Watershed Based Plan for Reduction of Nonpoint Source Pollution in Wailupe Stream Watershed

Draft Report

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Acronyms

CCH	City and County of Honolulu
CCH-ENV	City and County of Honolulu's Department of Environmental Services
CWA	Clean Water Act
CZARA	Coastal Zone Act Reauthorization Amendments
CZM	Coastal Zone Management
DAR	Division of Aquatic Resources
DBEDT	Hawai'i Department of Business, Economic Development and Tourism
DCIA	Directly Connected Impervious Areas
DLNR	Department of Land and Natural Resources
DOH	Department of Health
DQO	Data Quality Objectives
EA	Environmental Assessment
EAL	Environmental Action Levels
ED	Extended Detention
EMC	Event Mean Concentrations
EPA	Environmental Protection Agency
FCC	Fecal Coliform Concentration
FIRM	Flood Insurance Rate Maps
GIS	Geographic Information System
HAR	Hawai'i Administrative Rules
HAZWOPER	Hazardous Waste Operations and Emergency Response
HIDOT	Hawai'i Department of Transportation
LUO	Land Use Ordinance
MS4	Municipal Separate Storm Sewer System
MSL	Mean Sea Level
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	Non-point Source
NWS	National Weather Service
O&M	Operations and Maintenance
OCCL	Office of Conservation and Coastal Lands
QA/QC	Quality Assurance and Quality Control
QAPP	Quality Assurance Project Plan
R	Residential
RCRA	Recovery Act of 1976
SWCD	Soil and Water Conservation Districts
SWMP	Storm Water Management Plan
TMDL	Total Daily Maximum Load
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S Geological Service
WBP	Watershed Based Plan
WLA	Waste Load Allocation

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Executive Summary

Historically, Maunalua Bay was a healthy marine ecosystem comprised of native sea grass beds and coral reef that provided habitat for a variety of species. Man-made impacts, including the discharge of non-point source (NPS) pollutants generated off the ten watersheds draining into the bay, have impaired its water quality. As a result, the bay is on the Clean Water Act (CWA) Section 303(d) list of impaired water bodies. Pollutants identified on the 303(d) list as triggering the water quality impairments are various forms of nitrogen and chlorophyll A. Fine terrigenous (land-based) sediments are another significant pollutant of concern. Additionally, research conducted on coral reefs has found that other urban contaminants, such as petrochemicals and heavy metals, are significant stressors affecting reef health. Control and reduction of NPS pollutant loads discharged into the bay therefore is a necessary step towards restoring the health of Maunalua Bay.

Wailupe Watershed is drained by Wailupe Stream, the only non-hardened (concrete lined) stream discharging into Maunalua Bay. The *Watershed Based Plan (WBP) for Reduction of Nonpoint Source Pollution in the Wailupe Stream Watershed, O'ahu,* was developed under a Hawai'i State Department of Health CWA Section 319(h) grant to Mālama Maunalua. The WBP is comprised of four sections: *Watershed Characterization*, *Pollution Control Strategies*, *Implementation Strategies*, and an *Evaluation and Monitoring Plan*. The WBP adheres to the Environmental Protection Agency (EPA) CWA Section 319 guidelines for watershed plan development. These guidelines require that the WBP utilize 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.

The *Watershed Characterization* summarizes the general environmental conditions of the watershed. It was developed using existing data and information, field investigations, and geospatial data analysis using geographic information system (GIS) software. In general, there is a lack of quantitative data to develop numerical estimates on NPS pollutant concentrations in runoff water generated off the watershed. However, there is sufficient qualitative information to make informed inferences about where and what types of pollutants are generated and the flow paths that carry them into the receiving waters of Wailupe Stream and Maunalua Bay. A significant finding with respect to generation and transport of NPS pollutants is that human induced alterations to the ground cover have changed the rainfall runoff regime. Impervious surfaces such as roads, driveways, and roof tops prevent infiltration of rain into the ground and instead generate runoff under moderate or heavy rainfall. The runoff picks up and transports NPS pollutants, resulting in frequent pollutant loading of the receiving waters. Upland watershed areas are dominated by alien vegetation and contain feral ungulates, both of which increase erosion rates above background levels. Wailupe Stream, while in a quasi-natural condition, is itself a source of sediment due in part to unstable banks and a degraded riparian zone.

Flooding is of concern to both residents and business owners with property located in the 100-year floodway adjacent to Wailupe Stream. The US Army Corps of Engineers (USACE) conducted a Flood Feasibility Assessment that evaluated several flood control strategies focused on protecting people and property along the stream's floodway. The strategies did not meet USACE economic criteria and have not advanced to the engineering design phase. The USACE is currently pursuing alternatives that would provide some level of flood protection while at the same time providing benefits to enhance Wailupe Stream ecologic function and enhance the quality of water it discharges to Maunalua Bay.

NPS pollutants adversely impact the quality of stream and ocean waters, diminishing habitat for plants and animals and resource use by people. The *Pollution Control Strategies* section identifies the sources and types of NPS pollutants in Wailupe Watershed and recommends management strategies. To refine the discussion of pollutants and their control strategies, the watershed was delineated into four management units (upland forest, steep slopes, urban footprint, and stream corridor) based on dominant land uses and types. Management measures were grouped into two major types, preventative and treatment controls. Preventive measures focus on controlling or eliminating pollution at its source. Treatment involves filtering, trapping, or bioremediating NPS pollutants along the pollutant stream prior to reaching the receiving waters. Both types of controls can be achieved through structural and nonstructural practices. From a watershed-based perspective the best approach is to prevent the generation of NPS pollutants, however implementation and the benefits can take many years to be realized. Specific practices and technologies were selected based on their ability to reduce generation of, capture or remediate NPS pollutants, cost, logistical aspects of installation, and any link to regulatory or management objectives that either require or promote measures to reduce NPS pollutants. Educational outreach on pollution prevention should be conducted to inform stakeholders how they can reduce their generation of NPS pollutants.

The *Implementation Strategy* section identifies locations for management practice implementation and prioritizes installation within management units based on load reduction potential and relative cost. Management practices to reduce pollutant loads are generally required under regulatory statutes or implemented voluntarily as part of stakeholder programs. The regulatory responsibility for implementing these management practices often falls on landowners or permittees of the parcel the practices will be installed on or those who own the system that transports the pollutants. Reduction of pollutant loads is a function of both the types and number of management practices installed. The Wailupe WBP identified the municipal separate storm sewer system (MS4) that is located within and services the urban area as a primary target for management efforts. Comprising a series of inlets, pipes, ditches, and outlets, the MS4 is the primary conveyance feature of urban storm water, as well as runoff generated off the steep side slopes. MS4 inlets along the base of the highly erodible steep side slopes on both sides of the Aina Haina neighborhood capture sediment-laden runoff and rapidly-convey it without treatment into Wailupe Stream or the bay. The efficiency of the MS4 in capturing and transporting runoff increases both the frequency and magnitude of runoff routed to the receiving waters. Since it captures a majority of the NPS pollutants, the MS4 is an ideal location for treatment control. Recommended management practices include retrofit installation of baffle boxes onto the MS4 and construction of rain gardens and other practices that encourage infiltration to attenuate overland flow and trap NPS pollutants. Properties identified to house recommended management practices include parcels owned by the City and County of Honolulu, State of Hawaiʻi, and private entities.

The *Evaluation and Monitoring Plan* describes three types of monitoring necessary to track management measures: implementation, baseline and effectiveness. Implementation monitoring verifies that management practices have been installed and documents logistical aspects of the installation. Baseline monitoring involves the collection of data and information to establish resource conditions prior to implementation of the recommended management measures. Baseline monitoring can transition into effectiveness monitoring after a management measure has been installed. Effectiveness monitoring evaluates the management measure to determine if it is working as designed. This qualitative and quantitative information helps determine their effectiveness and apply the findings to other watersheds.

The Wailupe WBP provides a framework for addressing NPS pollutant control in Wailupe Watershed. Implementation of the management measures presented in the WBP is expected to reduce generation and transport of land-based pollutants, resulting in improved water quality and ecosystem health in Maunalua Bay. Recommended next steps include developing a comprehensive monitoring program, including management of a centralized database, to document baseline data on key parameters. Implementation of the management practices, per the identified priorities, is crucial to reducing the generation and transport of sediments and other NPS pollutants. The monitoring program will expand to include effectiveness monitoring once management practices are installed. The Wailupe WBP provides a framework that can be used for other watersheds in the region. Follow-on work involves characterizing these watersheds to identify target pollutants and determine the type of and location for installation of management practices.

Watershed Based Plan for Reduction of Nonpoint Source Pollution in Wailupe Stream Watershed

Watershed Characterization Report

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1 Introduction

1.1 Purpose

A *Watershed Based Plan (WBP) for Reduction of Nonpoint Source Pollution in the Wailupe Stream Watershed, O'ahu* was developed under a Hawai'i State Department of Health 319 grant to Mālama Maunalua. This *Watershed Characterization Report* is a component of the WBP and summarizes the general environmental conditions in Wailupe Watershed to provide a basis for future recommendations. Characterizing a watershed from ridge to reef involves gathering and processing existing data and information in order to document baseline watershed conditions. The characterization provides a mechanism to evaluate watershed processes and determine if alterations to hydrologic and ecologic processes are having an adverse impact on the watershed's ecosystem. Analyzing data to characterize the watershed and pollutant sources provides the basis for developing effective management strategies to meet watershed goals (USEPA 2008). The watershed characterization includes a summary of data collection and results gained from previous water quality planning and implementation efforts in the Wailupe Watershed, as well as the identification of important gaps in data and knowledge bases and suggestions for additional information needs and future priorities.

The watershed approach, which has been adopted and is supported by the Environmental Protection Agency's (EPA) 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.[1]

1.2 Overview of Project Area

Wailupe Watershed is located near the middle of Maunalua Bay on the leeward side of the Ko'olau Mountain Range at Latitude 21°16'65" North, Longitude 157°45'30" West (see Figure 1). Maunalua Bay is located on the leeward southeast coast of the island of O'ahu, Hawai'i. The Maunalua region covers approximately 22 square miles of land, seven miles of shoreline, and 6.5 square miles of ocean water. As part of the larger Maunalua region, Wailupe Watershed is one of ten watersheds that drain into Maunalua Bay. It was identified as a priority watershed in the 2006 Community Action Plan co-developed by Mālama Maunalua (Malāma Maunalua 2009). The ten watersheds that make up the Maunalua Bay region from west to east are: Wai'alae Nui, Wai'alae Iki, Wailupe, Niu, Kuli'ou'ou, Kaalakei, Haha'ione, Kamilo Nui, Kamilo Iki and Portlock. Each of the ten watersheds drains the land within their boundaries between the crest of the Ko'olau mountains down to their outlets at the ocean. Wailupe Stream along its entire flow length is the only unhardened, semi-natural stream in the Maunalua region. All major streams draining the other nine watersheds are channelized and hardened within the urban corridors. The upper undeveloped areas of the watersheds are dominated by steep slopes covered primarily in non-native vegetation. Urban development occurs within each watershed from the shoreline of Maunalua Bay inland on the valley floors as well as some of the ridges that divide the watersheds.

Hydrologic issues in Wailupe Watershed include the potential for flood damages and hazards to residential and commercial establishments within the estimated 100-year flood plain. In addition, Mālama Maunalua has identified the highest ranking critical threat to Maunalua Bay as the runoff of sediment and other non-point source (NPS) pollutants at rates that exceed the bay's ability to naturally process and

[1] Details can be found at http://www.epa.gov/water/waterplan/.

transport the pollutants to ocean waters beyond the reef. Urban development led to significant changes in ground cover and the creation of numerous swaths of impervious surfaces, and the channelization and hardening of streams. This has resulted in adverse alterations to the rainfall runoff regime in the watersheds.[2] The urban areas are serviced by an extensive municipal separate storm sewer system (MS4) fitted with curbs, gutters, and drainage pipes with outfalls that discharge storm water runoff either directly into the bay or inland into ditches or streams that terminate at the bay. A result of the extensive impervious areas and the MS4 system is the increase in magnitude and frequency of storm water runoff and pollutants carried in it. This rapid transport of runoff reduces detention time of water on the watershed and the amount that infiltrates into the ground. This, in turn, diminishes the capture of pollutants in soils. The primary objective of the MS4 system is storm water conveyance and there are no management practices in place on the current system to reduce or treat pollutants transported through it.[3]

1.3 Summary of Previous Reports and Information

Watershed and stream resources in Hawaiʻi have been studied by a range of public and private entities including University of Hawaiʻi researchers, State and Federal agencies (e.g., City and County of Honolulu's Department of Environmental Services (CCH-ENV), Hawaiʻi Department of Land and Natural Resources (DLNR) - Division of Aquatic Resources (DAR), U.S. Department of the Interior, U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS)) and community organizations (e.g., Maunalua Fishpond Heritage Center). The types of work and reports range from flood control studies to forest bird inventories. Information regarding the current overall health of Maunalua Bay, Wailupe Stream, and Wailupe Watershed and their designated uses to be supported were sought from several sources including water quality standards and State water quality reports (i.e. Hawaiʻi's Administrative Rules (HAR), and under Sections 303(d) and 305(b) of the Clean Water Act (CWA).

In response to a flood that occurred on New Year's Eve 1987, the Hawaiʻi Senate requested that the USACE complete an assessment of the condition and adequacy of East Oʻahu's drainage systems. This reconnaissance report, titled *Urban Flood Control Study* (USACE 1992), determined that Wailupe Stream warranted a feasibility level investigation for proposed improvements and the determination of Federal interest in providing measures to reduce the threat of flooding and debris flow to the community of Aina Haina. The *Final Feasibility Report, Wailupe Stream Flood Control Study, Oʻahu, Hawaiʻi* recommended nine flood reduction alternatives and project costs of which two alternatives were extensively detailed for a benefit-cost summary (USACE 1998). The USACE feasibility study concluded that even the alternative with the highest benefit/cost ratio (0.89) would not meet the National Economic Development criterion of having positive net benefits. It also concluded that "experience has shown that the construction of debris basins without channel improvements can disrupt the delicate balance of natural stream degradation and replenishment, thus leading to increased erosion within the stream," and that "this alternative would not satisfy the study objectives of reducing the flood hazard with Aina Haina." The alternative was eliminated from further consideration (USACE 1998). However, because of continued community concern for flood

[2] Rainfall runoff regime refers to the amount of rainfall from a storm that becomes surface overland flow. Factors affecting it include the intensity and duration of the rainfall event, ground cover, soil infiltration rate, and ground slope. Changes to ground cover can have a pronounced effect on the volume and timing of runoff; increases in impervious surface increases runoff volume and decreases time before runoff begins.

[3] Management practices refers to treatments or preventative actions, which are either structural or non structural, and are used to reduce generation of, trap or remediate non point source sediments thereby reducing their loading of receiving waters.

control, as well as concern expressed by local, State and Federal governments, the USACE is continuing to explore options, including those contained in their 1998 report, to address flood control in the region (CCH-ENV 2007).

A 2007 *Storm Water Management Plan* (SWMP) followed up on a 2001 report by CCH-ENV that recommended retrofitting structural management practices to address storm water runoff from new development and redevelopment projects that result in a land disturbance of one acre or more and smaller projects that have the potential to discharge pollutants to the CCH MS4 (CCH-ENV 2001; CCH-ENV 2007). The 2001 SWMP indicated that the cost-benefit ratio of retrofitting structural management practices for Wailupe is expected to be significantly higher than that of surrounding watersheds. The 2007 SWMP addressed programs and activities that the Hawai‘i Department of Transportation, Highways Division (HIDOT Highways) will implement to reduce, to the maximum extent practicable, the amount of storm water containing pollutants entering and discharging from the HIDOT Highways O‘ahu MS4. Chapter Eight of the SWMP provides the scope for a retrofit feasibility study that would explore how to improve the quality of O‘ahu MS4 discharges that empty into 303(d) water bodies, which are defined as water bodies having beneficial uses but are impaired by one or more pollutants. The permanent management practice options include the following categories:

- *Vegetated swales*: dry swales and wet swales;
- *Infiltration facilities*: infiltration trenches; infiltration basins and bio-retentions;
- *Storm water wetlands*: shallow wetlands, extended detention wetlands and pocket/pond wetlands;
- *Storm water ponds*: wet ponds, extended detention ponds and multi-pond system;
- *Filtering systems*: sand filters, and organic filters; and
- *Proprietary hydrodynamic type devices*.

Biological surveys of the Wailupe Stream and watershed area were conducted by USFWS and DAR, respectively (USACE 1998; Parham, Higashi et al. 2008). USFWS conducted a detailed study as part of the 1998 USACE feasibility report with specific objectives that included obtaining biological data from their stream project site, evaluating and analyzing the impacts of the proposed projects on fish and wildlife resources and their habitats, and recommending mitigation for unavoidable project-related habitat losses (USACE 1998). Although the objectives focus on a limited section of the watershed, the evaluation identified real concerns within the watershed and made recommendations for conservation measures that can be applied throughout. DAR conducted a watershed survey of Wailupe for the distribution and abundance of organisms, both native and introduced that occupy Hawaiian streams. This statewide database has attempted to collect historical biota information and methodically assign labels and rankings to features within Hawaii’s watersheds.[4]

2 Watershed Components

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*

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

for Developing Watershed Plans to Restore and Protect Our Waters, were used to document the watershed area and condition of Wailupe Watershed (USEPA 2008).[5]

- Population and land use
- Physical and natural features
- Waterbody monitoring data
- Waterbody conditions
- Pollutant sources

2.1 Population and Land Use

2.1.1 Anthropogenic Impacts on Wailupe Watershed

There are approximately 60,000 people living in the Maunalua region and many more who transit through it daily in vehicles. A 2000 block population census recorded the population in Wailupe Watershed as 10,734. Maunalua Bay is a significant recreational and commercial use area for both residents and off-island visitors. The region has a history of diverse land uses that may have contributed to the land-based pollution now threatening the bay. Early residents of the region engaged in fishing, gathering and subsistence agriculture. During the 1900s the region supported cattle grazing, farming and commercial fishing. Urban development began in the early 1950s, leading to the suburban character of the region.

Historical Anthropogenic Impacts on Wailupe Watershed Hydrology

During the formation of O‘ahu, and for many millions of years following, the hydrologic cycle was unaffected by human impacts. During this time fluvial processes eroded the landscape carving streams and creating steep ridgelines that define the watersheds we see today.

The first anthropogenic impacts to the Wailupe Watershed likely resulted from Polynesian settlers who diverted a portion of water out of the streams and into taro and fish loi’s. Extraction of resources such as plants and animals likely occurred from the upland forests, low-lying coastal areas and the ocean. Significant impacts to the hydrologic cycle in the Wailupe Watershed from the Polynesian settlers were likely minimal. A second wave of human contact to the island was made by peoples of European and Asian ancestry beginning in the 1800’s. These peoples brought animals and resource extraction techniques that resulted in significant alterations to vegetation communities in the coastal zones and inland forest. Prior to the early 1950s the Wailupe Watershed can best be characterized as rural and beyond the footprint of the Honolulu urban zone. Beginning in the early 1950s urbanization began in earnest across the Maunalua region including the Wailupe Watershed. An air photo taken in 1977 reveals that most of the urban footprint in Wailupe Watershed had been developed by the mid 1970s, with the exception of Hawai‘i Loa Ridge and a portion of the development that has occurred on Wiliwilinui Ridge neighborhood.

2.1.2 Land Use

Land within Wailupe Watershed falls into two district types classified by the State Land Use Commission: Conservation and Urban. The Conservation District makes up a majority (1,450 acres or 61%) of the watershed area. The State owns 64% of the Conservation District lands, which are administered by DLNR’s Office of Conservation and Coastal Lands (OCCL). Conservation lands are

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

further subdivided by OCCL into sub-zones that are arranged in a hierarchy based on environmental sensitivity ranging from the most environmentally sensitive (Protective) to the least sensitive (General). Conservation lands in the watershed include the steep side slopes adjacent and upslope of the urban corridor and the *mauka* lands draining the upland forested areas. The upper portion of the watershed consists of multiple large land owners including the State, CCH, and Kamehameha Schools (see Table 1; Figure 2). A majority of land use in the upper forested Conservation District is zoned as Restrictive Preservation (the highest degree of environmental sensitivity) and has been designated a Honolulu Watershed Forest Reserve.[6] This area is also designated as a Public Hunting Area (see Figure 3).

The Urban District encompasses areas within the valley floor, extending inland from the ocean for approximately 1¾ miles, and includes the two ridges that bound the valley. The CCH has zoning rules that are regulated by Chapter 21 of the Revised Ordinances of Honolulu, *Land Use Ordinance* (LUO). The Urban District in Wailupe Watershed is approximately 942 acres; zones defined by CCH consist of 180 acres zoned as general preservation, 105 acres as road cover, and 657 acres zoned as Residential, Business, and Federal. The LUO Residential (R) zone areas are regulated and subzoned by development purpose and intent. For example, the intent of the R-20 and R-10 districts is to provide areas for large lot development, which, for example, may be transitioning between preservation and agriculture, while the intent of the R-7.5, R-5 and R-3.5 districts is to provide areas for urban residential development (see Figure 5).

Table 1. Major Land Owners in Wailupe Watershed[7]

Land Owner	Acres
Government: Honolulu County	401.78
Government: State	993.32
Kamehameha Schools	34.85
Private (Residential/Commercial)	963.36
Watershed Total	**2393.30**

The USGS conducted a National Water Quality Assessment on O‘ahu that delineated land within the watershed that has been altered by human activities into four categories: moderate residential use, high residential use, commercial use, and other (see Figure 4). The USGS classification characterizes the type of potential land based pollutants and quantities derived off the four types and are not a jurisdictional or regulatory classification system.

Land Cover

The urban and suburban landscape of the lower valley floor has a high amount of impervious surface (see Figure 6). Impervious surface refers to ground cover, both natural and man-made, which cannot be penetrated by water (USEPA 2005). However, review of land cover maps reveals that nearly all impervious surfaces in Wailupe Watershed are manmade features. Buildings, rooftops, parking lots, and other impervious surfaces generate surface runoff following all rainfall events including short-duration low precipitation events. Wailupe's urban zone consists of 43% of impervious surfaces, resulting in

[6] Per Hawai‘i Revised Statutes Chapter 183, and Hawai‘i Administrative Rules Title 13, Chapter 104.

[7] Data derived from the Office of Planning, State of Hawai‘i DBEDT GIS Program, ‘Major Landowners’.

nearly 405 acres of impervious surfaces (NOAA 2007). The average area of a residential lot is 0.26 acres and about half of that area is impervious.

The predominant vegetative cover in the upper watershed is invasive tree species with approximately 15% native vegetation including koa (*Acacia koa)* and ‘ohia (*Metrosideros polymorpha*) forest. Existing vegetation in the lower developed area consists mostly of invasive species including kiawe (*Prosopis pallida*), koa haole (*Leucaena leucocephala*), and strawberry guava (*Psidium cattleianum*) (see Figure 7).

2.2 Physical and Natural Features

2.2.1 Watershed Boundaries

A watershed is a geographical area that shares a common location where surface water runoff concentrates at or is drained to, e.g. the mouth of a stream. Watersheds boundaries are formed by topographic divides and within any size watershed smaller subwatersheds can be delineated within the larger watershed boundary. Wailupe Watershed is located near the middle of Maunalua Bay on the southeastern (leeward) coast of the island of O‘ahu, Hawai‘i. The 2,393 acre rectangular basin is approximately 3.5 miles long and one mile wide extending from the crest of the Ko‘olau Range to Maunalua Bay and bounded along its east and west axis by Hawai‘i Loa and Wiliwilinui Ridges respectively. This assessment uses a land management definition of a watershed, the area delineated by Malama Maunalua’s geographically defined Wailupe *āpana*[8], which includes associated nearshore waters in Maunalua Bay. An *āpana* has characteristics similar to the historical boundaries of an *ahupua‘a*[9], which in this case, is larger than the natural watershed boundary and includes land that does not drain into Wailupe Stream. Manmade drainage features such as pipes and other drainage structures can convey runoff across natural topographic watershed boundaries and increase or decrease the watershed area artificially.

Wailupe Watershed can be divided into upper and lower sections.[10] The upper forested area is dissected by headwater streams and steep valley walls, while the lower section contains a valley floor, and coastal lowlands. The latter two have been highly developed. The residential neighborhood of Aina Haina is located from the middle of the watershed to the shoreline on the valley floor and coastal lowland. Two other neighborhoods, Hawai‘i Loa and Wiliwilinui, fall on the watershed’s east and west ridges, respectively. Boundaries in the upper watershed fall along the topographic breaks created by the crest of ridgelines. The upper watershed can be divided into four sub-watershed areas: East Wailupe, West Wailupe, Laulaupoe, and Kulu‘i (see Figure 8). These four sub-watersheds share a common outlet, which is the location where the stream draining their areas flows into Wailupe Stream. Wailupe Stream is the primary drainage channel within the larger Wailupe Watershed and the sub-watersheds have tributary streams that join. Boundaries of the lower section of the watershed do not represent true topographic watershed delineation since the water running off portions of the landscape within the lower watershed does not share a common outlet with other parts of the watersheds, in this case Wailupe Stream. Instead, this water flows directly out to the ocean.

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[8] *Āpana*. Piece, slice, portion, fragment, section, segment, installment, part, land parcel, lot, district, sector, ward, precinct (Pukui and Elbert 1986).

[9] *Ahupua‘a*. A land division usually extending from the uplands to the sea (Pukui and Elbert 1986). As used by the ancient Hawaiians, an *ahupua‘a* 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).

[10] Discussions in this report that refer to ‘Wailupe Watershed’ are inclusive of the entire watershed.

2.2.2 Topography

Wailupe Watershed has topography that 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) (see Figure 9). Elevations range from 2,600 feet msl at the crest of the *pali* to sea level, with an average elevation of 560 feet msl.[11] Slopes range from 68% in the steep *pali* sections to near flat in the coastal zone area with an average of 24%. When viewed from above Wailupe Watershed appears roughly rectangular, and its topographic boundaries are distinct due in part to the two ridges that bound it along its longest axis, The toe of these ridges end *mauka* of the shoreline. The coastal plain, the more *mauka* portions of the watershed that contain the Aina Haina neighborhood, butts up against the toe and extend slightly up the base of the steep slopes that fall from the ridges. A result of the topography is that rainfall and surface runoff derived on most of the watershed drains towards the urban area.

2.2.3 Climate

Ancient Hawaiians distinguished the annual precipitation cycle into two 6-month seasons: *kau* (May to October) and *ho'oilo* (November to April) (Lau and Mink 2006). Modern analysis now divides the annual cycle in Hawai'i into a summer season of five months (May to September) and a winter season of seven months (October to April) (Blumenstock and Price 1967). The climate of the Hawaiian Islands is controlled in large part by the presence of the Pacific Subtropical Anticyclone (PSA), a high-pressure ridge located north and east of the islands. The ridge of high pressure generates winds that blow from its base and travel from a northeasterly direction toward the island chain. These winds are referred to as 'trades'. During the summer season, when tradewinds are dominant, areas of maximum rainfall are generally located on windward slopes where orographic effects are most pronounced (Chu and Chen 2005).[12] 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.

Rainfall in Hawai'i is characterized by steep spatial gradients (Giambelluca, Nullet et al. 1986). Precipitation in Wailupe Watershed is highly variable with a mean annual rainfall of 78 inches at the higher elevations to about 31 inches at the stream mouth (see Figure 10). Rainfall from trade wind showers is tempered since the watershed is located on the leeward side of the Koola'u mountains. About half the total surface area of the watershed, from its mid elevation to the crest of the Ko'olau *pali*, receives 59 to 78 inches annually. However, year to year rainfall averages for any part of the watershed can vary significantly. Rainfall data used to characterize rainfall amounts in Wailupe Watershed were collected at weather station 723.6 located at Wailupe Valley School for the period of 1977 to 2009. The school is located at an elevation of approximately 140 feet msl at a distance of 1 mile from the shoreline of Maunalua Bay. On March 27, 2010 Sustainable Resources Group Intn'l, Inc. personnel assisted Mālama Maunalua with the installation of two event-based rain gages in Wailupe Watershed. One gage was installed at head of valley and just makai of Ko'olau ridgeline. The second. gage was installed along the Ewa-side ridgeline upslope from the Wiliwilinui neighborhood.

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[11] *Pali* refers to a steep precipice or cliff and is commonly used to describe these features.

[12] *Orographic*. Of or pertaining to the effects of mountains on weather.

Evaporation in Hawai‘i is affected by the three primary controls that govern rainfall: the marine position of the major Hawaiian islands, the PSA, and the high mountains (Lau and Mink 2006). Trade winds and temperature inversion are two principal features of the PSA and their interaction with the high mountains accounts for the spatial variation of the evaporation climate. As trade winds move onshore in windward areas, the orographic cloud reduces radiation and evaporation beneath the cloud becomes nearly constant throughout the year.

Temperatures on O‘ahu are mild and generally range from a daily mean minimum of 65° Fahrenheit (F) to a maximum of 89° F, the warmest temperatures occurring in August and September (WMO 2009).

2.2.4 Hydrology

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

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 groundwater, 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 hydrological 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). 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 can affect all of the pathways, and in many cases the alterations results in adverse impacts to the ecosystem.

Watershed Hydrology

Hawai‘i streams tend to be naturally flashy, meaning they rise and fall quickly during and following rainfall due to their small steep watersheds and associated intense rainfall rates. Urbanization and land use changes that alter the surface further enhance the natural flashiness of stream runoff. Wailupe Stream is no exception. 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.[13] Under either situation, when the volume of water delivered to the stream is sufficient to maintain conditions of continuous water in the channel, the

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

stream is classified as perennial. When the water is intermittent the stream is classified as intermittent, and when the channel flows only following rain it is classified as ephemeral.

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. Since the surface water regime in Wailipe Watershed's urban area, and to a lesser degree in the conservation uplands, has been altered, there is likely more surface runoff and less infiltration during and following storm events than historic values. The reduction of water infiltrating into the ground during rain events reduces the volume of water that returns to the stream following storms. As a result, it is possible that baseflow values in Wailupe Stream are lower now than in the past. 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. Under natural conditions the volume of runoff is attenuated and the contaminants contained in it remediated along the flow path or sequestered on the watershed. Ground water recharge rates and subsequently stream baseflow have likely decreased across the urban area of the watershed due to extensive covering of the land with impervious surfaces.

Wailupe Stream Hydrology

Wailupe Stream has been classified as intermittent and perennial in various reports. Along its entire flow length, Wailupe Stream is the only unhardened, semi-natural stream in the Maunalua region.

Sections of the stream beginning 1,500 feet upstream of Kalanianole Highway and extending upstream of a manmade debris basin located 8,380 feet above the highway were observed to be dry during several sites visits between February 2008 and October 2009. It is likely that in the upper most *mauka* stream reaches there are year round pockets of water in the channel, qualifying the channel as intermittent. It is unknown if the dry section of the stream flowed year round prior to urbanization of the watershed.

The USGS operated a crested stage stream gage immediately upstream of Ani Street Bridge for 47 years (1957 – 2004). This type of gage records the peak flow between site visits by a hydrologist, and is not used for continuous flow measurements. No evaluation can be made as to whether daily flows have been trending up or down during the period of record. Nor is it possible to evaluate how urbanization impacted peak flows at the gage location since there were no gage recordings made prior to development for comparison. In addition, the gage's location near Ani Street only accounts for drainage off a small portion of the urban area of the watershed. Most of the developed lands are adjacent to the stream below Ani Street towards the ocean.

The most extreme discharge during the period of record is a maximum discharge of 3,600 cfs on December 18, 1967. Discharge from this event caused severe flooding along both banks downstream of Kalanianaole Highway near the stream mouth, reportedly from the combination of overland sheet flow generated off areas adjacent to the highway and the overtopping of Wailupe Stream (USACE 1998). This discharge estimate does not include the contribution of flow generated from the urban area downstream of Ani Street or from the uplands adjacent to and upslope of the urban area and. As a result, the actual peak at the mouth of the stream was higher than the volume recorded at the gage.

The New Year's Storm of December 31, 1987 – January 1, 1988 caused the greatest concern with the stream's capacity to handle high flows and initiated the State Senate's request to assess the condition of the existing flood control systems in eastern O'ahu. This historic New Year's flood event has been analyzed extensively and was estimated to have precipitation totals exceeding 15 inches in 6 hours and 22 inches in 24 hours (Dracup, Cheng et al. 1991). These values exceed the estimated values for a 100-year event and are probably as much as would occur in a 200-year event.[14] Although no damages were reported for Wailupe's Aina Haina community, this storm caused extensive flood damage to areas in windward and leeward east O'ahu.

Wailupe Stream has an estimated maximum bankfull capacity of approximately 2,200 cfs just above the Kalanianaole Highway Bridge (USACE 1998).[15] This flow is equivalent to a 10-year storm event, which has a 10 percent chance of occurring on any day. Historical flooding to the Aina Haina community has generated concern among the valley's residents about the stream's capacity to handle large storm events, in particular a 100-year storm event. Under hydrologic model runs using existing watershed conditions, Wailupe Stream begins to overtop its banks upstream of Kalanianaole Highway, and the probable flood plains are those areas susceptible to stream overflow and ponding created by runoff from upslope portions that is backed up when it encounters the waters that overtopped the stream (USACE 1998). The 100-year return interval discharge for Wailupe Stream at the Kalanianaole Highway Bridge is estimated to be 5,750 cfs, which is 3,550 cfs more than the stream's estimated 2,200 cfs capacity (USACE 1998).

Impacts of Urbanization on Wailupe Watershed Hydrology

During urbanization nearly half the land surface (43%) of Wailupe Watershed within the urban area was covered by impervious surfaces (e.g., paved roads, parking lots, and roofs) that prevent rainfall from infiltrating into the ground. Urbanization increases surface runoff and modifies its quality. Surface runoff flowing over impervious areas has a higher velocity then when flowing over surfaces covered in vegetation because impervious surfaces are smoother. This increase in velocity, along with the increase in runoff volume and the concentration of runoff into the MS4 system, results in a quicker time of concentration of flows from the watershed to Wailupe Stream and the ocean.[16] The end result is that peak flows increase and the transport of contaminants off the watershed accelerates. The degradation to this terrestrial system then results in adverse impacts to the receiving waters of Maunalua Bay.

Hydrologic studies conducted in both temperate and tropical watersheds show that the largest changes in runoff from urbanization are seen in the frequently occurring storms such as the two-year storms.[17] The changes in runoff were found to be smallest for the 100-year storms. These studies suggest that in Wailupe Watershed, the frequent tradewind showers and small winter rainfall events generate higher runoff volume carrying more pollutants than for a rainfall event of similar magnitude prior to urbanization. This is mainly due to the directly connected impervious areas (DCIA) in urbanized areas. DCIA are impermeable areas that drain directly to an improved drainage component such as a street, gutter, ditch or pipe that is part of the MS4 system. For example, a roof that drains into a gutter that drains

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[14] A 100-year storm is a storm with a one percent change of occurring on any given day. A 200-year storm has a half percent chance of occurring on any given day.

[15] Bankfull is a term used to describe when water in a channel begins to spill out of the channel and onto adjacent lands. For altered channels a more appropriate term is channel capacity flow.

[16] Time of concentration is the travel time it takes for water to flow from one location on the watershed to another. For design hydrology it is the time it takes for water falling on the furthest point in the watershed to reach the watershed's outlet.

[17] A two year storm is a storm with a 50 percent chance of occurring on any given day.

into a downspout that discharges onto a driveway that discharges water onto a street that runs down a curb into an inlet into a pipe and into Wailupe Stream is a DCIA. The smooth surfaces of these man-made features increase the velocity that water travels at from its point of concentration to its outlet. A reconnaissance survey of the Wailupe Watershed during preparation of this report confirmed the existence of DCIA across many of the neighborhoods. Contaminants on DCIA surfaces come from both human activity and natural sources, and when their concentration exceeds water quality standards they become pollutant loads. Most of the contaminants are simply by-products of daily human activities and are not thought of as pollutants or potential pollutants by most.

Changes to Hydrology of Upland Areas

Although the upland conservation areas in the Wailupe Watershed have not been urbanized, they have been adversely impacted by human activities. 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 vegetation does not function as well as native plants in controlling erosion and that it uses more water than its native counterparts. There are no definitive papers that support these hypotheses and research into the ecohydrology of Hawaiian watersheds continues.

Hoofed animals, both domestic and feral, have had adverse impacts on ground cover and soil physical condition by removing vegetation and trampling soil, causing reduced infiltration rates and increasing erosion rates. The extent of plant use from the Wailupe Watershed for wood products is unknown, but it is assumed that some harvest has occurred during human occupation of the area. A jeep trail runs along the crest of Wiliwilinui Ridge up to an elevation of 2,300 feet. There are several areas of mass wasting along this road, most likely induced by the road. These alterations have likely altered the runoff regime in the upper watershed to some degree with increased runoff and rates of erosion when compared to pre-disturbed conditions.

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 Aina Haina community the flood prone areas extend inland along Wailupe Stream. Flood hazard areas (which include tsunami inundation areas) are categorized by the probability of hazard, based upon surveys prepared by USACE. According to the FIRM, approximately 187 acres, or 20% of the 942 acre Urban District, are located with the 100-year floodway. These areas are designated by FIRM as Zone AE.[18] Figure 11 depicts the FIRM map flood zone classifications and Table 2 provides definitions.

Inquires were made to the USACE to obtain the status of current flood control efforts. To address land owners living within the floodway, USACE is continuing their evaluation of flood control treatments with the objective of reducing the lateral extent of the flood inundation. Public sentiment has identified bank erosion as a priority to be addressed, with an on-going request that measures to reduce erosion be included in USACE study objectives. Although the USACE has not investigated erosion reduction independent of storm-induced events (USACE 1998), they are exploring strategies to achieve flood control while at the same time enhancing, and at a minimum not degrading, ecosystem functions associated with the stream and ocean.

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[18] The flood insurance rate zone that corresponds to the 100-year floodplain is determined in the Flood Insurance Study by detailed methods. Mandatory flood insurance is required for land owners in this zone.

Table 2. Definitions of FIRM Flood Zone Designations[19]

ZONE	DESCRIPTION
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
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 instances, base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
B, X	Areas outside the 1-percent 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.
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.

2.2.5 Geomorphology

Geomorphology is a sub-discipline of geology that discusses the processes that shape the earth surface. Fluvial geomorphology refers to the subset of processes 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.[20] In general, 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.[21]

Wailupe Stream is approximately 19,650 feet long as measured along its main channel from its headwater down to the ocean. It has five distinct morphological reaches. The first reach begins in the upper headwaters of the Wailupe West sub-watershed and extends downstream approximately 6,000 feet. It is extremely steep with slopes reaching 35 percent, deeply incised, and strewn with large boulders creating a cascading channel. At the downstream end of the first reach the tributary Laulaupoe Stream drains Laulaupoe Gulch into the main channel. The second reach begins at this location and extends approximately 4,000 feet downstream, ending below the confluence with the Wailupe East Gulch Stream near the start of the urban area. This reach is morphologically similar to the first reach, though it is not as steep and the valley it flows through is less entrenched. The third reach extends from where the stream enters the urban area to approximately 1,200 feet downstream of the Ani Street Bridge, for a total distance of approximately 3,950 feet. Kulu‘i Stream drains Kulu‘i subwatershed and joins the main stem of

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

[20] 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.

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

Wailupe Stream upstream of the Ani Street bridge within the third reach. A distinguishing feature in this section is the uniformity of the channel geometry along long stretches, a result of channelization that occurred in the 1950s when the channel was straightened. The slope is significantly less than upstream reaches, however at approximately five percent, it is still a steep channel. In this reach the channel becomes more entrenched and its bank slopes are nearly vertical in several sections. The fourth reach extends for about 3,600 feet. It differs from the third reach with a wider channel and less steep banks. The fifth reach is about 1,400 feet long, has an average slope of 0.8% and is tidally influenced for most of its reach. Stream reaches 3 and 4 of the urban corridor appear to be net transporting sections, meaning that they move more sediment of all size classes out of their reach as compared to what is delivered into them. The sediment generated in these reaches is delivered downstream, and eventually deposits in the ocean.

Wailupe Stream was once a meandering water body and that several of its reaches were straightened during urbanization in the late 1950s (USACE 1998). Approximately two miles of the channel were modified during the 1950's. Modification included vegetation removal for channel realignment, an elevated culvert, and revetment (Timbol and Maciolek 1978). Banks were lined with concrete-rubble masonry walls below the debris basin for approximately 1,000 feet and also from Kalanianaole Highway to the mouth (USACE 1998). A review of historical photographs and maps depicting the stream shows a channel within the urban area that had some minor meanders, however the radius of curvature of these was quite small and it would not be accurate to classify the stream as once being a meandering water body. Sinuosity of a stream channel is the ratio of a channel's flow path to its straight-line length and is used as indicator of meandering. Based on the photographs, the sinuosity of Wailupe Stream prior to urbanization and channelization was estimated at 1.15 for the reach between Kulu'i Stream and the ocean. This same stream reach now has a sinuosity 1.05, indicating that the stream has been straightened to some degree and some of the small meander bands removed. Straightening a natural stream channel shortens the distance water must travel through a reach. This can have several effects including: an increase in stream velocity due to a reduction in surface area that water must flow over and the subsequent increase in stream energy that increases transport of sediments delivered to the channel, and erosion and adverse morphologic adjustments of the stream beds and banks. It is likely that the lower reaches of Wailupe Stream became more incised and less stable due to modifications made during urbanization to straighten it.

Wailupe Stream contains a debris basin that is located 1.5 miles upstream from the mouth of Wailupe Stream at the upstream end of the modified stream channel near the *mauka* end of Hao Street. The basin is used to trap coarse sediments debris and has a capacity of two acre-feet.

2.2.6 Soils

Figure 12 illustrates the soil series in the Wailupe Watershed as classified by the Natural Resources Conservation Service.[22] The upland conservation area of the watershed and along the steep valley walls to the east and west consists of rough mountainous (rRT) and rocky lands (rRK) where the parent soil material, basaltic lava still remains to be weathered. These upland soils are classified as having very severe erosion hazard. The soils of the valley floor are clays, silty clays, clay loams, stony clay loams and stony silty clay loams. The predominate soil types along the upper valley floor and stream is Lualualei (LPE) and Pamoa (PID), which are alluvial in nature and compromised of fine particles of clay (mean

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

diameter less than 0.002 mm) and silt (mean diameter 0.002– 0.05 mm) and larger particles of sand (mean diameter 0.05 mm – 2.00 mm diameter) and gravel (mean diameter greater than 2 mm diameter). Lualualei soils are described as well drained; slow to rapid runoff, depending on slope; with slow permeability, while Pamoa soils are considered well drained; medium runoff; moderate permeability to depths of 40 inches and moderately slow below.

Closer to the stream mouth and entrance to the bay the soil turns to Waialua (WKA) and Honouliuli (HxA) both of which are fertile alluvial soils found in the lowlands of Oʻahu that are very fine and halloysitic nature.[23] Both are characterized as well drained, slow to medium runoff with moderately slow permeability. Clay soils contain very small void spaces, which retain moisture for long periods using capillary action and chemical bonds. These small voids are 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.

2.2.7 Biotic Environment

The USFWS and DAR biological surveys both concluded that Wailupe Watershed and its streams have the ability to support abundant terrestrial and aquatic life (USACE 1998; Parham, Higashi et al. 2008). Although Wailupe Stream has been highly altered and channelized, it has been identified as a habitat of concern (USACE 1998). A survey recorded the presence of native fish and plants particularly the native dragonfly (*Pantala flavenscens*) and the indigenous stream goby (*Awaous guamensis*), which was found using the lower portions of the stream as a migratory corridor for larvae and adult to travel from the ocean to the natural upstream pools. USFWS noted that because *A. guamensis* is present in low and declining numbers on Oʻahu, their habitat is important and should be conserved. Five types of native fish species were found to utilize this watershed, *Awaous guamensis, Eleotris sandwicensis, Kuhlia xenura, Mugil cephalus, Mugilogobius cavifrons*; as well as introduced species of amphibians (*Bufo marinus),* crustaceans (*Macrobrachium lar*), fish (*rchocentrus nigrofasciatus*, *Poecilia reticulate, Tilapia sp., unidentified poeciliidae*), reptiles (*Chrysemys sp.*), and snails (*Planorbid sp.*, *Pomacea sp*, *Tarebia granifera*, *Thiarid sp*). The full list of species identified can be found in the USFWS survey portion of the 1998 USACE Feasibility Report (USACE 1998).

Wailupe Watershed contains critical habitat for the largest remaining subpopulation of the Oʻahu endemic elepaio (*Chasiempis sandwichensis ibidis*), a small forest-dwelling bird that is federally listed as endangered (see Figure 13) (USEPA 2001). The State recognizes the upper elevations of Wailupe Watershed as a highly critical habitat for numerous native threatened and endangered plant species. Some of these species include *Bonamia menzeisii*, *Lobelia sp*., five types of *Cyanea sp.*, and *Tetraplasandra gymnocarpa*.

Invasive plant and feral animals in the upper conservation areas of Wailupe Watershed 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, Mira et al. 2008). In Hawaiʻi feral pig populations thrive, with the greatest densities typically existing within wet forest

[23] Halloysite is a 1:1 aluminosilicate clay mineral, a product of hydrothermal alteration or surface weathering of aluminosilicate minerals, such as feldspars.

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. Expansion 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 Wailupe Watershed, however pigs are known to frequent the area and pig damage can be readily observed. The strong correlation between alien 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). To date there are no efforts for ungulate control in Wailupe's preservation area with the exception of the upper reserve designation as State hunting grounds.

2.2.8 Waterbody Monitoring Data

Monitoring data, including water quality, flow and geometry are critical to characterizing the watershed. Without such data, it is difficult to evaluate the condition of the waterbodies in the watershed (USEPA 2008). The waterbody data gathered and evaluated for the watershed characterization includes past work conducted by USACE (e.g., Feasibility Report), DAR (watershed assessment), University of Hawai'i (Maunalua Bay discharge studies), and the USGS (Wailupe Gulch stream gage height and discharge) (USACE 1998; Parham 2008; Wolanski 2009; USGS 2009).

Water Quantity

A 1976 Survey Report and the 1998 Feasibility Report presented basic hydrologic characteristics of the lower reach of Wailupe Stream, as well as important findings and techniques to determine stream flow estimates for varying frequencies and the associated flood plains of the area (USACE 1976; USACE 1998). The primary difference between the two reports is the adopted stream flow amounts for their projected 100-year project design. The 1998 Feasibility Report flow amount used an additional 20 years of stream flow data collected by the USGS, used different flow routing methods (Kinemetic Wave and Muskingum-Cunge Routing), and applied expected probability adjustment. This characterization report uses USACE information from the 1998 qualitative analysis of the lower Wailupe Stream channel.

A USGS crest-stage stream gauge located at Latitude 21°17'33.4", Longitude 157°45'19.9", on right and left bank wingwalls downstream of the Ani Street bridge and one mile upstream of Kalanianaole Highway in Aina Haina, reports drainage of the Wailupe drainage area (USGS 2009). The period of record for this stream gage is from October 1957 to September 2004 and October 2007 to the present. The local USGS office that performs periodic manual field measurements to verify the accuracy of the time-series readings has rated the measurements as being predominantly "fair" to "poor", and occasionally "good".

Water Quality

A quantitative data set of water quality monitoring for Wailupe Stream is limited to the USGS stage-discharge gage (16247550) located at the East Hind Street Bridge that has been collecting 15 minute interval water flow (cubic feet per second) and peak flow sediment discharge data for Wailupe Gulch, starting from October 1, 2008 through to the present. Currently, data for total suspended solids, temperature, and dissolved oxygen is being collected from Wailupe Stream to provide data for use in part by the USACE.

2.3 Waterbody and Watershed Condition

There are various designations and classifications for waters in the Wailupe Watershed. Some of these offer protections to water resources while others rank the area to support needed action. Under CWA Section 303(d), the EPA requires that each state develop a list of waters that fail to meet established water quality standards. The existing Water Quality Management Plan for the State of Hawaiʻi (HAR Chapter 11-54) defines State standards for particular parameters for Hawaiʻi waters by both narrative and numerical criteria.[24]

Maunalua Bay

Marine waters in the project area are designated 'Class AA, open coastal waters' by the State of Hawaiʻi (DOH 2006). The objective of Class AA waters is: "…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" (DOH 2004). Maunalua Bay's flat reef and reef communities are protected under 'Class II' designation for which existing or planned harbors may be located within nearshore reef flats showing degraded habitats and only where feasible alternatives are lacking and upon written approval by the director, considering the environmental impact and public interest (DOH 2004). All flat reefs and reef communities around the State of Hawaiʻi are protected with the objective that no action shall be undertaken that would substantially risk damage, impairment, or alteration of the biological characteristics of the areas.

Maunalua Bay is considered an impaired open coastal waterbody on the CWA's Section 303(d) list of impaired waterbodies. Maunalua Bay first appeared on the 2002 list, and remained on the 2004 and current 2006 listing. Elevated levels of ammonium nitrogen, algal growth (chlorophyll-a), nitrate/nitrite, and total nitrogen were found in the bay, but it was assigned to be a low priority for Total Maximum Daily Load development by the State (DOH 2006).

Maunalua Bay is within the boundaries of waters delineated as a Whale Sanctuary that is part of the Hawaiian Islands Humpback Whale National Marine Sanctuary co-managed as a federal-state partnership by DLNR, the National Oceanic and Atmospheric Administration's (NOAA), National Ocean Service, and the Office of National Marine Sanctuaries. The bay also contains managed marine areas such as artificial reef and a larger area where bottomfish fishing is prohibited.

Wailupe Stream

Wailupe Stream is classified as State waters as this inland freshwater stream flows perennially (or intermittently depending on its location within the watershed). Standards for inland fresh water systems follow the regulations listed in the Water Quality Management Plan for the State (HAR Chapter 11-54) that assesses for basic criteria of which elevated levels above numeric toxic pollutant standards would be cause for listing. Intermittent and perennial streams are considered for the following specific water quality criteria: basic criteria (narrative 'free of' and numeric standards for toxic pollutants; HAR §11-54-4),

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[24] Details can be found at http://gen.doh.hawaii.gov/sites/har/AdmRules1/11-54.pdf.

inland recreational waters (HAR §11-54-8.a), water column (HAR §11-54-5.2.b), and stream bottom (HAR §11-54-5.2.b.2) (DOH 2006).

In a survey done by the USFWS between 1975-1976, Wailupe Stream was classified as 'Exploitive-Consumptive', meaning that it is a stream with moderate to low natural resources (environmental-biological) and/or water quality (those that are well exploited, modified or degraded) and is intended for water related recreational activities (Timbol and Maciolek 1978). The survey showed that streams containing altered sections had greater means and ranges in temperature, pH, and conductivity. It also showed that species diversity and numbers of native stream animals were lower in altered streams than in unaltered streams. The State of Hawaiʻi Water Quality Monitoring and Assessment Report does not currently list Wailupe Stream as an impaired waterbody (DOH 2006).

Wailupe Watershed

Wailupe Watershed is not listed as a priority watershed by the criteria outlined in EPA's *Watershed Restoration Action Strategies* (USEPA 1998). An assessment by 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, Higashi et al. 2008). For Wailupe Watershed, the decision ruling for historical ranking indicates that the watershed had not been determined to be of special quality in previously published reports. The DAR decision ruling to consider the biotic importance of streams utilized criteria including an evaluation of the presence of native species, diversity of insects, and the absence of Priority One (highly invasive) introduced species. DAR determined that Wailupe Stream did not meet the qualifying criteria to be considered of biotic importance. DAR did a second biotic ranking of Wailupe Stream taking into consideration native and introduced species. The Total Species Rating for Wailupe Stream is a three and the Total Biological Ranking for Wailupe's Stream is a three. When combined with the Total Watershed Rating (based on the combination of criteria that includes land cover, shallow water, stewardship, size, wetness, and reach diversity) and Total Biological Rating, the Overall Rating for Wailupe Watershed is a four. The Rating Strength for Wailupe Watershed, which represents an estimate of the overall study effort in the stream and is a combination of the number of studies, different reaches surveys, and the number of different survey types, is a four.

2.4 Pollutant Sources

2.4.1 Point Source and Non-Point Source Pollutants

Pollutants transported in storm water runoff in the Wailupe Watershed can be categorized as either point or non-point source (NPS) pollution. Point source pollutants are discharged directly into surface waters from a conveyance feature (e.g., pipe). These sources include municipal sewage treatment plants, combined sewer overflows, and storm sewers. NPS pollutants are derived from diffuse origins (e.g. streets, parking lots). Practically, MS4 outlets can be considered point discharges even though the sources of most of the pollutants contained within the runoff are diffuse and classified as non-point sources. Both point and NPS pollutants degrade water quality, place stressors on biotic organisms, and may render the water non-usable or unsafe to humans. Identification of point sources and storm water and erosion hot spots throughout a watershed assists in identifying locations for treatment or management prescriptions to correct or mitigate the generation and/or transport of pollutants. Effectively targeting NPS pollutants is a complex undertaking as a wide variety of underlying conditions may exist.

A primary objective of this project is to identify the types and sources of activities that generate NPS pollution to facilitate the development of targeted remedial actions aimed at reducing pollutant loads delivered to Maunalua Bay in storm water runoff. The rate at which NPS pollutants are generated and transported to water sources is greatly influenced by urban development and anthropogenic behaviors within a watershed. Urban land development makes up approximately 39% of Wailupe Watershed, while the other 61% of watershed coverage consists of undeveloped land and forest reserve. Terrigenous sediments have been identified as one of the most significant NPS pollutants degrading the water quality of Maunalua Bay (R. Richmond, pers. comm.).[25] Sediments carried in storm water runoff come from any surface in the watershed that is vulnerable to erosion including the bed and banks of Wailupe Stream and its tributaries. Since nearly half of the watershed's urban area is covered in impervious surfaces, and large portions of the pervious surface in the urban area are landscaped, it is postulated that the urban areas are not a significant source of fine sediments.

The Conservation District lands are mostly covered in vegetation, with plant densities varying from low on the *makai* slopes below Hawaii Loa and Wiliwilinui Ridges to moderately dense in the upper portions of the watershed. Feral pigs frequent the upper portions of the watershed, creating trails, wallows, removing vegetation, and generally degrading the landscape. The steep gulches that fall off the ridges lining the watershed are vulnerable to surficial erosion and mass wasting.[26] Several areas along the upper section of Wiliwilinui Ridge are exposed and show signs of active erosion and sliding. Although rates of erosion throughout the watershed have not been quantified, observations and knowledge of erosion processes suggest that most of the sediments derived from areas outside of the streams are generated off the Conservation District lands.

Sediments also come from the bed and banks of streams. The slopes and morphologies of the streams in the Wailupe Watershed are clear indicators that for most of their lengths the channels are eroding and are net transporters of fine sediments generated from within their channels and delivered to them from adjacent uplands.

Runoff generated from impervious surfaces in the urban zone transports a wide range of contaminants into the ocean (Table 3). Residential areas not only alter the surface hydrology, but are also significant sources of NPS pollutants (Schuler, Kumble et al. 1992). Common activities that generate these pollutants include: driving, changing automobile oil, normal wear of automobile brake pads and tires, automobile emissions, automobile fluid leaks, washing cars, gardening and lawn maintenance (including the use of pesticides and fertilizers, lawn mower use, discharge of leaves or cuttings into storm drain system), dirt from construction or landscaping activities, improper disposal of waste (including littering, pet waste, food-related, household chemicals, appliances), use of metal roofs and gutters, and discharge of chlorinated water (e.g. from pools or fountains).

A major factor of NPS pollutants associated with urban areas is the phenomena referred to as the 'first flush'. During dry periods, many impervious surfaces accumulate NPS pollutants generated by human activities or from atmospheric dry fall. The time between runoff-generating rainfall events is referred to as the accumulation phase. Runoff interrupting the accumulation phase generally transports 80 percent of the contaminants in the first five minutes of the runoff period. This first flush contains the highest

[25] Terrigenous refers to sediments derived from terrestrial sources.

[26] Mass wasting refers to down slope movement of earth (e.g. landslides, debris flows, sloughing, slumps).

concentration of contaminants, and the highest pollutant loads at its receiving waters (Scholze, Novotny et al. 1993). Similar to the first flush associated with NPS pollutants from urban areas, the first storm event that generates overland flow following periods of relatively little rainfall in the Koʻolau Range appears to transport the highest sediment loads. Wolanski (2009) found that much of the fine sediment from the watersheds is discharged into the Maunalua Bay during the first flush at the rising stage of floods. For both situations it can be stated with confidence that NPS pollutant concentrations are inversely proportional to the frequency of runoff events.

Table 3. Major Categories of Stormwater Pollutants, Sources and Related Impacts[27]

Stormwater Pollutant	Major Sources	Related Impacts
Nutrients: Nitrogen, Phosphorus	Urban runoff; failing septic systems; croplands; nurseries; orchards; livestock operations: gardens; lawns; woodlands; fertilizers; construction soil losses	Algal growth; reduced clarity; lower dissolved oxygen; release of other pollutants; visual impairment; recreational impacts; water supply impairment
Solids: Sediment (clean and contaminated)	Construction sites; other disturbed and/or non- vegetated lands; urban runoff; mining operations; 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; shellfish processing waste; milk solids; other food processing wastes; antifreeze; 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; failing septic systems; landfills; illegal cross-connections to sanitary sewers; 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	Industrial processes; mining operations; normal wear of automobile brake pads and tires; automobile emissions; automobile fluid leaks; metal roofs; gutters; landfills; corrosion; urban runoff; soil erosion; atmospheric deposition; contaminated soils	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.); industrial processes; nurseries; orchards; lawns; gardens; historically	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; mining operations; landfills; road salting and uncovered salt storage	Toxicity of water column and sediment

[27] Excerpted from Field et al. (2004).

2.4.2 Storm Water Rules and Wailupe Watershed's MS4 System

MS4 Regulatory Information

As authorized by the CWA, the Federal Water Pollution Control Act of 1972 created a system for permitting wastewater discharges (Section 402), known as the National Pollutant Discharge Elimination System (NPDES). In 1987, Congress added Section 402(p) to the CWA, requiring the regulation of storm water discharges. The NPDES permit program controls water pollution by regulating point sources that discharge pollutants into the ocean and other bodies of water. Point sources are discrete conveyances such as the MS4 in urbanized areas. The State of Hawai‘i is the NPDES Permitting Authority for all regulated discharges in Hawai‘i. On February 28, 2006, NPDES Permit No. HI S000002 was issued by the Hawai‘i Department of Health (DOH) to the City and County of Honolulu. The effective date is March 31, 2006 for a five-year period ending midnight, September 8, 2009.

The type of permit required for storm water point sources is the *general permit*. The process for developing and issuing general permits includes deriving water-quality based discharge limits. The permit requires compliance with standard NPDES permit conditions as determined by DOH. Permit requirements for regulated MS4s include the development, implementation and enforcement of a SWMP that implements management practices to address the following minimum control measures:

1. Public education and outreach on storm water impacts;
2. Public involvement/participation;
3. Illicit discharge detection and elimination;
4. Construction site storm water runoff control;
5. Post-construction storm water management in new developments and redevelopments;
6. Pollution prevention/good housekeeping for municipal operations;
7. Industrial and commercial Activities Discharge Management Program

A separate NPDES permit (No. HI S000001) was issued to HIDOT to address storm runoff and certain non-storm water discharges identified in the permit from HIDOT's MS4 outfalls into State waters and waters of the United States on the Island of O‘ahu. HIDOT's NPDES permit covers the same standard condition as stated in CCH's permit. HIDOT's MS4 coverage in Wailupe Watershed includes storm drainage along Kalanianaole Hwy and its embankments.

Recently the EPA has focused on integrating the NPDES program with the concept of watershed planning. A watershed permitting program would allow for local leadership in conducting watershed planning and selecting appropriate management options to meet watershed goals and CWA requirements.

Wailupe MS4 System

An extensive MS4 system services the urban zones of Wailupe Watershed (see Figure 14). The primary objective of the MS4 system is to reduce and minimize the duration of ponding and inundation of runoff on low lying areas in the watershed by collecting and transporting runoff off the watershed into either Wailupe Stream or the ocean. The MS4 system is comprised of three basic elements: inlets that capture runoff from areas upslope of their inverts, conveyance pipes or ditches, and outlets or outfalls that discharge storm water into a receiving water body or into other natural drainage features (e.g. gulches or swales) that feed into the stream or ocean.[28] A MS4 system is designed in concert with development of a

[28] Invert refers to the bottom of or low point.

basin. Roadways and their utility easements provide locations for inlets and the alignment of pipes below ground or ditches and runoff gutters on the surface. Many of the storm water inlets in Wailupe Watershed are placed along the curbs and gutters of roads primarily because the streets generate significant runoff during rainfall events. Additional runoff from private residences and commercial properties onto public roadways and into the MS4 system is common. If there is no pervious area between different impervious surfaces a system referred to as 'directly connected impervious areas' is created.

Based on review of GIS maps, it appears that most MS4 features the Wailupe Watershed are located on land zoned Urban. The adjacent Conservation zone is not developed, and most of the drainage system does not contain civil works. However, the MS4 system servicing the urban portions of the watershed is linked to those lands classified as conservation where no formal MS4 system is located. Sections of the Aina Haina neighborhood are bounded along their east and west edges by two slopes that extend from their toes at the interface with the valley bottom and to the ridge crest upslope. Most of the areas on these slopes are steep, sparsely vegetated, and have gullies and rills aligned from their crests to the slopes toes at the valley floor. The slopes located above the urban area of the Aina Haina neighborhood on the east side of Wailupe Valley between Hawaii Loa Ridge and the valley bottom have a total surface area of approximately 133 acres (USACE 1998). Storm water inlets have been placed at six locations at the base of the slope within natural drainage ways, along the urban-conservation zone interface. They are all connected to MS4 conveyance pipes; five of which are routed across the eastern half of the valley towards Wailupe Stream and one towards the ocean.

A similar situation occurs on the western side of the valley where slopes adjacent to the urban area cover an area of 158 acres. The interface of the urban and conservation zone is 7,000 feet long. A cut off ditch follows the contours of the land immediately upslope of the residential properties for approximately 2,000 feet of this length. This cut off ditch is used to intercept overland flow coming off the slope as either sheet flow or in one of three gulches. At two locations along this cut off ditch there are inlets that convey water directly into a conveyance pipe that runs across the eastern half of the valley and empties into the Wailupe Stream. Along the other 5,000 feet of the interface are six inlets that capture runoff generated from the slope. These inlets are fitted to conveyance pipes that empty into Wailupe Stream. So even though these slopes are not officially part of the MS4 system, the runoff generated from their surfaces following rainfall is routed into the MS4 at the urban interface and transported rapidly to Wailupe Stream or the ocean. Sediments contained in this runoff water from steep upland slopes are routed to the MS4. These slopes, which are steep and sparsely vegetated, erode and generate sediments at rates significantly higher than the urban area in the valley bottom and coastal plain. Prior to development, a portion of this runoff and associated sediments would have been deposited between the toe of the slope and Wailupe Stream as alluvial depositions.

Within the Aina Haina neighborhood there are 39 MS4 outfalls that discharge storm water runoff directly into Wailupe Stream between the ocean and a debris basin located 8,380 feet upstream of the stream mouth. Another three outfalls discharge into the stream upstream of the debris basin. The number of outfalls is significant for a watershed of this size and confirms that the MS4 system is extensive and rapidly drains the impervious areas of the basin as well as the steep slopes.

The Hawaii Loa neighborhood also has an MS4 system to drain storm water generated off its ridgeline development. The bottom half of this ridgeline neighborhood's storm water runoff is routed into a pipe aligned beneath Puuikena Drive, the primary access road that starts at Kalanianaole Highway. This pipe conveys flow to an outfall that appears to discharge into the ocean *makai* of the highway directly across from Puuikena Drive. The upper half of the neighborhood is fitted with four MS4 outfalls that discharge storm water runoff into two gulches that drain out into the Wailupe Watershed downslope. Discharge from two of the outfalls drops into an unnamed gulch that appears historically to be a tributary to Wailupe Stream and has subsequently been cut off by the Aina Haina residential development. This gulch is fitted at its mouth with an MS4 inlet that transports the water generated from the upslope areas to Wailupe Stream. The other two outfalls appear to discharge onto the top of the slope above Kulu‘i Gulch. None these four outfalls were visually inspected and it is unknown if there are energy dissipating devices to reduce kinetic energy and minimize erosion below the outfall on the steep slopes. It is unknown if the MS4 system of Hawaii Loa neighborhood is part of the CCH permitted MS4 system or if it is a private MS4 system permitted it to the managing entity of the parcel.

The Wiliwilinui Ridge neighborhood has an MS4 system that is part the CCH system. The lower half of this neighborhood’s MS4 system drains into areas outside of the Wailupe Watershed boundaries. The upper half drains water into the unnamed gulch that dissects the ridge on its east side and is located within Wailupe Watershed. The gulch conveys water to a storm water inlet on the *mauka* side of Kalanianaole Highway connected to a pipe and outfall that discharges into the ocean in the middle of Wailupe Beach Park. There are at least three outfalls that discharge water into the upper sections of the gulch, and it is unknown if they are fitted with devices to reduce energy and minimize erosion of the slopes or the gulch.

In addition to the outfalls described above, there are another ten outfalls that discharge storm water directly into the ocean along the land fronting the Wailupe Watershed at the ocean. Some of these outfalls appear to be connected to inlets located along Kalanianaole Highway, and others collect drainage off the residential properties and streets located between the highway and the ocean.

The MS4 systems are located in all areas in the urban footprint of Wailupe Watershed. Steep slopes adjacent to both sides of the Aina Haina neighborhood zoned conservation with no development are hydrologically connected to the MS4 system via inlets that collect overland flow generated of the slopes. The sediments contained in the runoff from these slopes are rapidly transported from the slopes to Wailupe Stream. The best available information regarding the MS4 system is that there are no management practices to reduce, sequester, or otherwise lessen the transport of sediments and other NPS pollutants transported in storm water runoff. The primary objective of the MS4 system is to prevent ponding and inundation of low lying areas in the developed areas of the watershed, and this is done without consideration to the adverse impacts that the system has on the geomorphology of Wailupe Stream and its and the ocean’s water quality.

3 Identification of Data Gaps and Future Priorities

Fine terrigenous sediments are the primary land-based pollutant causing significant adverse impacts to Maunalua Bay. Identification of the sediment sources can provide mangers with spatial locations to treat and remediate these sources. There is currently very little information and data available to develop a sediment budget analysis for Wailupe Watershed. A sediment budget would identify the relative loads of sediment delivered off of each sub basin within the larger Wailupe Watershed, and could be used to more accurately target areas for sediment remediation. There is one stream and suspended sediment sampler in the watershed. It is located upstream of the Ani Street Bridge on the main stem of Wailupe Stream and captures drainage from an area above it of 2.84 square miles. While this total area is a significant amount of the total watershed, it does not partition out the contributions of runoff and sediment load generated off each of the subwatersheds above the sampling station. In addition, there is no data available to estimate the loads contribute from runoff generated from the basin area below the sediment sampling station. Thus it is not possible to compute the total runoff volume and sediments loads transported out the mouth of Wailupe Stream, which is approximately 1.5 miles downstream of Ani Street sampling station. In addition there are no detailed cross sections or a longitudinal profile of the Wailupe Stream channel geometry, and thus no way to compute how much sediment is generated during runoff events along the stream course over time.

Other missing data is empirical data on the types and concentrations of other NPS pollutants generated off the watershed. There are no reliable data on the nutrient concentrations in the streams discharging into Maunalua Bay (Wolanski et al. 2009). Information used in this report to characterize the types of NPS pollutants that are generated from land use activities and natural process occurring in the watershed are derived from published literature that identify pollutant types associated with various activities and processes, and from limited empirical data in various reports. Even though there is a dearth of empirical data, a robust characterization of the Wailupe Watershed was possible due in part to available literature regarding land based pollutants, extensive GIS maps and data, and data from ground based surveys and interpretation of high resolution air images.

Information about the existing condition, stability, composition of bed and bank materials and substrate along Wailupe Stream is not currently available. This information is necessary in order to develop pollution control strategies to control in-channel erosion rates, reduce transport of non-point source pollutants, and enhance habitat and ecologic functions. To fill this gap we used information collected during Summer 2009 by contractors that conducted a stream inventory and reach assessment.

Sediment and debris runoff that quickly filled existing debris basins, blocked drainage channels, and diverted streams from their natural and man-made channels was the major cause of damage to residences and infrastructure during the New Years flood of 1987 (Dracup, Cheng et al. 1991). In 1998 USACE conducted a stream flood control study feasibility assessment. Their focus was to evaluate proposed alternatives to mitigate the probable impacts floods may have on the infrastructure within the Wailupe watershed. Some of the information in the study is relevant to this WBP, especially data pertaining to the hydrology and hydraulic characteristics in the watershed. USACE is currently conducting an Environmental Assessment (EA) for flood control alternatives pursuant to the National Environmental Policy Act. The EA is in a preliminary phase and exactly what alternatives are being assessed is unknown at this time. It is believed that at least one alternative includes lining the unlined sections of Wailupe Stream within the developed portion of the watershed. There are no design criteria for sediment and debris flows established by CCH. Data regarding sediment discharge from the debris basins and erosion rates from the slopes within the watershed above the residential areas, including a determination of what is being ‘caught’ in the runoff ditches are needed to understand practical considerations for the design and implementation of management practices.

Current rainfall data for Wailupe Watershed is characterized using the gage in the adjacent watershed of Niu Valley (NOAA HI06). Rainfall in Hawai‘i is typically characterized by steep spatial gradients (Giambelluca, Nullet et al. 1986), so even a network of rain gages is usually too sparse to reflect the full spatial variability at basin scale. Local rainfall data from the lower, middle and upper elevation locations in the watershed will help to predict and characterize potential flooding hazards to the community. Development and implementation of a monitoring plan to increase the spatial resolution of the sampling network to measure both surface runoff and NPS pollutants would provide information to help refine selection of areas for treatments to reduce pollutant loads and storm water runoff attenuation. An expanded sampling station could also be used as part of an effectiveness monitoring protocol to evaluate future treatments to be prescribed in the next phase of this report.

Appendix A. Figures

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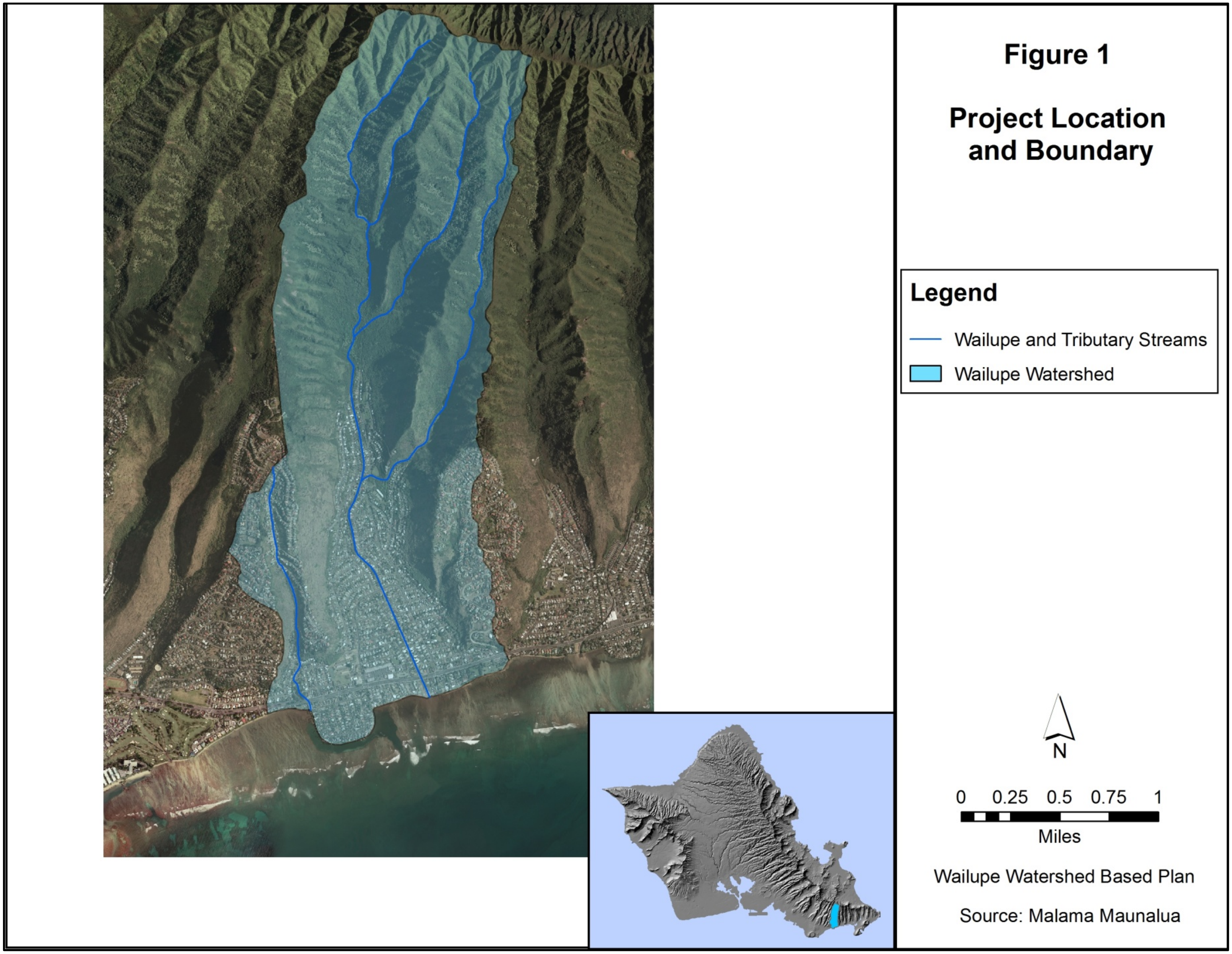


Figure 1
Project Location and Boundary
Legend
Wailupe and Tributary Streams
Wailupe Watershed
N
0 0.25 0.5 0.75 1
Miles
Wailupe Watershed Based Plan
Source: Malama Maunalua

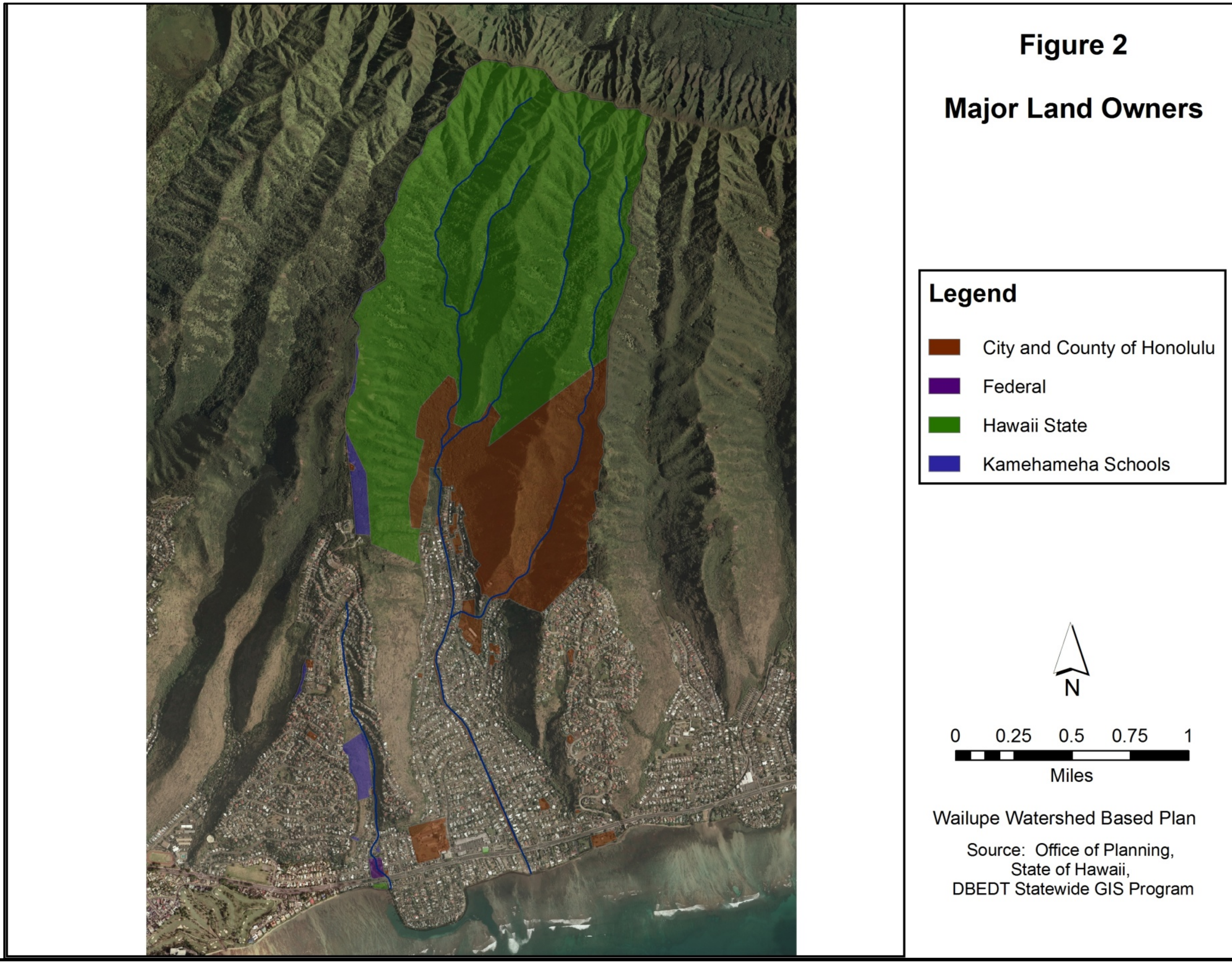
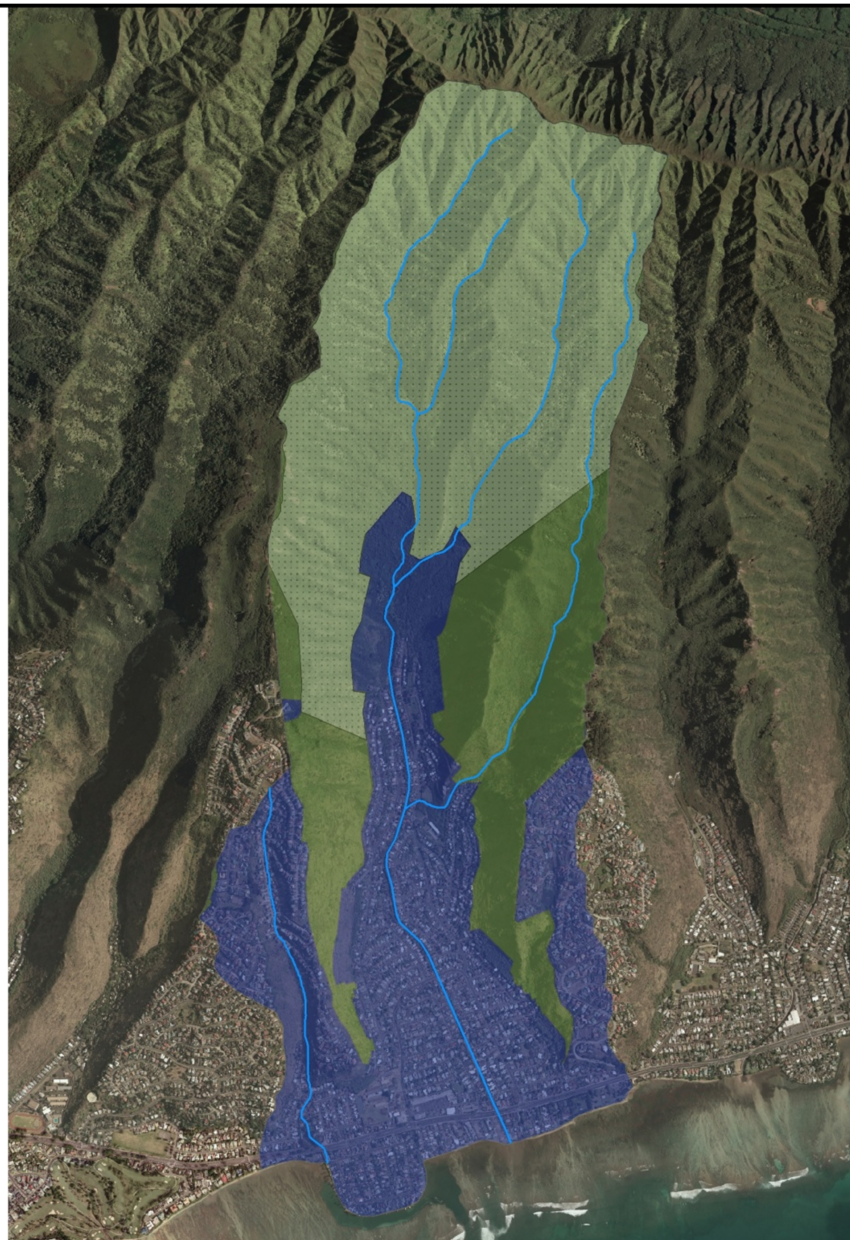


Figure 2

Major Land Owners

Figure 3

Hunting Areas



Legend

Hunting area

State Land Use Districts

Conservation

Urban

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

Source: Office of Planning,
State of Hawaii,
DBEDT Statewide GIS Program

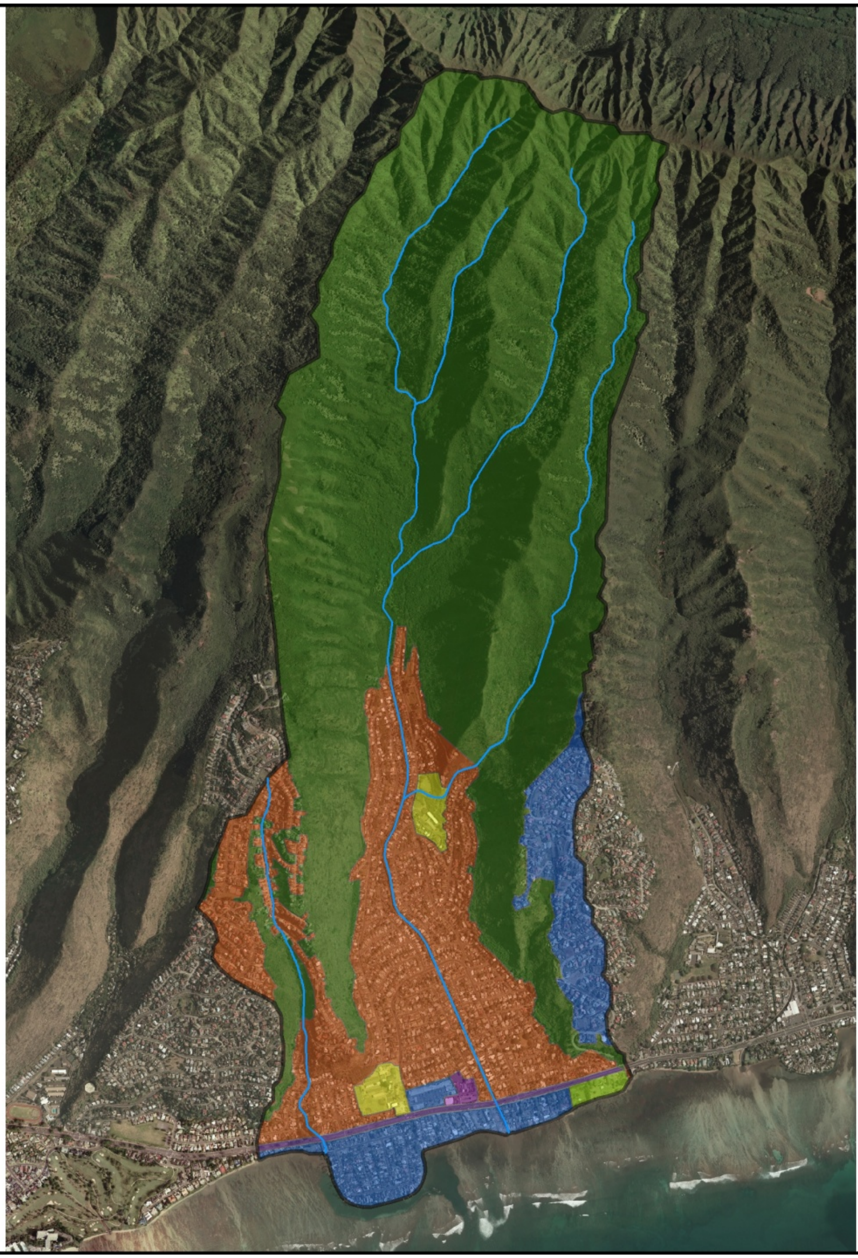


Figure 4

Land Use
USGS NAWQA

Legend

- Automotive
- Education
- Government
- High Density
- Maintained Vegetation
- Moderate Density
- Preservation

N

0 0.25 0.5 0.75 1
Miles

Wailupe Watershed Based Plan

Source: Leahy, P.P., Rosenshein, J.S., and Knopman, D.S., 1990, Implementation plan for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 90-174.

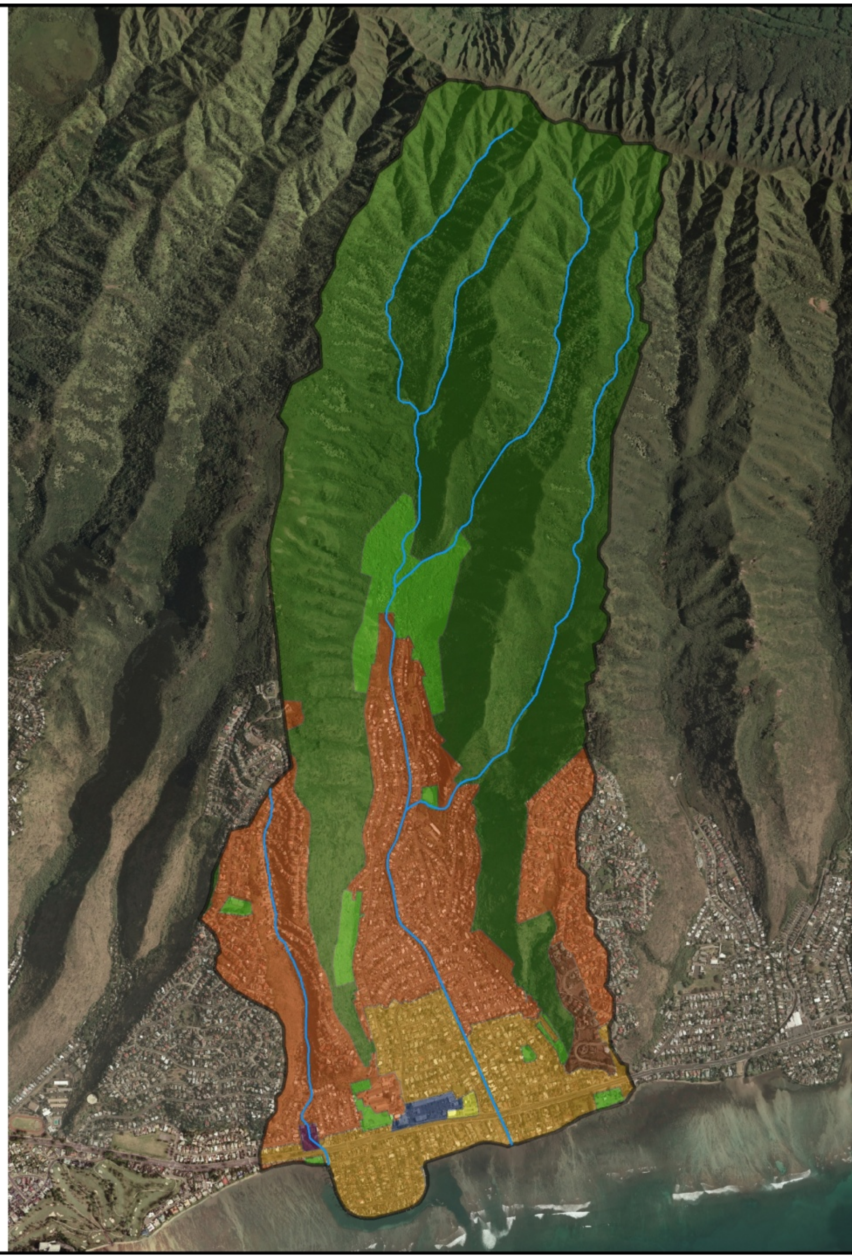


Figure 5

City and County of Honolulu Zone Descriptions

Legend

- B-1 Neighborhood Business
- F-1 Federal & Military Preservation
- P-1 Restricted Preservation
- P-2 General Preservation
- R-10 Residential
- R-20 Residential
- R-5 Residential
- R-7.5 Residential

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

Source: HoLIS. City and County of Honolulu, Planning and Permitting Department, State Land Use Boundary Amendment.

Figure 6

Impervious Surfaces

Legend

Impervious Surface

N

0 0.1 0.2 0.3 0.4

Miles

Wailupe Watershed Based Plan

Source: NOAA's Ocean Service, Coastal Services Center (CSC)

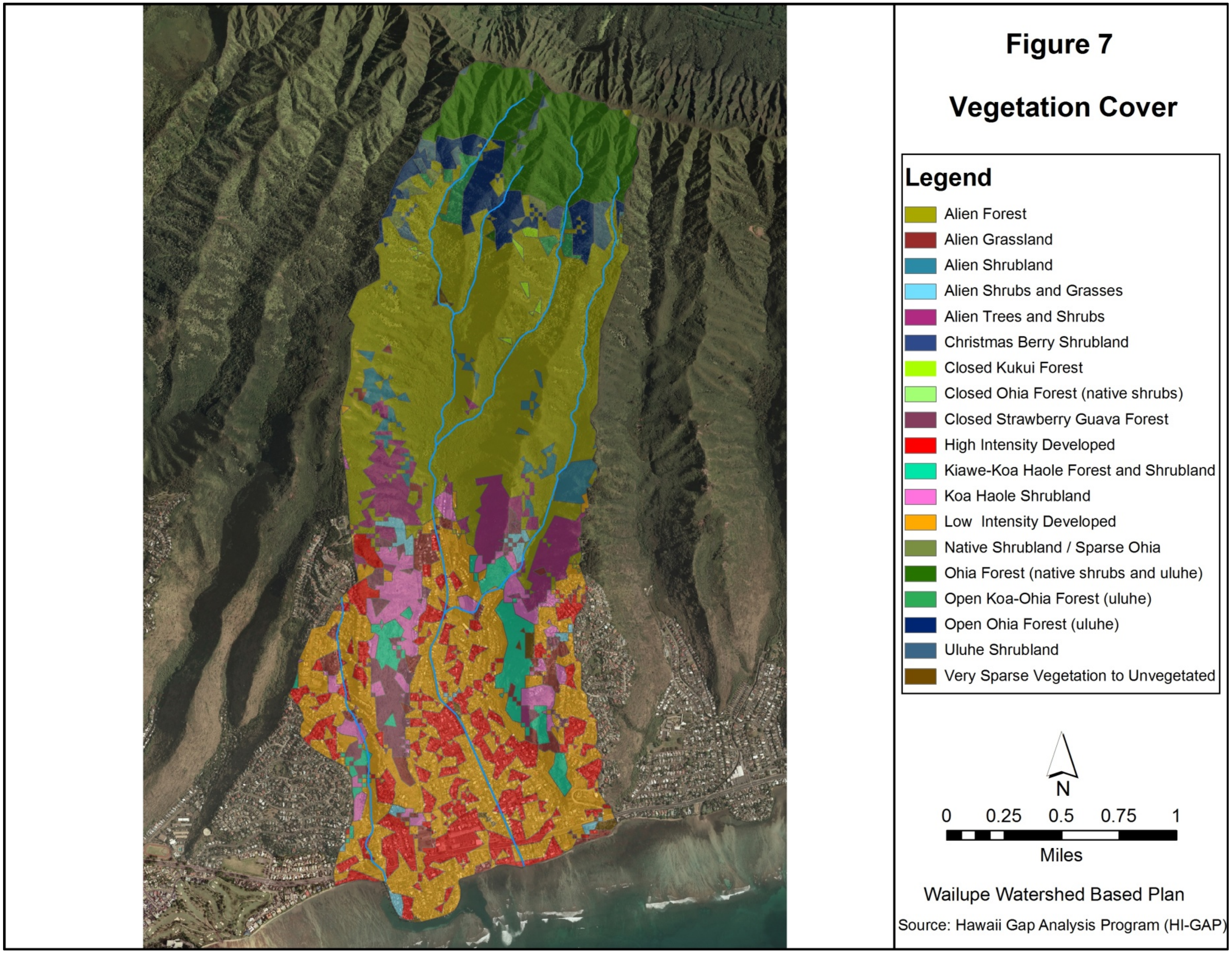


Figure 7
Vegetation Cover
Legend
Alien Forest
Alien Grassland
Alien Shrubland
Alien Shrubs and Grasses
Alien Trees and Shrubs
Christmas Berry Shrubland
Closed Kukui Forest
Closed Ohia Forest (native shrubs)
Closed Strawberry Guava Forest
High Intensity Developed
Kiawe-Koa Haole Forest and Shrubland
Koa Haole Shrubland
Low Intensity Developed
Native Shrubland / Sparse Ohia
Ohia Forest (native shrubs and uluhe)
Open Koa-Ohia Forest (uluhe)
Open Ohia Forest (uluhe)
Uluhe Shrubland
Very Sparse Vegetation to Unvegetated
N
0 0.25 0.5 0.75 1
Miles
Wailupe Watershed Based Plan
Source: Hawaii Gap Analysis Program (HI-GAP)

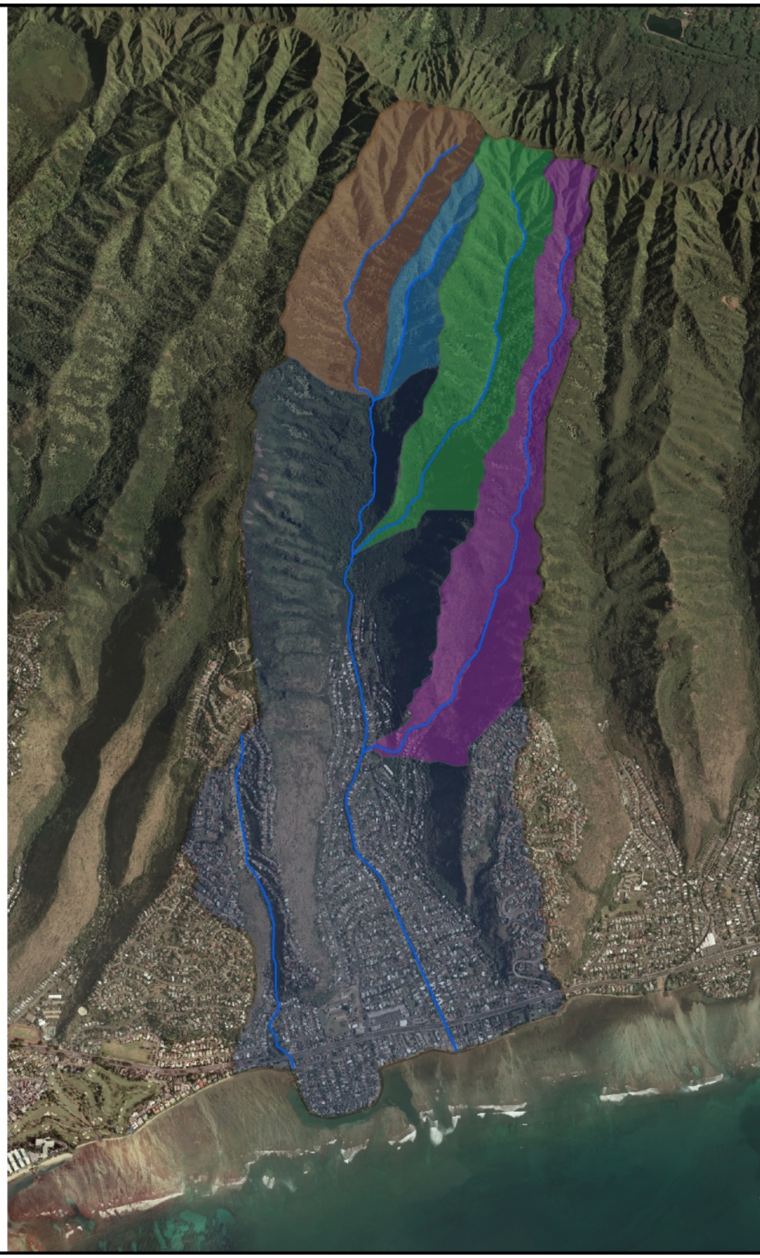


Figure 8

Upper Wailupe Sub-Watersheds

Legend

- Kului
- Laulaupoe
- Wailupe East
- Wailupe West

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

Source: SRGII

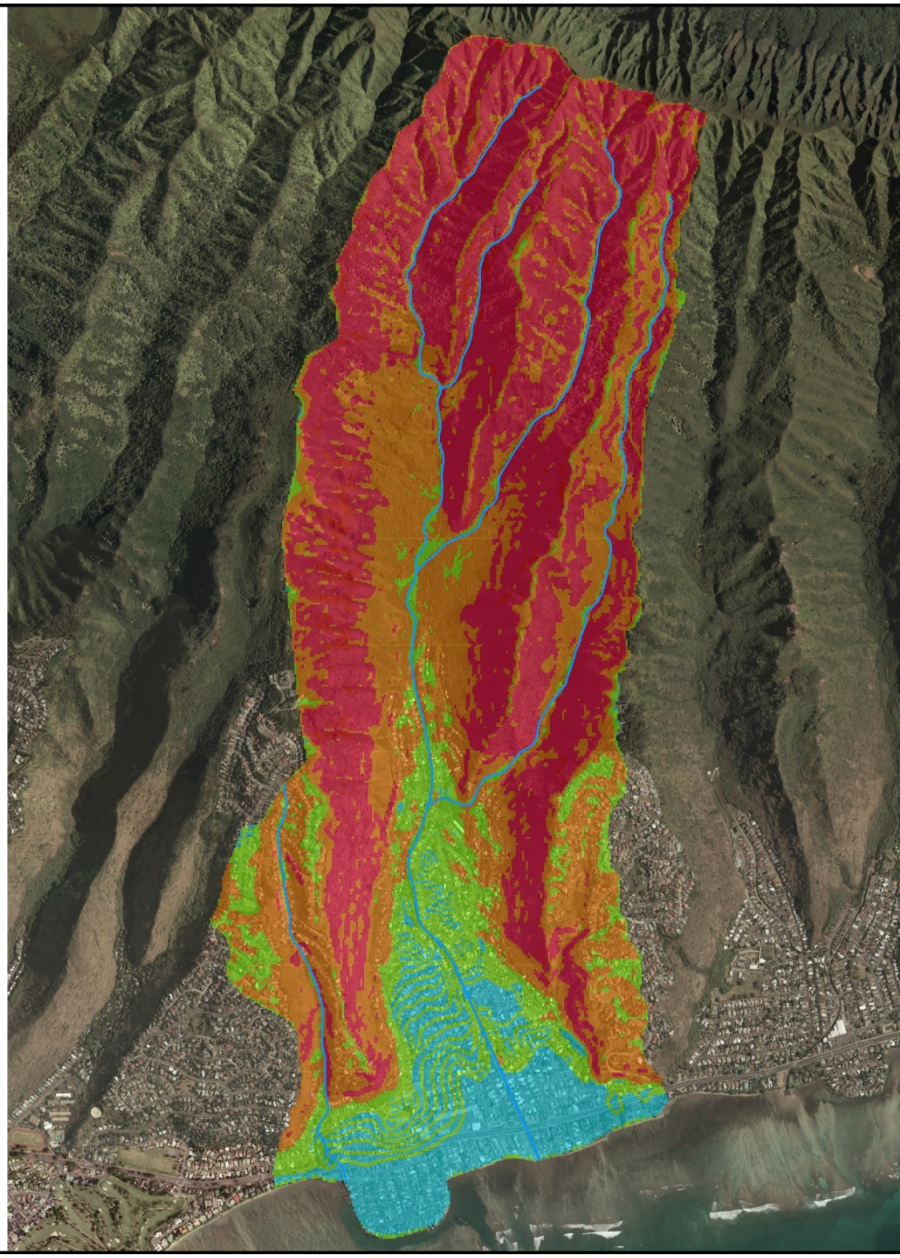


Figure 9

Topography

Legend

Slope (percent value)

- 0 - 2
- 3 - 10
- 11 - 30
- 31 - 50
- 51 - 68

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

Source: SRGII

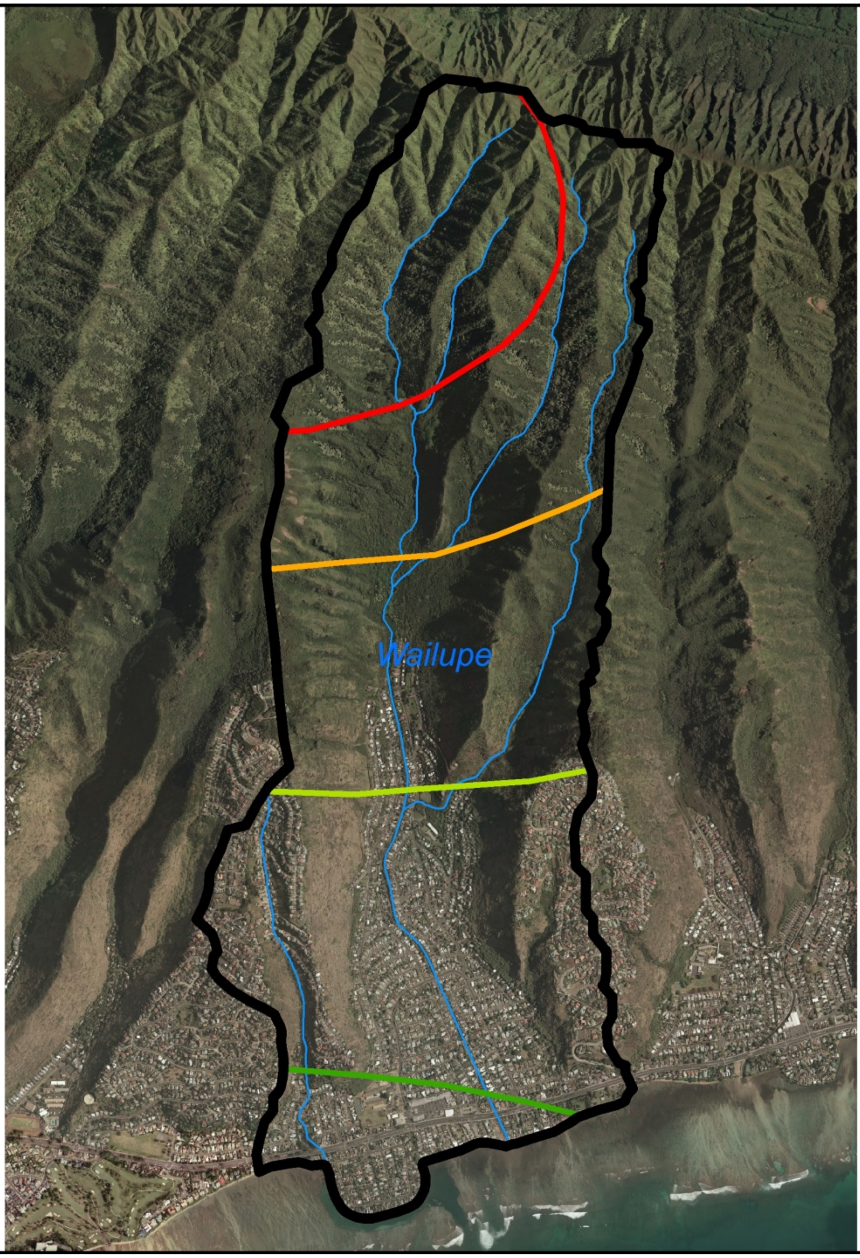


Figure 10

Rainfall

Legend

Median Annual Rainfall (in.)

- 32
- 39
- 59
- 79

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

Source: Giambelluca, T.W., Nullet, M.A., and Schroeder, T.A. 1986. Hawaii Rainfall Atlas, Report R76, Hawaii Division of Water and Land Development, Department of Land and Natural Resources, Honolulu. vi + 267 p.

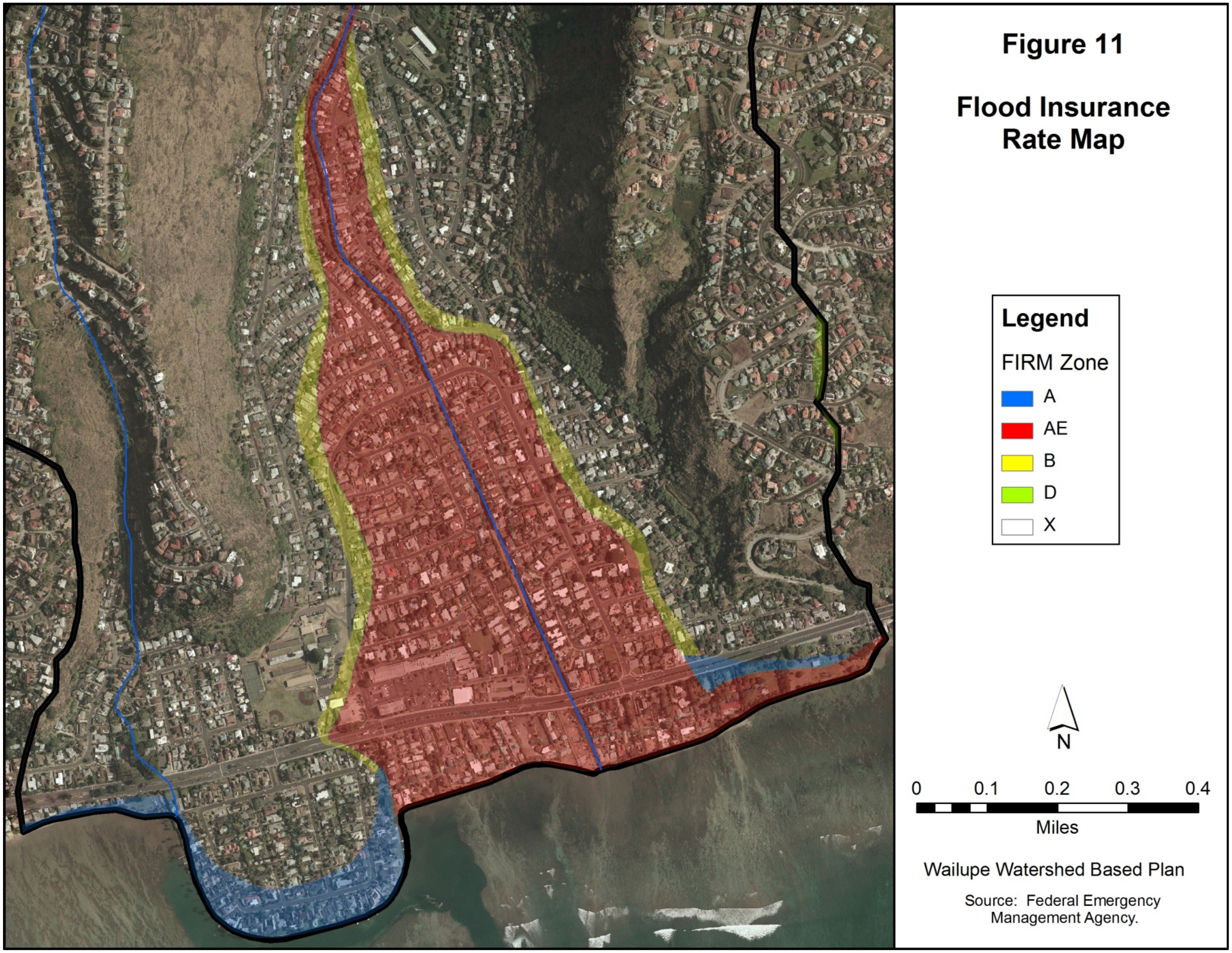
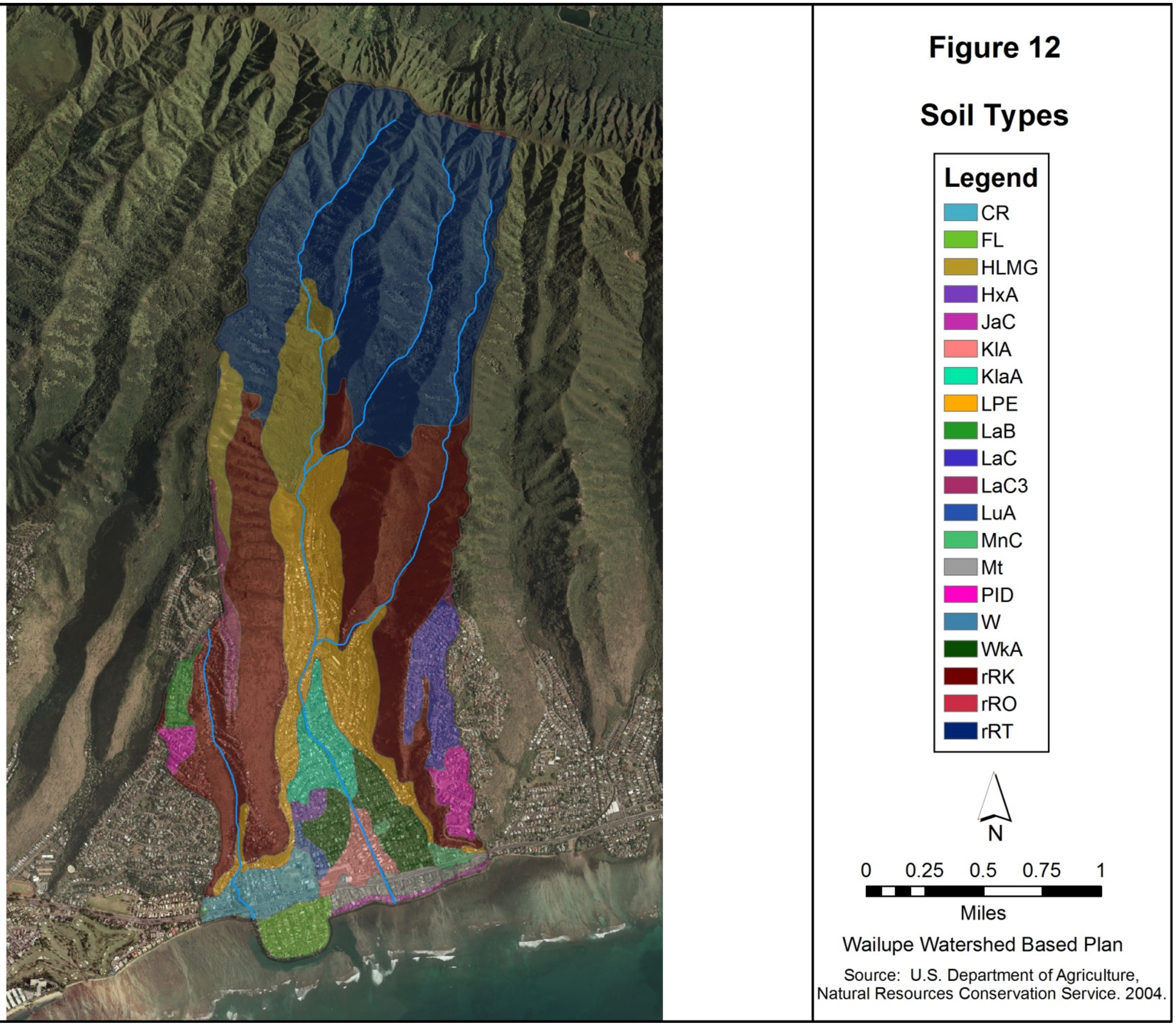


Figure 11
Flood Insurance Rate Map
Legend
FIRM Zone
A
AE
B
D
X
N
0
0.1
0.2
0.3
0.4
Miles
Wailupe Watershed Based Plan
Source: Federal Emergency Management Agency.

Figure 12

Soil Types



Wailupe Watershed Based Plan

Source: U.S. Department of Agriculture, Natural Resources Conservation Service. 2004.