils formed in organic material overlaying clay weathered from basalt. Alakai series mucky peats are found adjacent to the Waialeale series peaty silty clay loams at the high elevations on Mt. Waiʻaleʻale in the Waiʻoli Watershed.

Inceptisols are poorly developed soils with minimal development of soil horizons. The Hanalei series, of the Inceptisols order, are somewhat poorly drained to poorly drained soils occurring in areas where the mean annual rainfall is about 90 inches (229 cm) and from near seal level to 300 ft (91 m) elevation. Hanalei series soils formed in alluvium derived from igneous rock. Hanalei series silty clays are bottom land soils found along some portions of the streams in all four watersheds.

The Hihimanu series, of the Inceptisols order, are deep, well drained soils that occur in uplands with a mean annual rainfall of about 95 inches (241 cm) and from 100 to 2,000 ft (30 to 610 m) elevation. Hihimanu series soils formed in material weathered from basic igneous rock. Hihimanu series silty clay loams are the. prominent soil type in the lower elevations of the Conservation District in the Hanalei, Waiʻoli, Waipā and Waikoko Watersheds. The majority of the Agricultural District of Waikoko Watershed is this soil type.

The Hulua series, of the Inceptisols order, are poorly drained soils that occur in the uplands with a mean annual rainfall of 150 inches (381 cm) and from 400 to 2,400 ft (122 to 732 m) elevation. Hulua series soils formed in material weathered from basic igneous rock. Hulua series gravelly silty clays are the prominent soil type in the upland areas of the Hanalei Watershed.

[75] Detailed information on the soil series can be found at http://soils.usda.gov/technical/classification/scfile/index.html.

Mollisols are moderately weathered, fertile soils with high organic carbon and high base saturation. The Kolokolo series, of the Mollisols order, are poorly drained to well drained soils that occur in bottom lands with a mean annual rainfall of 25 to 150 inches (64 to 381 cm) and from sea level to 500 ft (152 m) elevation. The Kolokolo clay loams are found along segments of the Waiʻoli and Waipā Streams in the Conservation District of the Waiʻoli and Waipā Watersheds.

The Mokuleia series, of the Mollisols order, are well drained soils that occur in coastal plains in areas with a mean annual rainfall of 40 inches (101 cm) and from sea level to 100 ft (30 m) elevation. The Mokuleia series formed in recent alluvium deposited over coral sand. Mokuleia series clay loams are found in all of the Urban District lands surrounding the bay. It is one of the dominant types of the Agricultural District in the Hanalei Watershed and to a lesser extent in the Waiʻoli, Waipā and Waikoko Watersheds.

Oxisols are highly weathered tropical soils with low nutrient holding capacity and high iron and aluminum oxides. The Hanamaulu series, of the Oxisols order, are very deep, well drained soils that occur in stream terraces in areas with a median annual rainfall of 80 inches (203 cm) and from 200 to 700 ft (61 to 213 m) elevation. Hanamaulu series soils formed in alluvium from basic igneous rocks. The Hanamaulu series silty clays are found in the Hanalei Watershed in patches along the Hanalei River and tributaries in the Conservation District. In the Waiʻoli, Waipā and Waikoko Watersheds they are found in patches along streams in the Agricultural and Conservation Districts.

The Makapili series, of the Oxisols order, are very deep, well drained soils that occur in uplands in areas with a median annual rainfall of 80 in (203 cm) and from 100 to 350 ft (30 to 107 m) elevation. Makapili series soils formed in material weathered from basic igneous rock and influenced by tropospheric dust. Makapili series silty clays are found in very small patches in the Urban, Agricultural and Conservation Districts in the Hanalei Watershed.

The Pooku series, of the Oxisols order, are deep, well-drained soils that occur in dissected uplands on the north side of Kauaʻi in areas with a mean annual rainfall of 120 inches (305 cm) and from 250 to 1,000 ft (76 to 305 m) elevation. Pooku series soils formed in material weathered from basic igneous rock. Pooku series silty clays are found in small patches in the Hanalei Watershed Conservation District.

Spodosols are acidic, infertile soils. The Waialeale series, of the Spodosols order, are moderately deep, somewhat poorly drained soils that occur on high upland slopes with a mean annual rainfall of 175 inches (445 cm) and from 3,500 to 4,800 ft (1,067 to 1,463 m) elevation. Waialeale series soils formed in material weathered from basic igneous rock. The Waialeale series peaty silty clay loams are found adjacent to the Alakai series mucky peats at the high elevations on Mt. Waiʻaleʻale in the Hanalei and Waiʻoli Watersheds.

E.2. Soil Erodibility

The majority of the Hanalei Watershed and a significant portion of the Waiʻoli, Waipā and Waikoko Watersheds consist of rough mountainous land, rough broken land and rock land, where the parent soil material, basaltic lava, still remains to be weathered. These upland soils are classified as having very severe erosion hazard.

Table E1. Major Soils

Soil Order	Soil Series	Texture	Particle Size	Color	Runoff Rate	Permeability	Drainage	Typical Vegetation	Location Found
Alfisols	Marsh	Fine-loamy	Fine-loamy	Yellowish-brown to brown	Medium to rapid	Moderate to moderately rapid	Well drained	Shrub/scrub	Small amount in each of the Hanalei, Waiʻoli, Waipā and Waikoko Watersheds
Andisols	Koolau	Silty clays	Medial	Gray to yellow	Medium	Rapid	Poorly drained	Many types	Small patches in the Hanalei Watershed
Histosols	Alakai	Mucky peats	Clayey	Red to black to brown	Slow	Slow	Very poorly drained	Marsh	Small patch in the Waiʻoli Watershed on Mt. Waiʻaleʻale
Inceptisols	Hanalei	Silty clay	Very fine	Dark gray	Slow	Moderate	Somewhat poor to poorly drained	Cultivated for taro and pasture. On non-cultivated areas Shrub/scrub	Dominant soil series along the Hanalei River and tributaries within the Hanalei Watershed. A small amount along stream segments in each of the Waiʻoli, Waipā and Waikoko Watersheds.
	Hihimanu	Silty clay loams	Very-fine	Dark brown to reddish brown	Medium	Moderately rapid	Well drained	Forest and Shrub/scrub	Prominent soil type in the lower elevations of the Conservation District in the Hanalei, Waiʻoli, Waipā and Waikoko Watersheds. The majority of the Agricultural District of Waikoko Watershed is this soil type
	Hulua	Gravelly silty clay	Hydrous	Black, browns and reds	Rapid	Moderately rapid	Poorly drained	Scrub/shrub	Prominent soil type in the upland areas of the Hanalei Watershed
Mollisols	Kolokolo	Silty clay loam or stony clay loam	Fine	Brown	Slow	Moderate	Poorly drained to well drained	Forest	Along segments of the Waiʻoli and Waipā Streams in the Conservation District of the Waiolli and Waipā Watersheds

Soil Order	Soil Series	Texture	Particle Size	Color	Runoff Rate	Permeability	Drainage	Typical Vegetation	Location Found
	Mokuleia	Silty clay	Clayey over sandy or sandy-skeletal	Dark grayish brown to dark brown to light gray	Very slow	Moderate	Well drained	Grassland and Scrub/shrub	All of the Urban District surrounding the bay. One of the dominant types of the Agricultural District in the Hanalei Watershed and to a lesser extent in the Waiʻoli, Waipā and Waikoko Watersheds
Oxisols	Hanamaulu	Silty clay	Very fine	Dark grayish brown to dark reddish brown	Slow to rapid	Moderately rapid	Moderately well drained	Forest	In small patches in the Agricultural and Conservation Districts in the Hanalei, Waiʻoli, Waipā and Waikoko Watersheds
	Makapili	Silty loam or clay loam	Very fine	Brown to reddish brown	Slow to rapid	Moderately rapid	Well drained	Forest	Small patches in the Urban, Agricultural and Conservation Districts in the Hanalei Watershed
	Pooku	Silty clay	Very fine	Dark brown to dark red	Slow to rapid, depending on slope	Moderately rapid	Well drained	Forest	Small patches in the Conservation District in the Hanalei Watershed
Spodosols	Waiʻaleʻale	Peaty silty clay loam	Very fine	Reddish brown/ dark gray/ strong brown	Rapid	Moderately rapid	Poorly drained	Forest	Small patch in the Conservation District in the Hanalei and Waiʻoli Watersheds on Mt. Waiʻaleʻale

Appendix F. Hydrology and Climate Data

This appendix contains information on stream flow records and basin characteristics for the Hanalei River. The data and information were derived from USGS Stream Stats program found at: http://streamstatsags.cr.usgs.gov/gagepages/html/16103000.htm. Similar stream flow records are not available for the Waioli, Waipa and Waikoko Streams.

StreamStats Data-Collection Station Report

USGS Station Number	16103000
Station Name	Hanalei River nr Hanalei, Kauai, HI

Click here to link to available data on NWIS-Web for this site.

Descriptive Information

Station Type	Gaging Station, continuous record
Regulated?	Undefined
Period of Record	
Remarks	
Latitude (degrees NAD83)	22.18035
Longitude (degrees NAD83)	-159.4661
Hydrologic unit code	20070000
Local Basin	-
County	007-Kauai
MCD	-
Directions to station	

Physical Characteristics

Characteristic Name	Value	Units	Citation Number
Compactness_Ratio	1.836178	dimensionless	84
Drainage_Area	18.504939	square miles	84
Maximum_Basin_Elevation	5125.381182	feet	84
Mean_Basin_Elevation	1626.4538	feet	84
Minimum_Basin_Elevation	72.739767	feet	84
Relative_Relief	180.449214	feet per mi	84
Relief	5052.641414	feet	84
Mean_Basin_Slope_from_10m_DEM	62.6133	percent	84

Stream_Slope_10_and_85_Longest_Flow_Path	161.48092	feet per mi	84
Basin_Perimeter	28.000351	miles	84
Slopes_gt_30pct_from_10m_NED	74.988575	percent	84
Elev_10pct_LFP_from_DEM	107.879276	feet	84
Elev_10pct_LFP_from_3Dline	107.224046	feet	84
Elev_85pct_LFP_from_DEM	1500.827783	feet	84
Elev_85pct_LFP_from_3Dline	1501.629858	feet	84
LFP_length	11.513482	miles	84
LFP_slope_3Dline	423.089619	feet per mi	84
Soil_permeability_top_12_in	3.330401	inches per hour	84
Soil_permeability_top_24_in	3.271737	inches per hour	84
Open_and_Low_NLCD_2001	0.712811	percent	84
Medium_developed_NLCD_2001	0	percent	84
High_developed_NLCD_2001	0	percent	84
Barren_Land_NLCD_2001	0.08451	percent	84
Evergreen_Forest_NLCD_2001	72.58367	percent	84
Cultivated_Crops_NLCD_2001	0	percent	84

Streamflow Statistics

Statistic Name	Value	Units	Citation Number
Peak-Flow Statistics			
10_Year_Peak_Flood	28500	cubic feet per second	84
100_Year_Peak_Flood	43600	cubic feet per second	84
2_Year_Peak_Flood	14700	cubic feet per second	84
25_Year_Peak_Flood	35000	cubic feet per second	84
5_Year_Peak_Flood	23100	cubic feet per second	84
50_Year_Peak_Flood	39400	cubic feet per second	84
500_Year_Peak_Flood	52600	cubic feet per second	84
Log_Mean_of_Annual_Peaks	4.1432	Log base 10	84
Log_Skew_of_Annual_Peaks	-0.821	Log base 10	84
Log_STD_of_Annual_Peaks	0.2577	Log base 10	84
Regression_10_Year_Peak_Flood	20900	cubic feet per second	84
Regression_100_Year_Peak_Flood	39100	cubic feet per second	84
Regression_2_Year_Peak_Flood	9340	cubic feet per second	84
Regression_25_Year_Peak_Flood	27900	cubic feet per second	84
Regression_5_Year_Peak_Flood	15900	cubic feet per second	84
Regression_50_Year_Peak_Flood	33400	cubic feet per second	84

Regression_500_Year_Peak_Flood	52700	cubic feet per second	84
Stand_Er_of_Reg_10_Yr_Peak_Flood	43	percent	84
Stand_Er_of_Reg_100_Yr_Peak_Flood	32	percent	84
Stand_Er_of_Reg_2_Yr_Peak_Flood	78	percent	84
Stand_Er_of_Reg_25_Yr_Peak_Flood	36	percent	84
Stand_Er_of_Reg_5_Yr_Peak_Flood	53	percent	84
Stand_Er_of_Reg_50_Yr_Peak_Flood	33	percent	84
Stand_Er_of_Reg_500_Yr_Peak_Flood	35	percent	84
Stand_Er_of_Wgt_10_Yr_Peak_Flood	9.102	percent	84
Stand_Er_of_Wgt_100_Yr_Peak_Flood	14.62	percent	84
Stand_Er_of_Wgt_2_Yr_Peak_Flood	9.106	percent	84
Stand_Er_of_Wgt_25_Yr_Peak_Flood	10.96	percent	84
Stand_Er_of_Wgt_5_Yr_Peak_Flood	8.521	percent	84
Stand_Er_of_Wgt_50_Yr_Peak_Flood	12.74	percent	84
Stand_Er_of_Wgt_500_Yr_Peak_Flood	19.23	percent	84
Standard_Error_of_10_Yr_Peak_Flood	9.333	percent	84
Standard_Error_of_100_Yr_Peak_Flood	16.54	percent	84
Standard_Error_of_2_Yr_Peak_Flood	9.187	percent	84
Standard_Error_of_25_Yr_Peak_Flood	11.54	percent	84
Standard_Error_of_5_Yr_Peak_Flood	8.649	percent	84
Standard_Error_of_50_Yr_Peak_Flood	13.88	percent	84
Standard_Error_of_500_Yr_Peak_Flood	23.32	percent	84
Systematic_peak_years	47	years	84
Weighted_10_Year_Peak_Flood	28100	cubic feet per second	84
Weighted_100_Year_Peak_Flood	42600	cubic feet per second	84
Weighted_2_Year_Peak_Flood	14500	cubic feet per second	84
Weighted_25_Year_Peak_Flood	34200	cubic feet per second	84
Weighted_5_Year_Peak_Flood	22900	cubic feet per second	84
Weighted_50_Year_Peak_Flood	38400	cubic feet per second	84
Weighted_500_Year_Peak_Flood	52600	cubic feet per second	84
WRC_Mean	4.1432	Log base 10	84
WRC_Skew	-0.536	Log base 10	84
WRC_STD	0.2577	Log base 10	84
Flow-Duration Statistics			
1_Percent_Duration	1760	cubic feet per second	41
10_Percent_Duration	426	cubic feet per second	41
20_Percent_Duration	252	cubic feet per second	41
25_Percent_Duration	217	cubic feet per second	41
30_Percent_Duration	187	cubic feet per second	41
40_Percent_Duration	150	cubic feet per second	41
5_Percent_Duration	700	cubic feet per second	41

50_Percent_Duration	127	cubic feet per second	41
60_Percent_Duration	110	cubic feet per second	41
70_Percent_Duration	94	cubic feet per second	41
75_Percent_Duration	88	cubic feet per second	41
80_Percent_Duration	81	cubic feet per second	41
90_Percent_Duration	64	cubic feet per second	41
95_Percent_Duration	54	cubic feet per second	41
99_Percent_Duration	41	cubic feet per second	41
General Flow Statistics			
Average_daily_streamflow	224.819	cubic feet per second	41
Maximum_daily_flow	9580	cubic feet per second	41
Minimum_daily_flow	31	cubic feet per second	41
Std_Dev_of_daily_flows	363.074	cubic feet per second	41
Base Flow Statistics			
Average_BFI_value	0.449	dimensionless	42
Number_of_years_to_compute_BFI	48	years	42
Std_dev_of_annual_BFI_values	0.085	dimensionless	42
Precipitation Statistics			
24_Hour_10_Year_Precipitation	13.78798	inches	84
24_Hour_100_Year_Precipitation	21.34446	inches	84
24_Hour_2_Year_Precipitation	9.009099	inches	84
24_Hour_25_Year_Precipitation	16.68321	inches	84
24_Hour_5_Year_Precipitation	11.6809	inches	84
24_Hour_50_Year_Precipitation	18.97808	inches	84
24_Hour_500_Year_Precipitation	27.28095	inches	84
48_Hour_10_Year_Precipitation	18.68391	inches	84
48_Hour_100_Year_Precipitation	29.32643	inches	84
48_Hour_2_Year_Precipitation	12.0449	inches	84
48_Hour_25_Year_Precipitation	22.7384	inches	84
48_Hour_5_Year_Precipitation	15.7514	inches	84
48_Hour_50_Year_Precipitation	25.96828	inches	84
48_Hour_500_Year_Precipitation	37.85153	inches	84
6_Hour_10_Year_Precipitation	9.00754	inches	84
6_Hour_100_Year_Precipitation	13.32417	inches	84
6_Hour_2_Year_Precipitation	6.015738	inches	84
6_Hour_25_Year_Precipitation	10.70884	inches	84
6_Hour_5_Year_Precipitation	7.727153	inches	84
6_Hour_50_Year_Precipitation	12.0102	inches	84
6_Hour_500_Year_Precipitation	16.49568	inches	84
60_Min_10_Year_Precipitation	4.209294	inches	84
60_Min_100_Year_Precipitation	6.251447	inches	84

60_Min_2_Year_Precipitation	2.858893	inches	84
60_Min_25_Year_Precipitation	4.999325	inches	84
60_Min_5_Year_Precipitation	3.623954	inches	84
60_Min_50_Year_Precipitation	5.620486	inches	84
60_Min_500_Year_Precipitation	7.817271	inches	84
Mean_Annual_Precipitation	186.7783	inches	84

Citations

Citation Number	Citation Name and URL
41	Wolock, D.M., 2003, Flow characteristics at U.S. Geological Survey streamgages in the conterminous United States: U.S. Geological Survey Open-File Report 03-146, digital data set
42	Wolock, D.M., 2003, Base-flow index grid for the conterminous United States: U.S. Geological Survey Open-File Report 03-263, digital data set
84	Oki, D.S., Rosa, S.N., and Yeung, C.W., 2010, Flood-frequency estimates for streams on Kaua'i, O'ahu, Moloka'i, Maui, and Hawai'i, State of Hawai'i: U.S. Geological Survey Scientific Investigations Report 2010-5035, 121 p.

Appendix G. Information Cited

G.1. References

Aeby, G. 2007. Coral Disease in Hanalei Bay. Hanalei Watershed Workshop. M.E. Field, C.J. Berg and S.A. Cochran. Princeville, Kauai, USGS: 1.

Ainley, D.G., R. Podolsky, L. DeForest and G. Spencer. 1997. New Insights into the Status of the Hawaiian Petrel on Kauai. Colonial Waterbirds 20(1): 24-30.

Alderisio, K.A. and N. DeLuca. 1999. Seasonal Enumeration of Fecal Coliform Bacteria from the Feces of Ring-Billed Gull (*Larus delawarensis*) and Canada Geese (*Branta canadensis*). Applied and Environmental Microbiology 65(12): 5628-5630.

Aplet, G.H., S.J. Anderson and C.P. Stone. 1991. Association Between Feral Pig Disturbance and the Composition of Some Alien Plant Assemblages in Hawaii Volcanoes National Park. Plant Ecology 95(1): 55-62.

Atwill, E.R., R.A. Sweitzer, M. DasGrac, A.C. Pereira, I.A. Gardner, D. VanVuren and W.M. Boyce. 1997. Prevalence of and Associated Risk Factors for Shedding *Cryptosporidium parvum* Oocysts and Giardia Cysts within Feral Pig Populations in California. Applied and Environmental Microbiology 63(10): 3946-3949.

Ballantyne, C. 2009. Watch Out Hawaii: Veggies May Harbor Rare Parasite. Scientific American.

Benton, C., F. Khan, P. Monaghan and W.N. Richards. 1983. The Contamination of a Major Water Supply by Gulls (Larus sp.). Water Research 17(7): 789-798.

Boehm, A. 2010. Bacterial and Nutrient Contamination of Hanalei Area Rivers and Streams and their Potential Impacts on Coastal Water Quality.

Brandvold, D.K., C.J. Popp and J.A. Brierly. 1976. Waterfowl Refuge Effect on Water Quality: II. Chemical and Physical Parameters. Journal of Water Pollution Control Federation 48(4): 680-687.

Browning, C. 2008. A Preliminary Examination of the Effects of Feral Pigs (*Sus scrofa*) on Water Quality and Soil Loss Within a Hawaiian Watershed. Natural Resources and Environmental Management. Honolulu, University of Hawaii. Master of Science: 117.

Carlsson, N., C. Bronmark and L.A. Hansson. 2004. Invading Herbivory: The Golden Apple Snail Alters Ecosystem Functioning in Asian Wetlands. Ecology 85(6): 1575-1580.

Chen, Y.L. and A.J. Nash. 1994. Diurnal Variations of Surface Airflow and Rainfall Frequencies of the Island of Hawaii. Monthly Weather Review 122: 34-56.

Chu, P.S., Y.R. Chen and T.A. Schroeder. 2010. Changes in Precipitation Extremes in the Hawaiian Island in a Warming Climate. Journal of Climate 23: 4881-4900.

Chu, P.S. and H. Chen. 2005. Interannual and Interdecadal Rainfall Variations in the Hawaiian Islands. Journal of Climate 18: 4796-4813.

Clement, B. 1997. Issue Paper Concerning Possible Regulatory Requirements for Uncovered Finished Water Reservoirs and Cross-Connection Control. EPA Office of Research and Development.

Coastal Zone Management Program. 1996. Hawai‘i’s Coastal Nonpoint Pollution Control Program Management Plan Hawaii Coastal Zone Management Program.

Coastal Zone Management Program. 2009. Agency Programs, Projects, and Funding Opportunities that Support Ahupua‘a, Watershed, and Ecosystem-based Management.

Cole, M. L., I. Valiela, K. D. Kroeger, G. L. Tomasky, J. Cebrian, C. Wigand, R. A. McKinney, S. P. Grady and M.H. Carvalho da Silva. 2004. Assessment of a 15N Method to Indicate Anthropogenic Eutrophication in Aquatic Ecosystems. Journal of Environmental Quality 33: 124-132.

County of Kauai. 1972. Comprehensive Zoning Ordinance. County of Kauai.

County of Kauai. 2000. The General Plan for the County of Kauai. Planning Department.

Craig, D.L., H.J. Fallowfield, et al. 2002. “Comparison of decay rates of faecal indicator organisms in recreational coastal water and sediment.” Water Supply 2(3): 131-138.

Cuddihy, L.W. and C.P. Stone. 1990. Alteration of Native Hawaiian Vegetation: Effects of Humans, Their Activities and Introductions. Honolulu, University of Hawaii Cooperative National Park Resources Studies Unit.

Danovaro, R., L. Bongiorni, C. Corinaldesi, D. Giovannelli, E. Damiani, P. Astolfi, L. Greci and A. Pusceddu. 2008. Sunscreens Cause Coral Bleaching by Promoting Viral Infections. Environmental Health Perspectives 116: 441-447.

Davidson, K., M. Hamnett and C. Minato. 2003. The First Four Years: Hawaii Coral Reef Initiative Research Program (1998-2002). Social Science Institute, University of Hawaii at Manoa.

Department of Health and Coastal Zone Management Program. 2000. Hawaii's Implementation Plan for Polluted Runoff Control DOH Clean Water Branch Polluted Runoff Control Program and CZM. Retrieved from http://hawaii.gov/health/environmental/water/cleanwater/prc/implan-index.html.

Derse, E., K.L. Knee, S.D. Wankel, C. Kendall, C.J. Berg Jr. and A. Paytan. 2007. Identifying Sources of Nitrogen to Hanalei Bay, Kauaʻi, Utilizing the Nitrogen Isotope Signature of Macroalgae. Environmental Science and Technology 41: 5217–5223.

DOFAW. 2010. Haleleʻa Forest Reserve Draft Management Plan. State of Hawaiʻi Department of Land and Natural Resources, Division of Forestry and Wildlife, Forest Management Section.

Dong, D., W.T. Halapua, I. Lesnet, L. Moffat, B. Natale, A.N. Poerbonegoro, K. Polloi, N. Sumon, N. Settachai, V. Verawudh and M. Yamamura. 2002. Building Collaboration: Toward Co-Management for the Hanalei Ahupuaʻa, Kauaʻi, Hawaiʻi. Planning Practicum Fall 2002. Department of Urban and Regional Planning, University of Hawaiʻi at Manoa Honolulu, HI.

Draut, A.E., M.H. Bothner, M.E. Field, R.L. Reynolds, S.A. Cochran, J.B. Logan, C.D. Storlazzi and C.J. Berg. 2009. Supply and Dispersal of Flood Sediment from a Steep, Tropical Watershed: Hanalei Bay, Kauaʻi, Hawaiʻi, USA. Geological Society of America Bulletin 121: 547-585.

Dunkell, D.O. 2009. Runoff, Erosion, Fecal Indicator Bacteria, and Effects of Feral Pig (*Sus scrofa*) Exclusion in Manoa Watershed. Natural Resources and Environmental Management. Honolulu, University of Hawaii. Master of Science: 125.

Earle, T.K. 1978. Economic and Social Organization of a Complex Chiefdom: The Halelea District, Kauai, Hawaii. Anthropological Papers, Museum of Anthropology, University of Michigan: 63.

El-Kadi, A.I., M. Mira, J.E.T. Moncur and R.S. Fujioka. 2008. Restoration and Protection Plan for the Nawiliwili Watershed, Kauai, Hawaii, USA. Coastal Watershed Management. A. Fares and A.I. El-Kadi. UK, WIT Press: 251-282.

Environmental Protection Agency. 1994. Water Quality Standards Handbook: Second Edition.

Environmental Protection Agency. 2008. Handbook for Developing Watershed Plans to Restore and Protect Our Waters. U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Control Branch Washington, DC.

Fares, A. 2007. Evaluation of a Non-Point Source Pollution Model, AnnAGNPS, in Hanalei Watershed, Kauaʻi. Project Report. Prepared for USDA Natural Resources Conservation Service. Honolulu HI.

Field, R., A.N. Tafuri, S. Muthukrishnan, B.A. Acquisto and A. Selvakumar. 2004. The Use of Best Management Practices (BMPs) in Urban Watersheds. Lancaster, PA, DEStech Publications, Inc.

Fletcher, C.H., E.E. Grossman, B.M. Richmond and A.E. Gibbs. 2002. Atlas of Hazards in the Hawaiian Coastal Zone, USGS, United States Government Printing Office: 182.

Fletcher, C.H. 2009. Sea Level by the End of the 21st Century: A Review. Shore and Beach 77(4): 1-9.

Friedlander, A.M., R.C. DeFelice, J.D. Parrish and J.L. Fredrick. 1997. Habitat Resources and Recreational Fish Populations at Hanalei Bay, Kauai. Hawaii Cooperative Fishery Research Unit, Department of Zoology, University of Hawaii at Manoa Honolulu, HI.

Friedlander, A.M. and J.D. Parrish. 1998. Habitat Characteristics Affecting Fish Assemblages on a Hawaiian Coral Reef. Journal of Experimental Marine Biology and Ecology 224: 1-30.

Friedlander, A. and E. Brown. 2006. Hanalei Bay Marine Benthic Communities Since 1992: Spatial and Temporal Trends in a Dynamic Hawaiian Coral Reef Ecosystem. Hawaii Cooperative Studies Unit, University of Hawaii at Hilo, Pacific Aquaculture and Coastal Resources Center.

Friedlander, A., G. Aeby, R. Brainard, E. Brown, K. Chaston, A. Clark, P. McGowan, T. Montgomery, W. Walsh, I. Williams and W. Wiltse. 2008. The State of Coral Reef Ecosystems of the Main Hawaiian Islands. NOAA.

Fujioka, R. and C. Hardina. 1991. Soil: The Environmental Source of Escherichia coli and Enterorocci in Hawaii's Streams. Environmental Toxicology and Water Quality 6(2): 185-195.

Geldreich, E.E. and S. Shaw. 1993. New York City Water Supply Microbial Crisis. EPA.

Giambelluca, T.W., M.A. Nullet and T.A. Schroeder. 1986. Hawaii Rainfall Atlas, Report R76. Hawaii Division of Water and Land Development. Department of Land and Natural Resources. Honolulu.

Giambelluca, T.W., Q. Chen, A.G. Frazier, J.P. Price, Y. Chen, P. Chu, J. Eischeid and D. Delparte. 2011. The Rainfall Atlas of Hawaiʻi. Retrieved from http://rainfall.geography.hawaii.edu.

Glicker, J. 1999. Uncovered Finished Reservoirs Guidance Manual. EPA Office of Water. Retrieved from water.epa.gov/lawsregs/rulesregs/sdwa/mdbp/upload/ufw8p.doc.

Global Coral Reef Alliance. 2012. Eutrophication and Water Quality. Retrieved February 28, 2012, from http://globalcoral.org/Eutrophication%20and%20Water%20quality.html.

Hampton, J.P., B.S. Spencer, A.D. Elliot and A. Thompson. 2006. Prevalence of Zoonotic Pathogens from Feral Pigs in Major Public Drinking Water Catchments in Western Australia. EcoHealth 3: 103-108.

Hanalei Watershed Hui. 2006. Final Report to U.S. Environmental Protection Agency- Hanalei Targeted Watershed Initiative Grant

Hanalei Watershed Hui. 2012. Hanalei Watershed Hui. Retrieved from http://www.hanaleiwatershedhui.org/.

Hartz, A., M. Cuvelier, K. Nowosielski, T.D. Bonilla, M. Green, N. Esiobu, D.S. McCorquodale and A. Rogerson. 2008. Survival Potential of Escherichia coli and Enterococci in Subtropical Beach Sand: Implications for Water Quality Managers. Journal of Environmental Quality 37: 898-905.

Hasbrouck, E. 2005. Identification of E. coli Sources for the Peconic Estuary Watershed for Effective Mitigation of Nonpoint Source Pollution. Peconic Estuary Program State of the Bays Science Conference, Riverhead, NY.

Hawaiʻi Department of Health. 2009. Hawaii Administrative Rules §11-54 Water Quality Standards. Honolulu.

Hawaiʻi Department of Transportation. 2007. Stormwater Permanent Best Management Practices Manual. Highways Division. Honolulu: 1-136.

Hollyer, J., V.A. Troegner, R. Cowie, R. Hollingsworth, L. Nakamura-Tengan, L. Castro and A. Buchholz. 2010. Best On-Farm Food Safety Practices: Reducing Risks Associated with Rat Lungworm Infection and Human Eosinophilic Meningitis. College of Tropical Agriculture and Human Resources, University of Hawaii.

Hussong, D., J.M. Damare, R.J. Limpert, W.J.L. Sladen, R.M. Weiner and R.R. Colwell. 1979. Microbial Impact of Canada Geese (*Branta canadensis*) and Whistling Swans (*Cygnus columbianus columbianus*) on Aquatic Ecosystems. Applied and Environmental Microbiology 37(1): 14-20.

Intergovernmental Panel on Climate Change. 2007. IPCC Fourth Assessment Report: Climate Change 2007.

Jacobi, J. and S. Ambagis. 2007. Mapping Plant Species and Communities in the Hanalei Watershed. Hanalei Watershed Workshop. M.E. Field, C.J. Berg and S.A. Cochran. Princeville, Kauai, USGS: 2.

Jokiel, P.L., E.K. Brown, A. Friedlander, K.S. Rodgers and W.R. Smith. 2004. Hawaii Coral Reef Assessment and Monitoring Program: Spatial Patterns and Temporal Dynamics in Reef Coral Communities. Pacific Science 58(2): 145-158.

Kinsey, D.W. and P.J. Davies. 1979. Effects of Elevated Nitrogen and Phosphorus on Coral Reef Growth. Limnology and Oceanography 24(5): 935-940.

Knee, K.L., B.A. Layton, J.H. Street, A.B. Boehm and A. Paytan. 2008. Sources of Nutrients and Fecal Indicator Bacteria to Nearshore Waters on the North Shore of Kaua‘i (Hawai‘i, USA). Estuaries and Coasts 31(4): 607-622.

Lau, L.S. and J.F. Mink. 2006. Hydrology of the Hawaiian Islands. Honolulu, University of Hawai‘i Press.

Levesque, B., P. Brousseau, P. Simard, E. Dewailly, M. Meisels, D. Ramsay and J. Joly. 1993. Impact of the Ring-Billed Gull (*Larus delawarensis*) on the Microbiological Quality of Recreational Water. Applied and Environmental Microbiology 59: 1228-1230.

Levin, P. 2006. Statewide Strategic Control Pan for Apple Snail (*Pomacea canaliculata*) in Hawaii. The Hawaii Land Restoration Institute.

Lewis, S.E., J.E. Brodie, Z.T. Bainbridge, K.W. Rohde, A.M. Davis, B.L. Masters, M. Maughan, M.J. Devlin, J.F. Mueller and B. Schaffelke. 2009. Herbicides: A New Threat to the Great Barrier Reef. Environmental Pollution 157(8-9): 2470-2484.

Manny, B.A., R.G. Wetzel and W.C. Johnson. 1975. Annual Contribution of Carbon, Nitrogen and Phosphorus by Migrant Canada Geese to Hardwater Lake. International Society of Limnology 19: 949-951.

Manny, B.A., W.C. Johnson and R.G. Wetzel. 1994. Nutrient Additions by Waterfowl to Lakes and Reservoirs: Predicting Their Effects on Productivity and Water Quality. Hydrobiologia 279/280: 121-132.

Marion, L., P. Clergeau, L. Brient and G. Bertru. 1994. The Importance of Avian-Contributed Nitrogen (N) and Phosphorus (P) to Lake Grand-Lieu, France. Hydrobiologia 279/280: 133-147.

Markey, K., A. Baird, C. Humphrey and A. Negri. 2007. Insecticides and a Fungicide Affect Multiple Coral Life Stages. Marine Ecology Progress Series 330: 127-137.

McClanahan, T.R., B.A. Cokos and E. Sala. 2002. Algal Growth and Species Composition Under Experimental Control of Herbivory, Phosphorus and Coral Abundance in Glovers Reef, Belize. Marine Pollution Bulletin 44: 441-451.

Mink, J.F. and L.S. Lau. 1992 Aquifer Identification and Classification for Kauai: Groundwater Protection Strategy for Hawaii. September. viii + 37 pp. Technical Report No. 186.

NOAA. 2006. How Pollution Affects Coral Reefs. NOAA Celebrates 200 Years of Science, Service and Stewardship. Retrieved from http://celebrating200years.noaa.gov/visions/coral/side.html.

NOAA Coral Reef Conservation Program. 2009. NOAA Coral Reef Conservation Program Goals & Objectives 2010 - 2015. NOAA Silver Spring, MD.

Oki, D.S. 2004. Trends in Streamflow Characteristics at Long-term Gaging Stations, Hawai‘i. U.S. Geological Survey Scientific Investigations Report 2004-5080.

Orazio, C., T. May, R. Gale, J. Meadows, W. Brumbaugh, K. Echols, W. Steiner and C. Berg. 2007. Survey of Chemical Contaminants in the Hanalei River, Kaua‘i, Hawai‘i, 2001. Hanalei Watershed Workshop, Princeville, Kauai, USGS.

Parham, J.E., G.R. Higashi, E.K. Lapp, D.G.K. Kuamo'o, R.T. Nishimoto, S. Hau, J.M. Fitzsimons, D.A. Polhemus and W.S. Devick. 2008. Atlas of Hawaiian Watersheds and Their Aquatic Resources: Kauai Watersheds, Hanalei Region. Honolulu, HI, Bishop Museum and Division of Aquatic Resources. 2324. Retrieved from http://www.hawaiiwatershedatlas.com/.

Pettigrew, C.T., B.J. Hann and L.G. Goldsborough. 1998. Waterfowl Feces as a Source of Nutrients to Prairie Wetland: Responses of Microinvertebrates to Experimental Additions. Hydrobiologia (362): 55-66.

Piniak, G. 2004. Sediment Impacts of Reef Corals in Maui, Hawaii. Sound Waves Monthly Newsletter, USGS.

Post, D.M., J.P. Taylor, J.F. Kitchell, M.H. Olson, D.E. Schindler and B.R. Herwig. 1998. The Role of Migratory Waterfowl as Nutrient Vectors in a Managed Wetland. Conservation Biology 12(4): 910-920.

Råberg, S., M. Nystrom, M. Eros and P. Plantman. 2003. Impact of the Herbicides 2,4-D and Diuron on the Metabolism of the Coral Porities cylindrica. Marine Environmental Research 54(4): 503-514.

Ritchie, J. and P. Pedone. 2008. Determining Sediment Sources in the Hanalei River Watershed. International Soil Science Conservation Organization Conference (ISCO2008) Congress, Budapest, Hungary.

Roy, S.S. and R.C. Balling. 2004. Analysis of Hawaiian Diurnal Rainfall Patterns. Theoretical and Applied Climatology 79(3-4): 209-214.

Scherer, N.M., H.L. Gibbons, K.B. Stoops and M. Muller. 1995. Phosphorus Loading of an Urban Lake by Bird Droppings. Lake and Reservoir Management 11(4): 317-327.

Scholze, R., V. Novotny and R. Schonter. 1993. Efficiency of Best Management Practices for Controlling Priority Pollutants in Runoff. Water Science & Technology 28(3): 215-224.

Smith, J.E., C.L. Hunter and C.M. Smith. 2002. Distribution and Reproductive Characteristics of Nonindigenous and Invasive Marine Algae in the Hawaiian Islands. Pacific Science 56(3): 299-315.

State of Hawai‘i. 2010. Hawaii Coral Reef Strategy: Priorities for Management in the Main Hawaiian Islands 2010-2020. DLNR Division of Aquatic Resources Honolulu, HI. Retrieved from http://docs.lib.noaa.gov/noaa_documents/CoRIS/Hawwaiian_Arch_CRMP_Apdx_1.pdf.

Stewart, C. 2010a. Hawaii’s Management Measures for the Coastal Nonpoint Pollution Control Program DOH Clean Water Branch Polluted Runoff Control Program, Marine and Coastal Solutions International.

Stewart, C. 2010b. Responsible Agencies and Authorities - A Supplemental For Hawaii Management Measures. Hawai‘i DOH Clean Water Branch Polluted Runoff Control Program.

Stewart, C. 2011. Spike in Rat Lungworm Reported. Hawaii Tribune Herald Hilo.

Storlazzi, C.D., M.E. Field, M.H. Bothner , M.K. Presto , and A.E. Draut. 2009. Sedimentation Processes in a Coral Reef Embayment: Hanalei Bay, Kauai. Marine Geology 264: 140-151.

Tetra Tech and State of Hawaiʻi Department of Health, Clean Water Branch. 2008. Total Maximum Daily Loads for the Hanalei Bay Watershed. PHASE 1 – Streams and Estuaries. State of Hawaiʻi Department of Health, Clean Water Branch Honolulu, HI.

Tetra Tech and State of Hawaiʻi Department of Health, Clean Water Branch. 2011. Total Maximum Daily Loads for the Hanalei Bay Watershed. PHASE 2 –Embayment. December. State of Hawaiʻi Department of Health, Clean Water Branch Honolulu, HI.

Timm, O. and H.F. Diaz. 2009. Synoptic-Statistical Approach to Regional Downscaling of IPCC Twenty-First Century Climate Projections: Seasonal Rainfall Over the Hawaiian Islands. Journal of Climate 22(16): 4261-4280.

Tummons, P. 2011. Hogs Gone Wild: A Growing Problem Throughout the Continental United States. Environment Hawaii December.

Umezawa, Y., T. Miyajima, M. Yamamuro, H. Kayanne and I. Koike. 2002. Fine Scale Mapping of Land-Derived Nitrogen in Coral Reefs by δ15N in Macroalgae. Limnology and Oceanography 47: 1405-1416.

Valiela, I., M. Alber and M. LaMontagne. 1991. Fecal Coliform Loadings and Stocks in Buttermilk Bay, Massachusetts, USA, and Management Implications. Environmental Management 15(5): 659-674.

vanDam, J.W., A.P. Negri, S. Uthicke and J.F. Mueller. 2011. Chemical Pollution on Coral Reefs: Exposure and Ecological Effects. Ecological Impacts of Toxic Chemicals: 187-211.

VanHoutan, K.S., S.K. Hargrove and G. Balazs. 2010. Land Use, Macroalgae, and a Tumor-Forming Disease in Marine Turtles. Plos One 5(9).

Vermeer, M. and S. Rahmstorf. 2009. Global Sea Level Linked to Global Temperature. Proceedings of the National Academy of Sciences of the United States 106(51): 21527-21532.

Vecchi, G., B. Soden, A. Wittenberg, I. Held, A. Leetmaa and M. Harrison. 2006. Weakening of Tropical Pacific Atmospheric Circulation Due to Anthropogenic Forcing. Nature (441): 73-76.

Viau, E.J., K.D. Goodwin, K.M. Yamahara, B.A. Layton, L.M. Sassoubre, S.L. Burns, H.-I. Tong, S.H.C. Wong, Y. Lu and A.B. Boehm. 2011. Bacterial Pathogens in Hawaiian Coastal Streams - Associations with Fecal Indicators, Land Cover, and Water Quality. Water Research 45: 3279-3290.

Water Resources Research Center and Engineering Solutions Inc. 2008. Onsite Wastewater Treatment Survey and Assessment. State of Hawaiʻi Department of Business, Economic Development and Tourism, Office of Planning, Hawaiʻi Coastal Zone Management Program and Department of Health. Honolulu.

G.2. Personal Communication and Presentations

Culverhouse, G. 2011. Manager and Partner Ching Young Village (Personal Communication).

Fitzgerald, B. 2011. Taro Farmer (Personal Communication).

Giambelluca, T. 2010. University of Hawaiʻi at Manoa Professor (Personal Communication).

Hood, A. 2012. Sustainable Resources Group Intn’l Inc. Principal (Personal Communication).

Izuka, S. 2011. USGS Pacific Islands Water Science Center Hydrologist (Presentation).

Maly, K. 2009. Kumu Pono Associates LLC (Personal Communication).

Richmond, R. 2011. Kewalo Marine Laboratory Pacific Sciences Research Center (Presentation).

Rosener, M. 2012. Hydrologist, Waipā Foundation (Personal Communication).

Uyehara, K. 2012. Refuge Biologist, Kauaʻi National Wildlife Refuge Complex (Personal Communication).

G.3. Other Consultations

Persons consulted during preparation of Volume 1 and Volume 2 of the HBWMP.

Hobie Beck, Land owner/Taro farmer
Jonathan Deenick, University of Hawaii
Jeffrey Guest, Rancher
Kris Kobayashi, Taro farmer
Terry Lilley, Diver
Mike Loo, Princeville Land Manager
Michael Mitchell, USFWS, Kauaʻi National Wildlife Refuge Complex
Matthew Roesner, Waipā Foundation
Stacy Sproat, Waipā Foundation
Gaylord Wilcox, Land owner