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

Final Report

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Acronyms

CCH	City and County of Honolulu
CCH-DFM	City and County of Honolulu, Department of Facility Maintenance
CCH-ENV	City and County of Honolulu, 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
EDC	Every Drop Counts
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 NPS pollutant of concern. NPS pollutants, especially fine terrigenous sediments, adversely impact corals during all phase of their life cycle. At certain concentrations NPS pollutants, including petrochemicals and heavy metals, are known to be toxic to fish and corals and can induce physiologic impairment and mortality. NPS pollutants can also diminish recreational activities, create nuisance conditions, and impair aesthetic values. Control and reduction of NPS pollutant loads discharged into the bay is a necessary step towards restoring the health of Maunalua Bay.

Wailupe Watershed is drained by Wailupe Stream, the only non-hardened stream discharging into Maunalua Bay. The *Watershed Based Plan (WBP) for Reduction of Nonpoint Source Pollution in the Wailupe Stream Watershed, O‘ahu* (this document), was developed under a Hawai‘i State Department of Health CWA Section 319(h) grant to Mālama Maunalua. The WBP is comprised of five sections: *Watershed Characterization*, *Pollution Control Strategies*, *Implementation Strategies*, *Evaluation and Monitoring,* and *Education and Outreach*. 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* section summarizes the general environmental conditions of Wailupe 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 of 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 residents and business owners with property located within the floodplain of Wailupe Stream. The US Army Corps of Engineers (USACE) completed a flood feasibility assessment in December 1998 (Wailupe Stream Flood Control Study, Final Feasibility Report) that evaluated several management strategies focused on reducing flood risk to people and property within the stream’s floodway. However, after consideration of all economic, social, environmental, cultural, and engineering aspects, the study was terminated due to lack of net benefits. After receiving federal approval to conduct preconstruction, engineering and design activities, the USACE has been analyzing alternatives that would adequately reduce flood risks. With the recent concurrence of local sponsors, USACE is expanding the analysis to consider ecosystem restoration benefits, providing measures to enhance Wailupe Stream ecosystem 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 for prevention and treatment. 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, preventive and treatment controls. The term ‘management measure’ is used by EPA to include practices, actions, strategies, and plans. 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 responsibility for implementing these management practices often falls on landowners or permittees of the parcel where the practices will be installed, 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 identifies 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 highly erodible slopes. MS4 inlets along the base of the slopes on both sides of the ‘Āina Haina neighborhood capture sediment-laden runoff and rapidly convey it untreated 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 for installation of recommended management practices include parcels owned by the City and County of Honolulu, the State of Hawai‘i, and private entities.

The *Evaluation and Monitoring* section describes three types of monitoring necessary to track management measures: implementation, baseline and effectiveness. Baseline monitoring involves the collection of data and information to establish conditions prior to implementation of the recommended management measures. Implementation monitoring verifies that management practices have been installed and documents logistical aspects of the installation. Effectiveness monitoring evaluates the management measure to determine if it is working as designed. Baseline monitoring can transition into effectiveness monitoring after a management measure has been installed. This qualitative and quantitative information helps determine their effectiveness and apply the findings to other watersheds. The WBP identifies site-based monitoring for each of the recommended management practices. In addition, Mālama Maunalua has established a region-wide community-based monitoring component to help establish baseline conditions in watersheds and evaluate results of structural and nonstructural management practices that are implemented.

The *Education and Outreach* section provides details on Mālama Maunalua's current and planned activities to engage the local community in efforts to reduce NPS pollution. The activities are organized around four goals: building general public awareness about polluted runoff; building early community support for a holistic approach to planning and implementation of management measures and practices; engaging the community in order to promote participation in installation, monitoring and maintenance of projects; and increasing agency support for, and participation in, actions to reduce NPS pollution in Wailupe Watershed.

The Wailupe WBP provides a framework for addressing NPS pollutant control in Wailupe Watershed. Implementation of the recommendations 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.

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1. Watershed Characterization

The *Watershed Characterization* section 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 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]

1.1 Background

1.1.1 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 1-1). 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 its boundaries between the crest of the Ko‘olau mountains down to its outlets at the ocean. Wailupe Stream is the only one of these ten channels unhardened along its urban corridor reach, with the exception of the stretch between Kalaniana‘ole Highway and its mouth, where both banks are hardened with rock, mortar, and concrete. All major streams draining the other nine watersheds are channelized and hardened from the *mauka* end of the urban corridor to their mouths at the ocean. The upper undeveloped areas of the watersheds are dominated by steep slopes covered predominantly in non-native vegetation. Urban development occurs within each watershed from the shoreline of Maunalua Bay landward across the valley floors; and in some cases upon the ridges that divide the watersheds.

Hydrologic issues in Wailupe Watershed include the potential for flood damages and hazards to life and 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 transport the pollutants to ocean waters beyond the reef. Urban development has significantly changed

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

ground cover, created innumerable swaths of impervious surfaces, and channelized and hardened 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, inlets, 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 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 of water that infiltrates into the ground from rainfall. This, in turn, diminishes the capture and remediation of pollutants by microbes in the soils and from plant root uptake. The primary objective of the MS4 is to collect and rapidly move storm water off the watershed and into the receiving waters. The MS4 currently has no management practices in place to reduce or treat pollutants it transports in storm water runoff.[3]

1.1.2 Summary of Previous Reports and Information

Watershed and stream resources in Hawai‘i have been studied by a range of public and private entities including University of Hawai‘i researchers, State and Federal agencies (e.g., City and County of Honolulu’s Department of Environmental Services (CCH-ENV), Hawai‘i 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., Mālama Maunalua, Maunalua Fishpond Heritage Center). The type of work ranges 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. Hawai‘i’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 Hawai‘i Senate requested that the USACE complete an assessment of the condition and adequacy of East O‘ahu’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 ‘Āina Haina. The *Final Feasibility Report, Wailupe Stream Flood Control Study, O‘ahu, Hawai‘i* recommended nine flood reduction alternatives and project costs. Two alternatives, a large debris basin and lining the stream channel with concrete, were extensively detailed for a benefit-cost analysis (USACE 1998). The USACE feasibility study concluded that even the alternative with the highest benefit to 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 ‘Āina Haina.” The study was terminated. However, because

[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 in runoff volume; and decreases in 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.

of continued community concern for reducing flood risks, as well as concern expressed by local, State and Federal governments, the USACE received federal approval to conduct preconstruction, engineering and design activities to reduce flood risks 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 Hawaiʻi 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 Oʻahu MS4. Chapter Eight of the SWMP provides the scope for a retrofit feasibility study that would explore how to improve the quality of Oʻahu 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 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 an aquatic survey of Wailupe Stream with the objective of quantifying the distribution and abundance of organisms, both native and introduced, in the stream. This statewide database has attempted to collect historical biota information and methodically assign labels and rankings to features within Hawaii's watersheds.[4]

1.2 Regulatory Environment

Table 1-1 summarizes the multiple Federal, State and county agencies that have responsibility related to implementing activities related to controlling polluted runoff and maintaining water quality. Some of these entities have a role in promoting both regulatory and voluntary approaches. Implementation of management measures is most effectively done through economic incentives or by regulatory drivers. Regulatory approaches work best when adequate mechanisms are in place to provide oversight and enforcement. This section describes existing point source and NPS pollution control methods, including

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

adherence to the National Pollutant Discharge Elimination System (NPDES) permit program and other permit conditions.

1.2.1 Regulating Point Source Pollution

Historically, regulatory approaches focused on storm water management for the purpose of preventing property damage and the loss of life. With the enactment of the Clean Water Act (CWA) and its subsequent amendments, water quality controls were required for certain types of storm water runoff. Point sources are primarily controlled using regulatory approaches. Amendments to the CWA in 1972 (Section 402) introduced a permit system for regulating point sources of pollution and provided the statutory basis for the NPDES permit program for regulating the discharge of pollutants from point sources to waters of the U.S. In 1987, Congress added Section 402(p) to the CWA, requiring the regulation of storm water discharges. In 1990, Phase I of the NPDES storm water program was established, requiring a NPDES permit to discharge storm water runoff for large or medium municipalities that had populations of 100,000 or more. A ruling in 1999 expanded the NPDES program to apply to all urbanized MS4 and required the development of a storm Storm Water Management Program (SWMP) for storm water outfalls administered by the State. The NPDES permit program controls water pollution by regulating point sources that discharge pollutants into the ocean and other bodies of water. Point source pollutants have identifiable sources and discharge locations such as the outfall of a waste water treatment plant. The State of Hawaiʻi is the NPDES Permitting Authority for all regulated discharges in Hawaiʻi.

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

Hawaiʻi Department of Health (DOH) administers and approves NPDES permits in the State of Hawaiʻi. CCH and HIDOT, through their respective SWMP, are legally bound to implement the terms of the NPDES permit. In Wailupe Watershed both CCH and HIDOT hold NPDES permits. On February 28, 2006, NPDES Permit No. HI S000002 was issued by the Hawaiʻi Department of Health (DOH) to CCH. The effective date is March 31, 2006 for a five-year period ending midnight, September 8, 2009. The CCH permit covers most of the land within the urbanized section of the watershed and specifically addresses water discharge from CCH's MS4 into State waters. 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 Oʻahu. 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 Kalaniana'ole Hwy and its embankments.

Both permits mandate that discharges comply with the basic water quality criteria specified in Hawai'i Administrative Rules (HAR) Chapter 11-54-4, that pollutants be reduced to the maximum extent possible, and that the permittee take immediate action to stop, reduce, or modify the discharge of pollutants as needed to stop or prevent a violation. Pollutants include: floating debris, oil, grease, scum, or other floating materials; substances in amounts sufficient to produce turbidity or other conditions in receiving waters; substances or conditions or combination thereof in concentrations that produce undesirable aquatic life; and soil particles resulting from erosion on land involved in earthwork.

The CCH NPDES permit's Pollution Prevention/Good Housekeeping section requires the development and implementation of a system maintenance program. Under this plan, the Debris Control Program Plan includes a frequent scheduled sweeping of major streets and roadside litter pick up and includes a Chemical Application Program Plan to reduce the contribution of pollutants (i.e. pesticides, herbicides, and fertilizers) from municipal areas and activities. Suggested management practices include educational activities, non-chemical solutions, and use of native plantings. While the CCH NPDES permit provides direction for effective preventive measures, there are no provisions requiring management practices that could capture or treat pollutants in the MS4.

The HIDOT NPDES permit's Pollution Prevention/Good Housekeeping section (Part D-1-f) describes a Debris Control Program Plan that includes a street sweeping schedule. It also describes a maintenance schedule for catch basin cleaning and removal of green waste and accumulated soil. There are requirements to completely map HIDOT's storm drain structures and establish an asset management system to assist with appropriate maintenance scheduling. There are no requirements for management practices to address nutrient loads or other pollutants and toxins that are commonly found in the MS4 and/or can be attributed to vehicular transportation.

In both permits, Part D (Section f3) requires the implementation of erosion control measures in areas where there is potential for significant water quality impacts (i.e. evidence of rilling, gullying, and/or evidence of sediment transport). It is unclear if CCH and HIDOT are considering erosion from sources that are conveyed by their MS4s, or if the concern is focused on the outfall locations where the water from their pipes may be causing the erosion.

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.

1.2.2 Managing NPS Pollution

1.2.2.1 Federal and State Programs

The Federal Water Pollution Control Act [i.e. Clean Water Act] and Section 6217 of the Coastal Zone Act Reauthorization Amendments (CZARA) are the Federal laws that provide the principal guidance for NPS pollution control. The CWA addresses polluting activity in the nation's streams, lakes, and estuaries. In 1987 the CWA was amended to include Sections 305(b), 303(d), and 319, which require States to monitor water quality, identify waterbodies that do not meet water quality standards, and develop NPS pollution control programs. Under CWA Section 319, States may apply for Federal funds to pursue projects aimed at NPS pollution control. In 1990, while reauthorizing the Coastal Zone Management Act (CZMA), Congress enacted Section 6217 of CZARA entitled “Protecting Coastal Waters”. Section 6217 requires States with approved Coastal Zone Management (CZM) programs, including Hawaiʻi, to develop programs to implement NPS pollution controls. CZM programs have been developed pursuant to Federal requirements by States with coastal lands in order to manage their coastal and ocean resources. States with approved CZM Programs are eligible for Federal funds.

Section 305(b) of the CWA requires states to submit biennial reports to EPA on the condition of waters within their boundaries. Section 303(d) of the CWA requires states to identify water bodies with impaired water quality and the constituents that are impairing the water quality. Maunalua Bay is listed on the State of Hawaiʻi’s 303(d) list, and therefore any point discharge into the streams with outlets at the bay or the bay directly are required to comply with State of Hawaiʻi water quality standards. As part of the 303(d) the State is required to develop a Total Maximum Daily Load (TMDL) for each pollutant causing the impairment. The impairments for Maunalua Bay are: total nitrogen, nitrite-nitrate nitrogen, ammonium and chlorophyll a.[5]

At the Federal level, the CWA is administered by the EPA and the CZM Program is administered by the Office of Ocean and Coastal Resource Management, part of the National Oceanic and Atmospheric Administration. State and local government are responsible for the day-to-day implementation of programs designed to meet the requirements of the CWA and CZARA.

In Hawaiʻi, two programs exist specifically to implement polluted runoff controls. The Polluted Runoff Control Program[6] is administered by the DOH Environmental Management Division, Clean Water Branch. The Coastal Nonpoint Pollution Control Program is part of the State CZM Program and is administered jointly by the Hawaiʻi Department of Business, Economic Development and Tourism (DBEDT), Office of Planning and DOH Environmental Management Division, Clean Water Branch. These agencies work in coordination with other Federal, State and county agencies. DOH and the DBEDT maintain separate programs because they have different responsibilities and Federal funding sources, CWA Section 319 and CZARA Section 6217, respectively. To meet the program components required under Section 6217, the State developed *Hawaiʻi’s Coastal Nonpoint Pollution Control Program Management Plan* in 1996. In an effort to guide coordination between the DOH and CZM pollution control programs, the State established a single plan entitled *Hawaiʻi’s Implementation Plan for Polluted Runoff Control* (2000).

1.2.2.2 Voluntary Initiatives

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

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[5] Impaired constituents on 2006 303(d) list are available from DOH: http://hawaii.gov/health/environmental/env-planning/wqm/wqm.html/2006_Integrated_Report/2006_Chapter_IV_Assessment_of_Waters.pdf

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

Table 1-1. Agencies with Responsibility for Controlling Polluted Runoff and Maintaining Water Quality

Federal Agencies
U.S. Environmental Protection Agency (EPA) (Region 9) Responsible for providing clean and safe surface water, ground water, and drinking water and protecting and restoring aquatic ecosystems (Office of Water). Provides funding for Section 319 projects. For Hawai‘i, permitting activities have been delegated to the State.
USDA Natural Resources Conservation Service Provides technical assistance for conservation activities. Works closely with the 16 Soil and Water Conservation Districts (SWCD) in Hawai‘i. Provides permitting expertise and coordination with permitting agencies.
USDA Farm Services Agency Responsible for most of the Federal financial support regarding farming activities such as farm plans to reduce erosion or control animal impacts on water.
U.S. Army Corps of Engineers (USACE) Charged with protection of the Nation’s aquatic resources which is accomplished by: implementing the Nationwide Permits system for certain activities; regulating construction activities in navigable waters and dredging of harbors; regulating the discharge of fill material in wetlands and other U.S. waters; and conducting ecosystem restoration, flood damage reduction, water control projects and various water quality studies. Administers CWA Section 404.
U.S. Coast Guard Responsible for administration of a maritime protection program to prevent and control pollution in U.S. navigable waters. Enforces laws against individuals and companies that pollute marine waters.
State Agencies
DOH Clean Water Branch Responsible for enforcing and revising water quality standards. Water quality standards are maintained through monitoring and enforcement, sponsorship of polluted runoff control projects, review of permit issuance and public education. Administers Section 319 grants programs and NPDES permit process, regulates sewage treatment and disposal, hazardous waste and solid waste, and reviews and issues permits for industrial storm water discharge, construction storm water discharge, MS4 permits and NPDES.
DOH Environmental Planning Office Water Quality Management Program: Responsible for setting the State's water quality goals (Water Quality Standards), evaluating the progress in achieving these goals, and long-range planning to solve water quality problems. Planning Review Program: Reviews development projects with potential environmental impacts and coordinates departmental evaluations on mitigative measures. Implements environmental policies and standards at the earliest stages of the planning process for statewide project developments.
Department of Transportation Responsible for the developing and implementing strategies to control polluted runoff from transportation facilities (i.e. public highways and trails, airports, and commercial harbors). Authorized to enforce polluted runoff control mechanisms for commercial harbors, highways, roads and bridges, including through NPDES permits.
DBEDT Office of Planning Oversees the Hawai‘i CZM Program. This program guides appropriate land and water uses and activities through coordination of State and county agencies and ensuring compliance with laws, regulations and management policies, including the requirements of the CZMA. The CZM Program employs a variety of regulatory and non-regulatory techniques to address coastal issues and uphold environmental laws.

Department of Land and Natural Resources (DLNR) Manages State-owned terrestrial and submerged lands and regulates uses in the designated conservation districts. Administers the State's designated marine life conservation districts, marine and freshwater fisheries management areas, wildlife sanctuaries, and natural area reserves. Provides funding to the 16 local SWCDs through the Hawaiʻi Association of Conservation Districts.
DLNR Commission of Water Resource Management The Commission's staff is comprised of the Surveying, Planning, Ground-Water Regulation, and Stream Protection and Management Branches. Oversees the instream use protection program, which recommends appropriate interim and final instream flow standards. Issues permits for well construction, modification of existing well or pump installation, and alterations of stream channels and diversions.
DLNR Engineering Division Oversees the flood and dam safety program. Provides for the inspection and regulation of construction, enlargement, repair, alteration, maintenance, operation, and removal of dams or reservoirs to protect the health, safety, and welfare of the citizens of the State by reducing the risk of failure of the dams or reservoirs.
DLNR Division of Aquatic Resources Manages the state's aquatic resources and ecosystems through programs in commercial fisheries and resource enhancement; aquatic resources protection, habitat enhancement, and education; and recreational fisheries. Sets overall water conservation, quality and use policies; defines beneficial and reasonable uses; protects ground and surface water resources, watersheds and natural stream environments; establishes criteria for water use priorities while assuring appurtenant rights and existing correlative and riparian uses and establishes procedures for regulating all uses of Hawaiʻi's water resources.
Department of Agriculture Regulates activities to protect agricultural industries and natural resources against insects, diseases and pests. Controls all eradication services directed against weed and insect pests, and controls the sale and use of pesticides.
County Agencies
City and County of Honolulu Responsible for planning and zoning in urban districts, local transportation, solid waste disposal, subdivision and grading regulation, recreation, and water supply development. Manages state-mandated county regulatory programs dealing with erosion control, urban design, beach access, and park dedication. Legally bound, through the SWMP, to take action per the conditions of the NPDES permit.
CCH Department of Public Works Responsible for planning, designing, inspecting and managing construction projects, facilitating quality control, contracting, construction management, and equipping facilities and other improvements for State agencies. Each project untaken by the department requires consideration of erosion and sediment control, nutrient management and road construction/ reconstruction.
CCH Department of Environmental Services Issues permits and implements ordinances that address polluted runoff controls. Responsible for the collection and treatment of wastewater, storm water and green debris. Responsible for enforcement of illegal discharges and drain connections to the City's drain system, water quality monitoring and spill response and prevention. Administers the provisions of the City's NPDES storm water permit through the Storm Water Quality Branch.
CCH Department of Planning and Permitting Responsible for issuing and administering zoning and land use changes. Issues permits: building, clearing, stockpiling, grading, and construction dewatering. Issues private drain connection licenses to the MS4 and assesses the need for construction of permanent detention/retention and other engineering control structures in developments. Takes enforcement action against illegal grading or construction.

CCH Department of Design and Construction Manages authorized improvements to the City's public buildings, streets, roads, bridges and walkways, wastewater facilities, parks and recreational facilities, transportation systems, and drainage improvements and flood control. Provides technical assistance when needed.
CCH Department of Facility Maintenance Owns, operates, and maintains the MS4, which includes street sweeping, storm drain cleaning, roadside litter pickup, and maintenance of City-owned streams, channels, debris basins, and other structural practices.
CCH Department of Water Supply and the Board of Water Supply Manages municipal water resources and distribution system. Develops Watershed Management Plans that are used to meet the requirements of preparing a county water use and development plan under the State Water Code and City and County ordinances.

1.3 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 for Developing Watershed Plans to Restore and Protect Our Waters*, were used to document the watershed area and condition of Wailupe Watershed (USEPA 2008).[7]

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

1.3.1 Population and Land Use

1.3.1.1 Anthropogenic Impacts on Wailupe Watershed

There are approximately 67,000 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.

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 watershed boundaries we see today.

Early residents of the region engaged in fishing, gathering and subsistence agriculture. 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. Impacts to the hydrologic cycle in the Wailupe Watershed by Polynesian settlers were likely minimal. A second wave of human contact to the island was by peoples of European and Asian ancestry and began in the 1800s. These groups brought animals and resource extraction techniques that significantly altered vegetation

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

communities in the coastal zones and inland forest. During the 1900s the region supported cattle grazing, farming and commercial fishing. Prior to the early 1950s the Wailupe Watershed can best be characterized as rural and beyond the footprint of the Honolulu urban zone. Urban development began in the early 1950s across the Maunalua region, leading to the now suburban character. 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 since occurred on Wiliwilinui Ridge.

1.3.1.2 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 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 (Table 1-2; Figure 1-2). 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.[8] This area is also designated as a Public Hunting Area (Figure 1-3).

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 include general preservation (180 acres), road cover (105 acres), and Residential, Business, and Federal (657 acres). The zones in the urban district are managed under CCH ordinances. Each zone has regulations on the types of structures and land uses that can occur. 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 may be transitional 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 (Figure 1-4).

Table 1-2. Major Land Owners in Wailupe Watershed[9]

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

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

[9] Data derived from the Office of Planning, State of Hawai'i DBEDT GIS Program, 'Major Landowners'.

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 (Figure 1-5). The USGS classification system characterizes potential pollutant types and quantities derived from the four types and is not a jurisdictional or regulatory classification system.

1.3.1.3 Land Cover

The urban-suburban area of the lower valley floor has a high percentage of impervious surface (Figure 1-6). 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, roads and other impervious surfaces generate surface runoff following rainfall, including after short-duration low precipitation events. Wailupe’s urban zone consists of 43% impervious surface, or nearly 405 acres (NOAA 2007). The average area of a residential house lot is 0.26 acres and about half of that area on average is impervious.

The predominant vegetative cover in the upper watershed consists of invasive tree species with approximately 15% native vegetation including koa (*Acacia koa)* and ‘ohia (*Metrosideros polymorpha*) forest. Vegetation in the lower developed area consists mostly of invasive species including kiawe (*Prosopis pallida*), koa haole (*Leucaena leucocephala*), and strawberry guava (*Psidium cattleianum*) (Figure 1-7).

1.3.2 Physical and Natural Features

1.3.2.1 Watershed Boundaries

A watershed is a geographical area that shares a common location where surface water runoff concentrates or is drained to, e.g. the mouth of a stream. Watersheds boundaries are formed by topographic divides and within any size watershed, smaller subwatersheds can be delineated within the larger boundary. However in urbanized areas, 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 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 employs as a geographic unit of analysis the area delineated by Mālama Maunalua as Wailupe *āpana*[10], which includes associated nearshore waters of Maunalua Bay. An *āpana* has characteristics similar to the *ahupua‘a*[11] land management unit; and in this particular case, is larger than the natural watershed boundary and includes land that does not drain into Wailupe Stream.

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

[11] *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).

Wailupe Watershed can be divided into upper and lower sections.[12] The upper forested area is dissected by headwater streams and steep valley walls, while the lower section contains a highly developed valley floor and coastal lowlands. The residential neighborhood of ʻĀina Haina is located from the middle of the watershed to the shoreline on the valley floor and coastal lowland. Two other neighborhoods, Hawaiʻi Loa and Wiliwilinui, fall on the watershed's east and west ridges, respectively. Boundaries of 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 Kuluʻi (Figure 1-8) that share a common outlet for their tributaries to drain into Wailupe Stream. Wailupe Stream is the primary drainage channel within the larger Wailupe Watershed. 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.

1.3.2.2 Topography

Wailupe Watershed's topography is typical of many Hawaiian watersheds. Deep valleys have been cut by running water that destabilize the slopes by tearing away rock fragments, including local collapses, and debris remains in talus slopes or is carried downstream by floods (Lau and Mink 2006) (Figure 1-9). Elevations range from 2,600 feet msl at the crest of the *pali* to sea level, with an average elevation of 560 feet msl.[13] 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 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 ʻĀina Haina neighborhood, butts up against the toe and extends 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.

1.3.2.3 Climate

Ancient Hawaiians distinguished the annual precipitation cycle into two 6-month seasons: *kau* (May to October) and *hoʻoilo* (November to April) (Lau and Mink 2006). Modern analysis now divides the annual cycle in Hawaiʻi 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 PSA generates winds that blow from its base and travel from a northeasterly direction toward the island chain. These winds are referred to as 'trade winds'. During the summer season, when trade winds are most persistent, areas of maximum rainfall are generally located on windward slopes where orographic effects are most pronounced (Chu and Chen 2005).[14] 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.

[12] Discussions in this report that refer to 'Wailupe Watershed' are inclusive of the entire watershed.
[13] *Pali* refers to a steep precipice or cliff and is commonly used to describe these features.
[14] *Orographic*. Of or pertaining to the effects of mountains on weather.

Rainfall in Hawai‘i is characterized by steep spatial gradients (Giambelluca 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 (Figure 1-10). Rainfall from trade wind showers is tempered since the watershed is located on the leeward side of the Ko‘olau 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.[15] Average annual rainfall at station 723.6 is 34 inches. The school is located at an elevation of approximately 140 feet msl at a distance of one 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 the head of valley just *makai* of the Ko‘olau ridgeline. The second gage was installed along the Ewa-side ridgeline upslope from the Wiliwilinui neighborhood.

Evaporation in Hawai‘i is affected by the three primary controls that govern rainfall: the marine position of the major Hawaiian islands as a land mass surrounded by water in the subtropical latitudes; 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).

1.3.2.4 Hydrology

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

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). Groundwater that flows into streams is referred

[15] Weather station number is assigned by the National Weather Service.

to as baseflow. A portion of the total rainfall reaching the ground becomes surface runoff. Surface runoff occurs either when the rainfall rate exceeds a soil's infiltration rate (Hortonian overland flow) or when the soil is saturated and cannot absorb any additional water (saturated overland flow). The fate of water running over a watershed is of particular importance and plays a significant role in the transport of pollutants and formation of the landscape. Alterations to a watershed by people 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 intense rainfall rates. Urbanization and land use changes that alter the ground surface further enhance the natural flashiness of stream runoff. 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.[16] Under either situation, when the volume of water delivered to the stream is sufficient to maintain conditions of continuous water in the channel, the stream is classified as perennial. When the water 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. 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

Hydrologic data for Wailupe Stream are limited both in spatial extent of coverage and the period of time data have been compiled. Interpretation of the available data is based on a short period of record that does not allow for computing statistically significant inferences about the hydrologic regime. Along its entire flow length, Wailupe Stream is the only unhardened, semi-natural stream in the Maunalua region. It does appear, however, that the stream's alignment has been slightly straightened during urbanization, resulting in a finished geometry that has a relatively uniform channel along its flow path in the urban corridor. Wailupe Stream has been classified as intermittent and perennial in various reports; the disparity is likely the result of the location where the stream's flow was evaluated and the rainfall regime preceding field verification. Sections of the stream beginning 1,500 feet upstream of Kalaniana'ole 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 perennial pools of water in the channel, qualifying the channel as

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

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 using this gage data 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 only accounts for runoff generated 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 Kalaniana‘ole 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 flow generated off the urban area downstream of Ani Street or from the uplands adjacent to and upslope of the urban area that flows into the stream downstream of the gage. As a result, the actual peak at the mouth of the stream was higher than the volume recorded at the gage. The measured discharge of 3,600 cfs for this storm is nearly equal to the estimated 100 year flood of 3,750 cfs computed by the USACE. The USACE discusses this 1967 flood in their 1998 hydrologic feasibility report and states that the flood would have caused more damage if the channel had not been cleared just prior to the storm by the CCH maintenance crews.

The New Year's Storm of December 31, 1987 – January 1, 1988 caused the greatest concern about the stream's capacity to handle high flows and initiated a State Senate 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 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.[17] Although no damages were reported for Wailupe's ‘Āina 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 Kalaniana‘ole Highway Bridge (USACE 1998).[18] 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 ‘Āina 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 modeling using existing watershed conditions, Wailupe Stream begins to overtop its banks upstream of Kalaniana‘ole 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

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

[18] 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.

return interval discharge for Wailupe Stream at the Kalaniana‘ole 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).

In October 2008 the USGS fitted the Wailupe Stream gage with equipment to continuously record discharge. As discussed above, the approximately two year period of record is too short to generate statistically significant inferences. Going forward, the gage will provide data on trends of flows and can be used to assess the hydrologic relationship between rainfall and runoff for discrete storm events.

Impacts of Urbanization on Wailupe Watershed Hydrology

Due to urbanization, nearly half the land surface (43%) of Wailupe Watershed within the urban area has been covered by impervious surfaces (e.g., paved roads, parking lots, and roofs) that prevent rainfall from infiltrating into the ground. Reduced infiltration reduces the volume of water returned to the stream following storms. As a result, it is possible that baseflow values in Wailupe Stream are lower now than in the past. Urbanization increases surface runoff and reduces 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, results in a quicker time of concentration of flows from the watershed to Wailupe Stream and the ocean.[19] The end result is that peak flows increase and the transport of contaminants off the watershed accelerates, ultimately resulting 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.[20] The changes in runoff were found to be smallest for the 100-year storms. These studies suggest that in Wailupe Watershed, the frequent trade wind 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. For example, a roof that drains into a gutter that drains 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 by-products of daily human activities and are not considered as pollutants or potential pollutants by many people.

Changes to Hydrology of Upland Areas

Although the upland conservation areas in 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

[19] Time of concentration is the 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.

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

that non-native forest structure is less effective than a native system in controlling erosion rates. However, publications supporting this hypothesis were not found during a literature search. However, recent research has shown that non-native forest trees use more water compared to native trees, resulting in a decrease of ground water recharge and other alterations to the hydrologic cycle (Tom Giambelluca, pers. comm., 2010).

Hoofed animals, both domestic and feral, have had adverse impacts on ground cover and soil physical condition by removing vegetation and trampling soil, thereby causing reduced infiltration rates and increasing erosion rates. The extent of plant use from Wailupe Watershed for wood products is unknown, but it is assumed that some harvest 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 resulting in 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 ‘Āina 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 USACE surveys. 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.[21] Figure 1-11 depicts the FIRM map flood zone classifications and Table 1-3 provides definitions.

Table 1-3. Definitions of FIRM Flood Zone Designations[22]

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.

[21] 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.

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

Inquires were made to the USACE to obtain the status of current flood control efforts. To address threats to life and property within the floodway, USACE is evaluating flood management measures with the objective of reducing the lateral extent of the flood inundation. Public sentiment has identified bank erosion as a priority, 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), project managers are exploring strategies to reduce flood risk, while at the same time exploring ecosystem restoration measure to enhance, and at a minimum not degrade, ecosystem functions associated with the stream and nearshore environment.

1.3.2.5 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.[23] 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.[24]

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 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.

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[23] 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.

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

Wailupe Stream was once a meandering water body and several of its reaches were straightened during urbanization in the late 1950s (USACE 1998). Approximately two miles of the channel were modified during the 1950s. 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 Kalanianaʻole 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. 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 Kuluʻi 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, an 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.

1.3.2.6 Soils

Figure 1-12 illustrates the soil series in Wailupe Watershed as classified by the Natural Resources Conservation Service.[25] 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 composed of fine particles of clay (mean 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. Pamoa soils are considered well drained, medium runoff, with 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), fertile alluvial soils found in the lowlands of Oʻahu that are very fine and halloysitic nature.[26] 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

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

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

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.

1.3.2.7 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 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*. Other introduced species include: 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 (Figure 1-13) (USEPA 2001). The State of Hawaiʻi also 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 et al. 2008). In Hawaiʻi feral pig populations thrive, with the greatest densities typically existing within wet forest habitat due to the availability of food and water (Cuddihy and Stone 1990). In the 20th century pig population densities began to increase and the negative impacts associated with their presence were observed. Population growth resulted from an increase in area disturbed by humans and the expansion of non-native plants preferred by pigs, which in turn are spread by pig grazing and browsing (Cuddihy and Stone 1990). There are no known counts of pigs in the upper portion of 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.

1.3.2.8 Waterbody Monitoring Data

Monitoring data, including water quality, flow and geometry are critical to characterizing the watershed (see Section 4). 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 Hawaiʻi (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 the more recent 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 Kalanianaʻole Highway reports flows 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 by the USACE and others. An automated sediment sampler is co-located at the USGS stream gage and samples suspended sediment from the stream for flows above a minimum discharge threshold. The sampler has been collecting data for approximately two years and can be used to generalize suspended sediment load for the contributing watershed area.

1.3.3 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 Hawai'i waters by both narrative and numerical criteria.[27]

1.3.3.1 Maunalua Bay

Marine waters in the project area are designated 'Class AA, open coastal waters' by the State of Hawai'i (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 Hawai'i 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 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.

1.3.3.2 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), 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

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

unaltered streams. The State of Hawai‘i Water Quality Monitoring and Assessment Report does not currently list Wailupe Stream as an impaired waterbody (DOH 2006).

1.3.3.3 Wailupe Watershed

Wailupe Watershed is not listed as a priority watershed by the criteria outlined in EPA's *Watershed Restoration Action Strategies* (USEPA 1998). It has been designated as a priority site by the U.S. Coral Reef Taskforce, the Hawai‘i Coral Reef Initiative, and the State's Local Action Strategy to address key threats to coral reefs. CCH has chose Wailupe Watershed as a priority site for implementation of its green infrastructure pilot program for storm water management and pollution control. 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 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.

1.3.4 Pollutant Sources

1.3.4.1 Point Source and Non-Point Source Pollutants

Pollutants transported in storm water runoff in the Wailupe Watershed can be categorized as either point source 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 source 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. Urbanized area makes up approximately 39% of Wailupe Watershed, while the other

61% 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.).[28] 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 these areas are a lesser 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.[29] 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 Wailupe Watershed are clear indicators that for most of their lengths the channels are eroding and are net transporters of fine sediments that are both 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 1-4). Residential areas not only alter the surface hydrology, but are also significant sources of NPS pollutants (Schuler 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).

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

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

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

Table 1-4. Major Categories of Storm Water Pollutants, Sources and Related Impacts[30]

Storm Water 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	Toxicity of water column and sediment

1.3.4.2 Wailupe MS4

An extensive MS4 services the urban zones of Wailupe Watershed (Figure 1-14). The primary objective of the MS4 is to capture, route, and convey storm water runoff in order to reduce 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 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 feature (e.g. gulches or swales) that empties to a stream or ocean.[31] MS4 features are sized and installed in locations based on the hydrology of the basin they are installed in. Hydrologic calculations are used to generate estimates of the runoff volume for various return interval storms or rainfall events that will generate runoff and to identify the flows path the runoff will travel along. 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

[30] Excerpted from Field et al. (2004).
[31] Invert refers to the bottom elevation or lowest point of the feature.

private residences and commercial properties onto public roadways and into the MS4 is common. If there is no pervious area between different impervious surfaces a DCIA is created.

Most MS4 features in Wailupe Watershed are located on land zoned Urban. The adjacent Conservation zone is not developed and contains minimal civil works to convey runoff. However, the MS4 servicing the urban areas is linked hydrologically to the Conservation lands where no formal MS4 is located. For example, sections of the urban ʻĀina Haina neighborhood are bounded to the east and west by two slopes in Conservation that extend from the valley bottom to the ridge crest upslope. Most of 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 ʻĀina 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 conservation slopes adjacent to the urban area cover 158 acres. The interface of the urban and conservation zones 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 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, the runoff and associated sediments generated following rainfall is routed into the MS4 at the urban interface and transported rapidly to Wailupe Stream or directly to the ocean. 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 urban development, a portion of this runoff and associated sediments would have been captured between the toe of the slope and Wailupe Stream as alluvial depositions.

Within the ʻĀina 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. Another three outfalls discharge into the stream above the debris basin. The number of outfalls is significant for a watershed of this size and confirms that the MS4 is extensive and rapidly drains the impervious areas of the basin as well as the steep slopes.

The Hawaii Loa Ridge neighborhood also has an MS4 to drain storm water generated off its ridgeline development. The lower half of this neighborhood's storm water runoff is routed into a pipe aligned beneath Puʻuikena Drive, the primary access road that starts at Kalanianaʻole Highway. This pipe conveys flow to an outfall that appears to discharge into the ocean *makai* of the highway directly across from Puʻuikena Drive. The upper half of the neighborhood is fitted with four MS4 outfalls that discharge storm water runoff via two gulches into the Wailupe Watershed. 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 ʻĀina 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 Kuluʻi 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 of Hawaii Loa Ridge neighborhood is part of the CCH permitted MS4 or if it is a private MS4 permitted to the managing entity of the parcel.

The Wiliwilinui Ridge neighborhood's MS4 is part of the CCH system. The lower half of this MS4 drains into areas outside of the Wailupe Watershed boundaries. The upper half drains water into an 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 Kalanianaʻole 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 Wailupe Watershed at the ocean. Some of these outfalls appear to be connected to inlets located along Kalanianaʻole Highway,while others collect drainage off the residential properties and streets located between the highway and the ocean.

The MS4 is located in all areas of Wailupe Watershed's urban footprint. Steep slopes adjacent to both sides of the ʻĀina Haina neighborhood zoned conservation with no development are hydrologically connected to the MS4 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 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 or coastal water quality.

1.4 Identification of Data Gaps and Future Priorities

Fine terrigenous sediments are the primary land-based pollutant causing significant adverse impacts to Maunalua Bay. There is currently very little available information for developing a sediment budget analysis for Wailupe Watershed. A sediment budget would identify the relative loads of sediment delivered off each sub basin within the larger Wailupe Watershed, and could be used to more accurately target areas for sediment remediation.

There is one combined streamflow-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 2.84 square miles. While this area represents a significant portion of the total watershed, the gage does not partition out the contributions of runoff and sediment load from each of the subwatersheds above the sampling station. In addition, there is no data available to estimate the loads contributed from runoff generated from the area below the sediment sampling station. Thus it is not possible to compute the total runoff volume and sediment loads transported out the mouth of Wailupe Stream, which is approximately 1.5 miles downstream of the Ani Street sampling station. Further, 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.

Only minimal empirical data exists 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 in the watershed is derived from published literature that identify pollutant types associated with various activities and processes, and from limited empirical data in various reports. Nevertheless, a robust characterization of Wailupe Watershed was possible, due to available literature regarding land based pollutants, extensive GIS maps and data, data from ground based surveys, and interpretation of high resolution air images.

Detailed information about the composition, condition, and stability 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 reduce 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. This survey documented the location and extent of bank erosion and unstable sites along the Wailupe Stream channel.

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 also needed to understand practical considerations for the design and implementation of management practices. During the New Years flood of 1987 sediment and debris runoff that quickly filled existing debris basins, blocked drainage, and diverted streams from their channels was the major cause of damage to residences and infrastructure (Dracup et al. 1991). In 1998 USACE conducted a stream flood control study feasibility assessment for Wailupe Stream. This study evaluated proposed alternatives to mitigate the probable impacts of floods on the infrastructure within the 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 management alternatives pursuant to the National Environmental Policy Act. The EA is in a preliminary phase. CCH has not established design criteria for sediment and debris flows.

Current rainfall data for Wailupe Watershed is characterized using the single National Weather Service gage in the adjacent watershed of Niu Valley (NOAA HI06). Rainfall in Hawaiʻi is typically characterized by steep spatial gradients (Giambelluca et al. 1986), so a network of gages distributed at various elevations in a watershed is needed to accurately capture the spatial variability of rainfall. This is often difficult due to cost and access considerations. As a result, hydrologists make spatial inferences on rainfall using data from available gages and applying geo-statistical methods to estimate rainfall for the watershed. During 2010 several auto-logging rain gages were installed in Wailupe Watershed by Mālama Maunalua (see Section 4.1.4.3). These gages will assist in generating accurate estimates of rainfall over the watershed for both discrete storm events and for estimating rainfall for a variety of time steps, e.g. daily rainfall. Mālama Maunalua is also making home rain gages available free of charge to interested residents.

Development of a robust monitoring program to increase the spatial resolution of the water quality sampling network to measure both surface runoff and NPS pollutants would also provide needed information to help define areas for treatments to reduce pollutant loads and storm water runoff attenuation. Sampling multiple locations along Wailupe Stream and from various locations on the MS4 would provide data to refine where NPS pollutants are generated and routed over the watershed.

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2. Pollution Control Strategies

The objectives of this *Pollution Control Strategies* section are (1) to identify the types of and locations where NPS pollutants are generated and transported off the watershed into the receiving waters and (2) to identify management measures to reduce and when possible prevent NPS pollutant generation, or treat it before it reaches the receiving water body. The management measures are focused on addressing generation and delivery of land-based pollutants to the marine environment, with particular emphasis on fine terrigenous sediments that are having a significant adverse impact on the ecology of Maunalua Bay.

2.1 What are Management Measures?

Management measures are defined in Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 as economically achievable actions to control the addition of pollutants to coastal waters, which reflect the greatest degree of pollutant reduction achievable through the application of the best available NPS pollution control practices, technologies, processes, siting criteria, operating methods, or other alternatives. Simply, the term 'management measures' is used to describe practices, treatments, strategies, and plans to lessen generation and transport of NPS pollutants.

Management measures can be used to guide the implementation of a comprehensive NPS pollutant and runoff management program. In general, management measures are groups or categories of cost-effective management practices implemented to achieve a comprehensive goal, such as reducing NPS pollutant loads.[32] Some examples of management measures that can help control the delivery of pollutant loads to receiving waters are: reducing the availability of pollutants (reduce fertilizer applications), reducing pollutant generation (through erosion control), and treating pollutants before or after delivery to water (through biological transformation). Individual management practices are specific actions or structures that are often site-based that aid in the achievement of a management measure. Management measures and practices can be implemented for various purposes, such as:

- Protecting water resources and downstream areas from increased pollution and flood risks
- Conserving, protecting, and restoring Wailupe Stream's habitat
- Setting aside permanent terrestrial buffers for flow reduction and increased infiltration

EPA documents including *National Management Measures to Control Nonpoint Source Pollution from Urban Areas* (USEPA 2005) and the *National Management Measures to Control Nonpoint Source Pollution from Hydromodification* (USEPA 2007) are valuable resources for information on management measures. *Updated Management Measures for Hawaii's Coastal Nonpoint Pollution Control Program* (Stewart 2009) also includes a pollution prevention management measure for urban runoff that addresses a portion of the key outreach needs for residential applications

[32] This report will follow the lead of EPA and use the term management practice instead of the more familiar term best management practice. The word "best" has been dropped for the purpose of this report, as it was in the *Coastal Management Measures Guidance* (USEPA 1993) and *Hydromodification National Management Measures* (USEPA 2007) because the adjective is too subjective. A "best" practice in one region or situation might be entirely inappropriate in another region or situation.

Management measures identified for Wailupe Watershed are targeted for specific locations and types of NPS pollutants. There are numerous management measures that could be used, and ones not presented should not necessarily be excluded. A primary consideration when selecting management measures was to favor those that would address several types of NPS and/or attenuate generation of storm water runoff.

Management measures can be grouped into two major types: preventive and treatment control. Preventive measures focus on controlling or eliminating the pollutant at its source. From a watershed science perspective, preventive source control is usually the best way to address NPS pollutants. However, preventive measures are not always technically feasible or cost-effective, and it may take considerable time after they are installed for benefits to be realized. Or in some cases, a treatment control, which involves treating the NPS pollutant along its entire pollution stream[33] will be the most effective and therefore preferred means to reduce pollutant loads. Both types of controls can be achieved through hard and soft engineering practices. Hard engineering practices generally use structures made of concrete or synthetic materials, (e.g. storm water basins and hydrodynamic separators). Soft engineering practices, such as bioengineering, use vegetation and materials made from synthetic and natural fibers and designs based on ecologic practices. In many situations both hard and soft engineering practices are used to maximize the best elements of each approach. Selection of a specific practice is based on site conditions, the type of NPS pollutant or hydrologic condition it is remediating, and life expectancy of the design.

This section identifies practical measures to be implemented in Wailupe Watershed that are expected to reduce NPS pollutant delivery into Maunalua Bay. The recommended management practices address existing watershed impairments and/or features that generate and transport NPS pollutants in the watershed, but do not target new construction work. However, several of the management practices could be also incorporated into construction designs to attenuate NPS pollutants generated both during and after completion of new construction projects. In addition, this report is not intended to be a design manual for management practices or best management practices. Design considerations are included to guide policy discussions and present practical considerations to assist in deciding which measures to implement. Prior to implementation the recommended management practices will require additional detailed design work based on the complexity of the measure, site physiographic conditions, and land ownership and regulatory considerations. Strategies for implementing the range of management practices are discussed in Section 0.

2.2 Delineating Management Units

Four management units are delineated for the Wailupe Watershed. These are based primarily on dominant land use, and to a lesser extent on land type and ownership (Table 2-1, Figure 2-1). Delineating the watershed into management units creates discrete geographic areas for analysis of the sources and pathways of NPS pollutants and allows specific management measures to be recommended for each unit. The unit boundaries were delineated in a Geographic Information System (GIS) using high resolution one-and three-dimensional air images and data. This section provides additional detail on each management unit, including site descriptions and pollutant types generated and transported.

The units are presented in order of priority for implementation of the management practices. A metric was developed with several criteria that were weighted subjectively. The criteria included: unit size, topography, drainage density, amount of sediment generated and transported, proximity to receiving waters, NPS pollutant sources and pathways, and land use and cover. Based on the identification of fine

[33] Pollution stream refers to the pathway a pollutant follows across a watershed from its source to its sink.

sediment as the priority threat to the health of Maunalua Bay, the most heavily-weighted factor was the probability that the unit generates and transports fine terrigenous sediments to the marine environment (Mālama Maunalua 2009). Primary pollutant types that are generated from each management unit are identified in Table 2-2.

Table 2-1. Management Units in Wailupe Watershed

Management Unit	Area (acres)	Land Use	Land Type
Upland Forest	1260	Preservation	Vegetated/Forest
Steep Slopes	220	Open Space	Steep, exposed, vegetated
Urban	800	Residential/Commercial	Impervious, low and high Density
Stream Channel	12	Water Conveyance	Exposed banks, hardened and unhardened

Table 2-2. Storm Water Pollutant Generation Types for Management Units

	Management Unit (✓ = Pollutant Applies)			
Pollutant Type[34]	Upland Forest	Steep Slopes	Urban Footprint	Stream Corridor
Sediment	✓	✓	✓	✓
Nutrient	✓	✓	✓	✓
Oxygen-Depleting Substances[35]	✓	✓	✓	
Pathogens	✓	✓	✓	✓
Metals			✓	
Hydro-carbons			✓	
Organics			✓	
Storm Water Flow[36]		✓	✓	

2.2.1 Upland Forest Management Unit

Site: Conservation and preservation lands in the upper watershed. Steep valleys and mountainous terrain with forest canopy and hiking trails.

Pollution Type: Sediments; nutrients; oxygen-depleting substances; pathogens.

Description: The upland forest management unit consists of State-owned conservation land and a smaller area designated preservation land that is owned and zoned by the City and County of Honolulu (CCH). The upper watershed is undeveloped except for an area that houses radio and television repeater towers, and a high voltage electric line that traverses the west ridge of the watershed. This unit contains the

[34] Pollutant types are described in detail in Section I, Table I-3.
[35] Oxygen depletion is caused when bacteria use up dissolved oxygen in the water column. Elevated bacteria levels are usually the result of eutrophication (elevated nutrient levels that stimulate algal growth above normal levels).
[36] Storm water flow refers to runoff per unit area that, for current conditions, is estimated to be greater than historic or background levels.

headwater drainage area of the four sub-watersheds that drain into Wailupe Stream. The soils in this unit generally consist of steep rocky mountainous land (Udorthents) in the higher elevations where the original soil has been cut away; rockland (Lithic Ustorthents) along the lower exposed cliffs; and Molokai series soils near the toe of upper slopes. Runoff from the upland areas is slow to rapid with moderate permeability.

Mass Wasting. Surficial erosion and the movement of both fine and coarse sediments are generated from infrequent mass wasting events that occur in the upland forest management unit. Mass wasting is movement of particles in large amounts due to slipping, sloughing or debris flows that occur on steep valley walls and the ridgelines. Areas affected by mass wasting in this unit are depicted on high resolution air images along the power line/repeater access road along the west ridge of the watershed. Figures 2-2 and 2-3 show areas where the exposed ridgeline road has likely contributed to bare and exposed mass wasting sites.

> Mass wasting is often induced when the toe of a slope fails and is usually associated with high intensity rainfall events. Mass wasting is impairing the watershed in two ways, by delivering fine sediments that are rapidly transported through the stream system, and by depositing large particles such as boulders in stream channels that may decrease the conveyance capacity and induce erosion of the bed and banks due to the displaced water in the channel (Martin and Chock, Inc. 2003). Mass wasting and erosion are both natural processes, as evidenced by the steep valleys that dominate the watershed. However, when human activities or other introduced agents alter ground cover, reduce slope stability, or generate concentrated overland flow to areas where it would not naturally occur, the outcome is increased rates of erosion and mass wasting.

Vegetation. The upland forest management unit includes patches of dense forest canopy of both native and alien vegetation. It is likely that alterations to the watershed induced by humans, including alien plants and animals, have altered the canopy structure, resulting in erosion and runoff rates that are greater than background in this management unit.

> Rainfall is intercepted by leaves, branches, and understory plants, which reduces the kinetic energy and erosive energy of the rain drops. Roots facilitate infiltration of rain water into the ground and often anchor soil and rock they are in contact with. Vegetated ground cover reduces the velocity and volume of concentrated overland flows, protecting the soil surface from detachment and erosion. Overland flows occur during and following rainfall events when the rate of rainfall exceeds the soil's infiltration rate or when the soil is saturated. Under either runoff scenario, alterations to the land surface that affect infiltration rates result in changes to the timing and magnitude of runoff. Since the rate and magnitude of runoff usually increases, this in turn increases erosion rates and sediment transport across the watershed.
>
> The impact alien vegetation has on erosion rates is not well understood in Hawai‘i. Some scientists hypothesize that, besides altering natural ecological processes, alien vegetation increases erosion and storm water runoff rates in forested areas. It is likely that the modified canopy structure and the density of vegetative cover impact erosion and runoff rates.

Feral Pigs. Feral pigs remove vegetated ground cover, turn up soil, and trample the ground surface. These activities alter the physical structure of soil, change infiltration and runoff rates, and increase erosion rates.

Pollution Type: Sediments and oxygen-depleting substances are the primary NPS pollutant concern from the upland forest management unit, nutrients and pathogens are secondary concerns. Erosion rates and sediment generated from the upland forest management unit have not been quantified using models or empirical data. The analysis conducted for the watershed assessment included review of high resolution air images, use of GIS to assess physiographic variables, and interviews with persons familiar with the area. Based on this analysis it is postulated that the upland forest management unit generates the largest amount of sediment per year of the four management units (see Section 1, *Watershed Characterization*). Sediments are generated by surficial erosion and mass wasting. Due to steep topography they are routed quickly into the stream network, and transported to Wailupe Stream and then the ocean. Generation and delivery of NPS pollutants from this unit to lower elevation areas of the watershed are greater during high magnitude rainfall events that generate overland flow and runoff into streams. The upland forest management unit is also a source of large debris (e.g. boulders and branches) and oxygen-depleting substances in the form of fecal coliform concentrations (FCC) and other biodegradable materials (e.g. plant and animal matter). Conservation lands in Hawai‘i have exhibited lower and more consistent values for dissolved nitrogen and phosphorous during low-flow conditions and a higher FCC correlation with increased discharge when compared to urban and agricultural areas (Hoover 2002).

2.2.2 Steep Slope Management Unit

Site: Steep slopes adjacent to the urban neighborhoods. Residential communities border this unit and are primarily located along the toe of the slopes that begin on the two ridgelines bordering the ‘Āina Haina neighborhood.

Pollution Type: Sediments; nutrients; oxygen-depleting substances; storm water flow.

Description: Adjacent to the urban zone are steep, exposed slopes with sparse vegetation (non-native kiawe-koa haole, closed strawberry guava forest, and scrubland and alien grasses). Soil in this unit is characterized largely as rock land that is highly weathered and eroded. Mean annual rainfall is lower as compared to the upland forest management unit; however similar to the upland area, erosion and runoff rates are higher than natural background rates. These exposed slopes are prone to eroding during storm events. Rills thus formed along slopes can cause a weakened surface with increased chances of slope failure. There are numerous large gullies that extend from the ridgelines down to the boundary of the urban unit. Sediment and runoff transported via the gullies is routed directly into the municipal separate storm sewer system (MS4) located at the base of the steep slopes.[37] Figure 2-4 depicts the steep side slopes with the cutoff ditch located on the west side of the ‘Āina Haina neighborhood. The pollutants are then rapidly transported via the MS4 pipe network to Wailupe Stream. At present there are no practices in place to filter or treat runoff conveyed by the MS4, and storm water discharges to Wailupe Stream and the ocean are untreated (CCH-ENV 2010). Protecting water quality in the stream channel from sediment runoff from this region will require hard and soft engineering methods due to the extremely steep topography and the direct connection of runoff into the MS4.

Pollution Type: The primary NPS pollutant concern from the steep slopes is the runoff containing soil particles of various sizes that eventually is conveyed into the stream channel via the MS4. Although the rate of erosion from this steep slope unit has not been quantified, there is visible evidence of significant erosion (e.g. sediment deposits at the toe of the slopes and cutoff ditches maintained by CCH at the downslope area of Wiliwilinui ridge above the ‘Āina Haina community and at the base of the slopes

[37] *MS4*: A municipal separate storm sewer system consisting of a conveyance or system of conveyances designed or used for collecting or conveying stormwater (roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains). Stormwater discharges associated with MS4s are regulated through the use of National Pollutant Discharge Elimination System permits.

below Hawaii Loa Ridge). These cutoff ditches intercept overland flow and debris transported in it to protect the residential units down slope. In both cases the ditch outlets are tied to inlets of the MS4.

2.2.3 Urban Management Unit

Site: Residential and commercial footprint within the ‘Āina Haina, Wiliwilinui, and Hawaii Loa Ridge neighborhoods, and Kalaniana‘ole Highway.

Pollution Type: Sediments; nutrients, oxygen-depleting substances; pathogens; metals; hydro-carbons; organics; storm water flow.

Description: The urban footprint in Wailupe Watershed includes the ‘Āina Haina neighborhood that lies along the valley floor, a portion of the residential development on top of the adjacent steep slopes of Hawai‘i Loa to the east and Wiliwilinui Ridge to the west, the commercial district and Kalaniana‘ole Highway. Land use in this region ranges from residential to commercial and includes a school district, public parks, and a highway system (see Section 1, *Watershed Characterization* for further details on land use). This range of land use practices generates a variety of pollutant types from numerous diffuse sources throughout the region.

Land cover, topography, and the MS4 facilitate the conveyance of storm water runoff to the stream channel and the ocean at numerous storm water pipe outlets. The urbanized area is covered with impervious surfaces across nearly half of its total area. In many locations the impervious surfaces form a nearly contiguous layer extending from the edge of the waterways and the ocean to the edge of the urban footprint. The urban unit is serviced by two extensive MS4s, one owned and operated by the CCH and a second by the Hawai‘i Department of Transportation (HIDOT). The CCH MS4 is located in the residential and commercial areas, while the HIDOT MS4 is located primarily along Kalaniana‘ole Highway. Rainfall for all but the smallest of storms generates overland flow that is quickly transported into the MS4 and discharged into Wailupe Stream and the ocean. The runoff carries various NPS pollutants that concentrate across the landscape in between rainfall events.

Prior to urbanization small to moderate rainfall events likely did not generate overland flow at the frequency seen today since the ground was covered with vegetation that facilitated water infiltration. The increased frequency of runoff associated with urbanization means that there are more frequent pulses of runoff and more contaminants generated when compared to pre-urbanized conditions. This increase in discharge of polluted waters is a contributing factor to the degraded ocean water quality in Maunalua Bay. This scenario is not isolated to Wailupe Watershed, and is occurring across all ten watersheds that drain into the bay.

The CCH MS4 servicing the three neighborhoods contains 489 inlets, none of which are fitted with devices to trap, filter or otherwise remediate polluted runoff that enters the inlets or the pipe network. The HIDOT MS4 inlets are fitted with catchments that trap, via gravity settling, an unknown percentage of the total suspended solids contained in the storm water runoff that is routed into their inlets. Fine particles carried in the runoff most likely do not fall out of suspension, so the percentage of fine particles trapped in the catchments is probably less than coarser or heavier particles. Catchment capture efficiency is also function of storage space; if the vaults are full, additional material entering them will pass through the device and flow to the outfall. Although HIDOT schedules cleaning at six month intervals, the frequency at which HIDOT cleans the catchments varies.

Pollution Type: Pollutants that diminish water quality and negatively impact aquatic ecosystems can oftentimes be traced to residential and commercial activities. Urban areas present numerous opportunities for pollutants to be introduced into the environment. The types of pollutants that occur in urban storm water vary widely, from common organic material to highly toxic metals (Table 2-3). Some pollutants, such as fertilizers and detergents, are intentionally placed in the urban environment while other pollutants, such as oil dripping from automobiles are indirect results of urban activities. Whether intentional or not, these pollutants are carried off land and degrade waterways and coastal areas (USEPA 2005).

Based on the conditions observed across the urban management unit and the land uses and activities that take place within it, it is presumed that this unit generates the largest diversity of NPS pollutants and for some of the NPS pollutant types (e.g., metals, hydrocarbons, nutrients), the highest loads.

The commercial and highway corridor within the urban unit is a potential "hot-spot" for increased incidents and processes that produce NPS pollutants, particularly hydrocarbons (Tables 4 and 5). Large impervious surfaces (i.e. commercial and non-commercial parking lots) essentially function as water harvesting surfaces and generate high magnitude runoff containing by-products of the numerous vehicles that use them. The standard drainage design for parking lots servicing commercial and public parcels in this management unit is to slope the concrete or asphalt surface towards a storm water inlet. None of the parking lots in the unit have management practices to attenuate runoff volume or timing or remediate NPS pollutants. A few parking lots at ‘Āina Haina School border grassy areas and it appears that some of the storm water runoff would discharge onto grass, however, this did not appear to be intentionally designed.

Table 2-3. Typical Pollutant Concentrations Found in Urban Storm Water
(MDE 2000)

Typical Pollutants Found in Storm Water Runoff	Units	Average Concentration*
Total Suspended Solids	mg/l	80
Total Phosphorus	mg/l	0.3
Total Nitrogen	mg/l	2
Total Organic Carbon	mg/l	12.7
Fecal Coliform Bacteria	MPN/100 ml	3600
***E. coli* Bacteria**	MPN/100 ml	1450
Petroleum Hydrocarbons	mg/l	3.5
Cadmium	ug/l	2
Copper	ug/l	10
Lead	ug/l	18
Zinc	ug/l	140
Insecticides	ug/l	0.1 to 2.0
Herbicides	ug/l	1 to 5.0

*These concentrations represent mean or median storm concentrations measured at typical sites, and may be greater during individual storms. Mean or median runoff concentrations from storm water hotspots are 2 to 10 times higher than those shown here. Units = mg/l = milligrams/liter, µg/l = micrograms/liter.

Table 2-4. Common Road Runoff Pollutants and Source
(Kobringer 1984)

Constituent	Primary Sources
Particulates	Pavement wear, vehicles, atmosphere, maintenance, sediment disturbance
Nitrogen, Phosphorus	Atmosphere, roadside fertilizer use, sediments
Lead	Tire wear, lubricating oil and grease, bearing wear, atmospheric fallout
Zinc	Tire wear, motor oil, grease
Iron	Auto body rust, steel highway structures, engine parts
Copper	Metal plating, bearing wear, engine parts, brake lining wear, fungicides and insecticides use
Cadmium	Tire wear, insecticide application
Chromium	Metal plating, engine parts, brake lining wear
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, brake lining wear, asphalt paving
Manganese	Engine parts
Bromide	Exhaust
Sodium, Calcium	Grease
Sulphate	Roadway beds, fuel
Petroleum	Spills, leaks, blow-by motor lubricants, hydraulic fluids, asphalt surface leachate
PCBs, pesticides	Spraying of highway right of ways, atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria	Soil litter, bird droppings, trucks hauling livestock/stockyard waste
Rubber	Tire wear
Asbestos	Clutch and brake lining wear

Table 2-5. Mean Pollutant Concentration in Runoff from Urban and Rural Highways
(Driscoll et al. 1990)

Pollutant	Urban (ADT> 30,000) (µg/l)	Rural (ADT< 30,000) (µg/l)
TSS (Total Suspended Solids)	142,000	41,000
VSS (Volatile Suspended Solids)	39,000	12,000
TOC (Total Organic Carbon)	25,000	8,000
COD (Chemical Oxygen Demand)	114,000	49,000
NO3/NO2 (Nitrate + Nitrite)	760	570
TKN (Total Kjeldahl Nitrogen)	1,830	870
Phosphorus as PO4	400	160
Cu (Total Copper)	54	22
Pb (Total Lead)	400	80
Zn (Total Zinc)	329	80

Additionally, residential areas are known contributors of an array of certain other pollutants that cumulatively are having an effect on the health of the Bay. For example nutrients from diffuse sources are driving the proliferation of alien invasive macro-algae (seaweeds) in Maunalua Bay. Because the impact derives from the collective behaviors of many people living over a large area, solutions are best addressed via educational campaigns to raise awareness about the need for changed mass behaviors. This is discussed further in Section 5.1.

2.2.4 Wailupe Stream Channel Management Unit

Site: Wailupe Stream from the existing debris basin near the mauka end of Hao Street downstream to the ocean.

Pollution Type: Sediments; nutrients; pathogens; storm water flow.

Description: Although partially channelized, Wailupe Stream is the only completely unhardened stream that discharges into Maunalua Bay (Section 1.3.2.5). There are two sections that are lined with concrete-rubble masonry walls: below the debris basin for approximately 1,000 ft and from Kalaniana‘ole Highway downstream to the mouth. The stream above the existing debris basin is in a natural morphologic condition and does not appear to have been altered.

The Wailupe Stream channel management unit contains a two acre debris basin fitted with a slotted concrete weir designed to trap large rocks generated from the collapse of weathered rock in the upland area and to prevent debris flows from blocking or damaging the downstream channel during flood events. By design this debris basin does not trap or filter fine sediments or other NPS pollutants that are carried in runoff from the upland forest management unit. The stream is cleared annually by the CCH Road Maintenance Division, which uses a bulldozer to push deposited debris found on the bed of the stream channel toward the sides. The debris basin is cleared every six months or after major storm events (FWS 1998).

In many sections the stream banks have steep slopes covered with unconsolidated particles that vary in size from fine clay to large boulders. Vegetation is a mix of native and alien grasses, trees, and shrubs that grow along the flat area at the top of the upper banks and in and along the low flow channel. Many sections of the stream banks between the low flow channel and the upper banks are free of vegetation and unstable. Because the channel slope is relatively high (approximately five percent except for the last 1,000 feet of its alignment), when there are sustained flows that fill the channel the energy is sufficient to transport fine sediments in the stream. Field observations indicate that there are few deposits of fine sediments along most of the stream. The stream in the reach between the debris basin and the stream mouth could be classified as a net transporter of sediments. The stream is both transporting sediments that are delivered into it and is itself a source of sediment. The percentage of the total amount of sediment transported by the stream derived from upland sources versus the amount derived along the stream channel is unknown. It is likely during high flows when the channel is near capacity, that a significant percentage, or approximately 10 percent of the total load of suspended and bedload sediment transported by the stream, is generated from the bank and channel bed along the stream reach in this management unit.

According to the U.S. Army Corps of Engineers (USACE) 1998 Feasibility Report, there are 36 existing storm water outfalls that drain into the Wailupe Stream channel between the Kalaniana‘ole Highway

Bridge and the debris basin access road (USACE 1998). These piped outfalls enter the channel at an angle perpendicular to the normal stream flow and are the terminus of the urban region's MS4. Storm water conveyed in the CCH MS4 that discharges into Wailupe Stream through outfalls is untreated.

Along the stream, residents discharge runoff collected in rain gutters off their property into the stream channel. In several of these locations the water discharges onto unprotected channel banks causing localized scouring and in some instances undermining the banks beneath the residences.

Pollution Type: Wailupe Stream is the main conveyance feature for most of the storm water generated off Wailupe Watershed and contains pollutants from all other management units. Stream bank erosion from the unhardened banks is also a source of sediment that is carried downstream and re-deposited in the channel bottom or discharged into the bay.[38]

As described in Section 1, *Watershed Characterization*, flooding is a major concern in the region, and flood management is a primary topic of discussion and study by USACE. Management measures recommended for the stream and urban units are not expected to significantly attenuate the runoff generated from infrequent high magnitude rainfall events i.e. 100 year return storm. They are however, expected to attenuate flows and remediate NPS for the more frequent small to moderate storms. Over time these storms cumulatively result in the transport of high quantities of runoff and NPS pollutants as compared to the infrequent high magnitude events.

2.3 Implementation Recommendations

There are numerous publications and resources to guide land managers in the selection, acquisition, and installation of management practices to control storm water runoff and remediate NPS pollutants. Literature reviews, interviews, and site inspections were conducted to narrow the recommended list to address the specific issues and physiographic variables identified in Wailupe Watershed.

The primary NPS pollutant to control and reduce is the fine terrigenous derived sediments. The management practices selected and prioritized were weighted heavily to those that either prevent or reduce generation of fine sediments or treat the pollutant stream for fine sediments. Consideration was also given to other NPS pollutants the measure could remediate; cost; the practical and logistic elements of installation; and the link to regulatory or management objectives that either require or promote measures to reduce NPS pollutants.

Management measures for targeted pollutants and priority concerns for each management unit are shown in Table 2-6. Recommend priority practices and technologies for improvement in each management unit are presented in Table 2-7. Examples of management practices are presented in Appendix B. The highest priority management measures and management practices for implementation are outlined. Details are provided on the highest priority practices within each management unit. The priorities for implementation should not be considered rigid. If a land owner or entity responsible for a particular parcel has resources to implement a management practice that is lower priority, the opportunity should be taken. Any installation of a management practice is a positive gain towards reducing NPS pollution, regardless of order. Units that are contributing the most sediment should, to the extent possible, be targeted first in order to reduce the largest contribution of sediment to the ocean in a timely manner.

[38] Stream bank erosion is the wearing away of material from the land area along the stream banks. Erosion occurs when the erosive force of the water is greater than the resisting force of the bed and bank material.

Table 2-6. Management Measures Applicable to Management Units

Management Unit (✓ = Management Measure Applies)					**Objective**	
Upland Forest	**Steep Slopes**	**Urban**	**Stream Channel**	**Management Measure**	**Preventive**	**Treatment**
✓		✓		Install Bioengineered Filtering System		✓
	✓	✓		Capture and Filter Sediment		✓
			✓	Stabilize Channel	✓	
✓		✓		Increase Detention/Retention	✓	✓
	✓		✓	Protect Bare or Exposed Areas from Erosion	✓	
	✓	✓		Install Flow Restrictors/Regulators	✓	
		✓		Reduce Household Generation	✓	
✓	✓	✓	✓	Identify, Prioritize, Schedule Retrofit Opportunities		✓
	✓	✓	✓	Increase infiltration		✓
✓			✓	Instream Sediment Load Control		✓
✓	✓	✓	✓	Operation and Maintenance		✓
✓	✓		✓	Restore Natural Systems	✓	
	✓	✓		Intercept/Control Runoff	✓	
	✓	✓	✓	Dissipate Slope Energy	✓	
			✓	Preserve/Enhance Streambank	✓	
✓	✓		✓	Increase Vegetative Cover	✓	✓

Table 2-7. Management Practices Applicable to Management Units

Management Practice	Management Unit (✓ = Management Practice Applies) Upland Forest	Steep Slopes	Urban	Stream Channel
Baffle box		✓	✓	
Coir logs		✓		
Curb inlet baskets		✓	✓	
Extended detention basin	✓			✓
Good housekeeping practices			✓	
Grass swale			✓	
Green roof – Green grid			✓	
Infiltration trench		✓	✓	
Invasive species control	✓			
Modular wetland			✓	
Natural/Native vegetation	✓	✓	✓	✓
Porous pavement			✓	
Rain barrels			✓	
Subsurface storage			✓	
Turf reinforcement mats		✓		✓

2.3.1 Upland Forest Management Unit

Management Measures: Flow regulators; enhancement of vegetative ground cover; storm water detention and retention; restoring natural systems; retrofit opportunities; operation and maintenance.

Management Practices: Extended detention basins; invasive species control; natural/native vegetation; road and trail maintenance.

Due to its size, rainfall regime, and steep topography, the upland forest management unit likely generates the most fine sediments of the four management units. Reduction of erosion rates would result in significant reduction of fine sediment generation from this unit. However, a preventive strategy to control erosion rates in this steep, somewhat inaccessible and passively managed unit presents logistical and regulatory challenges. After reviewing the regulatory and management plans for the unit, considering the challenges of reforestation, and noting the lack of direct funding programs for preventive measures, it is concluded that while preventive measures are recommended, they are not the priority for this unit. The priority recommendations are treatment controls that are expected to have immediate positive impacts on reducing transport of fine sediments and other NPS pollutants upon implementation.

Extended Detention Basins. The primary recommendation is the installation of extended detention (ED) basins at the location of the present debris basin on Wailupe Stream and at Kului Gulch. If properly designed and maintained, ED basins can reduce fine sediment concentration in suspension; trap large particles; reduce downstream peak flows; decrease in-channel erosion rates; enhance ground water recharge; and assist USACE in achieving its mission to help attenuate flood impacts along Wailupe Stream.

ED basins are designed to allow particulates to settle out of the water and to control channel erosion by reducing the rate of discharge such that the velocity is below the critical velocity for the downstream channel. The specific engineering design needs to consider the resident time of water in the ED basin to allow for the fine particles derived off the upland soils and carried in the inflow to settle out. Constructing terraces for vegetation at various heights and planting vegetation able to withstand certain flow events or low flow in the basin is compatible with USACE flood reduction project ideas.

Major drawbacks of ED basins are that they require substantial land area, are costly to design and construct, and require routine and somewhat labor-intensive maintenance. Proposed locations in Wailupe Watershed include two areas: 1) at the existing debris basin on Wailupe Stream, and 2) at the base of Kului Watershed, behind the former Wailupe Valley School, which is on undeveloped property owned by CCH. The proposed locations are based on the existing basin and USACE's plan for a future retention basin in the Kului Gulch. Figures 2-5 and 2-6 depict the recommended locations for the ED basins.

Invasive Species Control. Control and removal of invasive ungulates and vegetation in the upper watershed reserves of the Koʻolau mountains is currently being studied by government entities, private entities (e.g., Koʻolua Mountain Watershed Partnership) and public institutions (i.e. University of Hawaiʻi). Management measures that address invasive species control can be expensive, lengthy, politically charged and require a strategic plan involving multiple stakeholders to be implemented. Partnerships between conservation groups working towards invasive species control will greatly enhance efforts in the upper watershed region. Programs to reduce or eliminate feral pig activity should be pursued regardless of the current numbers of pigs that reside in the watershed.

2.3.2 Steep Slope Management Unit

Management Measures: Capture and filter sediment; erosion protection of bare or exposed areas; flow restrictors/regulators; infiltration; retrofit opportunities; operation and maintenance; restoring natural systems; runoff interception/control; slope energy; vegetative cover.

Management Practice: Baffle boxes; coir logs; curb inlets baskets; infiltration trenches; natural/native vegetation; turf reinforcement mats.

Attenuating concentrated overland flow and preventing sediment laden runoff from flowing into the MS4 from the steep slopes will require both preventative and treatment controls that include soft and hard engineering due to the extremely steep topography and direct connection of runoff into the MS4 at several locations. Recommended preventive controls include reducing slope length, and increasing vegetative groundcover with preferably native or endemic species adapted to the dry conditions of the slopes. Treatment practices for this unit will address the reduction of fine sediments via filtering and traps.

Restoring Vegetatative Cover. Prevention practices will decrease the rate of overland flow and amount of erosion generated from the steep side slopes. The type and feasibility depends on site conditions, including existing vegetative cover and slope angles. Bare exposed areas are considered hot spots for sediment production and should be addressed first. A soft engineering practice to remediate these areas includes protecting the ground surface from rainfall and overland flow while at the same time providing micro-habitat for plant growth. Biodegradable erosion mats and coir logs provide ground cover on exposed areas, decrease slope length, and trap sediments. Covering exposed areas with an erosion mat and seeding with species such as dry land Pili grass (*Heteropogon contortus*), the drought tolerant aʻaliʻi (*Dodonaea viscose*), and alaheʻe (*Psydrax odorata*) are practices that have been successfully implemented during restoration efforts on Kahoʻolawe. Figure 2-7 identifies locations where coir logs could be placed along contours of the slopes to slow overland flow and trap sediments.

Baffle Boxes. Treatment to filter and trap sediments and other NPS pollutants generated off the steep slopes and delivered into the MS4 at the urban interface is focused on the installation of baffle boxes. Baffle boxes should be placed on the MS4 at the inlets located nearest to the toe of the slopes. This recommendation is essentially a retro-fit to the MS4 and is expected to significantly and immediately reduce the concentration of fine sediments, nutrients, and other NPS pollutants. CCH is currently using curb inlet devices made by Bio Clean Environmental Services, Inc. on the MS4 in the Waikiki area. This manufacturer makes a baffle box that can be customized to trap up to 95% of the sediment routed into its three chamber design. Based on the documented performance of this manufacturer's product and their existing relationship with CCH Department of Facilities Maintenance (the entity that services the MS4), baffle boxes from Bio Clean Environmental Services, Inc. are recommended. Figure 2-8 depicts the recommended locations and priority for installation of baffle boxes at the toe of the steep side slopes.

Retrofit Cutoff Ditch. CCH is currently in the engineering design phase to refurbish an existing cutoff ditch located along the west side of ʻĀina Haina neighborhood at the toe of the steep slope management unit. The ditch has two outlets that discharge into the CCH MS4. The primary design considerations are to increase the ditch flow conveyance capacity and to trap large rocks from moving past the toe area and towards houses downslope. The designs described by CCH personnel familiar with the project do not contain provisions to sequester, filter or otherwise treat fine sediments or NPS pollutants carried in runoff. Installing at least two baffle boxes on the ditch outlets as part of the refurbishment will provide a significant reduction of fine sediments and other NPS pollutants that would otherwise be routed untreated into Wailupe Stream. If baffle boxes are not installed, CCH should include design features within the ditch to capture and filter fine sediments (e.g. filters, screens, perforation holes, and energy dissipaters at the outlet of the ditch).

2.3.3 Urban Management Unit

Management Measures: Bioengineering filtering system; capture and filter sediment; flow restrictors/regulators; household generation; infiltration; retrofit opportunities; operation and maintenance; runoff interception/control; slope energy.

Management Practice: Baffle boxes; curb inlets baskets; good housekeeping practices; grass swale; green roof; infiltration trenches; modular wetlands; porous pavement; rain barrels; subsurface storage.

Recommendations in the urban unit focus on reducing NPS pollutants generated from moderately dense residential and commercial uses. Management measures range from prevention at the homeowner level to retrofits and hard engineering treatments to the existing MS4. Management practices include good housekeeping, retrofitting the MS4 at priority locations, installation of onsite storm water storage structures to attenuate peak flow, and utilizing open spaces for nonstructural storm water attenuation and filtration. This management unit has the most potential for implementing preventive measures to reduce and attenuate storm water flow, as well as for treating sediments and other NPS pollutants that flow through the MS4. The MS4s convey most of the storm water through the urban region, and it is crucial to implement management practices on this system that target hotspot areas and inlets for sediment and pollutant capture.

Good Housekeeping Practices. Infrastructure associated with residential and commercial land use typically increases impervious surfaces. Activities in these areas affect the types and amounts of contaminants that are generated, which impacts pollutant concentrations mobilized in runoff. Stakeholders should be educated and encouraged to practice good housekeeping practices (Table 2-8). Implementation of a good housekeeping program to reduce the generation of by-products associated with normal human activities is recommended for residents in Wailupe Watershed and is being implemented as an educational campaign by Mālama Maunalua. The program will include specific recommendations on how each individual could contribute to towards the goal of reducing contaminants that create NPS pollution.

Table 2-8. Good Housekeeping Practices for Residential Participation

Adapted from (HIDOT 2007)

Good Housekeeping Practices
a) Know the property boundaries, and where storm water from the property goes.
b) Use biodegradable and recyclable cleaners when possible.
c) Carefully select and control inventory. Having fewer materials on hand simplifies operations, reduces inventory cost, more effectively uses available roofed storage space, and lessens the opportunities for spills or leaks.
d) Use good material storage practices (avoid toxic materials to the extent possible, store containers of liquids in a way they are unlikely be knocked over, cover stockpiled materials, consider the best place to conduct specific activities.)
e) Conduct property maintenance (clean up the site, but not by washing grit and grime into the storm drainage system).
f) Eliminate improper discharges to storm drains - only rainwater should run off the site.
g) Clean up spills of materials or from equipment now, not later.
h) Practice waste management (pick up litter, sweep areas and dispose of sweepings in the garbage (unless they are hazardous and require special disposal)
i) Use good waste storage practices (keep dumpsters and other containers closed; store containers under cover)
j) Dispose of mop water to a sanitary sewer.
k) Maintain equipment and vehicles regularly. Check for and fix leaks.
l) Wash cars over grass patches, use phosphorus free soaps
m) Capture rainfall using rain barrels, placing downspouts on vegetated areas, install rain gardens.

Storm Water Capture. Field observations found that many houses are fitted with downspout pipes that discharge storm water off the property and onto the adjacent sidewalk and/or street. This practice is likely being conducted to reduce ponding on residential parcels that occurs during rainfall events. The funneled runoff combines with runoff generated from CCH-owned impervious areas (streets/sidewalks) and the higher volume of runoff increases the frequency and efficiency by which NPS pollutants are carried to MS4 inlets. Rain falling on house lots is lost as source water for the home's landscaped areas and adds to the disruptions to the hydrologic regime (see Section 1, *Watershed Characterization*). Mālama Maunalua's land-based pollution reduction outreach initiative will also focus on reducing storm water runoff from urban areas (see Section 5.1). A low tech, moderately low cost solution is to harvest runoff generated off roofs and other elevated surfaces and store it in rain barrels or other catchment on the homeowner's property. Storing water attenuates runoff and captures some contaminants generated off the roof areas. Water can be used to water lawns or garden plots. Unless adopted on a mass scale, capture of rainwater at the individual house level will not significantly reduce runoff volume reaching the MS4, nor will it increase the time of peak flows. However early benefits derived in terms of reduced water costs and increased awareness are real. Programs to harvest rainwater should be scaled up across watersheds in order to increase the number of homeowners that participate and the volume of water captured, and correspondingly decrease runoff.

A similar approach to capture and use runoff from large parking lots in the commercial and public areas would be to install subsurface water tanks. In several municipalities on the mainland U.S. subsurface storage of storm water runoff has proven to be effective in reducing peak flows delivered to receiving water bodies, remediating NPS, and in some cases providing water for irrigation of landscaped areas. Subsurface systems can be designed to either hold the water for use as irrigation, or fitted with perforated holes to allow the water to slowly drain into the substrate beneath the storage device. The Hawaiʻi Commission on Water Resource Management published *A Handbook for Stormwater Reclamation and Reuse Best Management Practices in Hawaiʻi* (DLNR 2008). This publication is a useful guide on methods and practices to harvest rainwater. In addition, many of the practices will assist in remediating NPS pollutants.

MS4 Retrofits. Retrofits to the MS4 inlets and pipe network are recommended to reduce NPS pollutants conveyed in the MS4. Two structures are recommended: curb/grate inlet baskets and baffle boxes. Curb/grate inlet baskets trap gross solids and are ideal for removing large quantities of hydrocarbons, including oils and grease when fitted with an optional absorbent polymer. Bio Clean Environmental, Inc. has tested their curb inlet basket system in Hawaiʻi and reports having the lowest installation time and highest rated catch basin insert for performance and maintenance (Bio Clean 2009). There are 489 inlets on the CCH MS4, a portion of which are targeted for curb basket retrofits due to their proximity to areas that receive high traffic volume (i.e. commercial parking lots, school pick-up zones) and adjacent to areas where vehicles stop frequently (i.e. stoplights along Kalanianaʻole Hwy).

Baffle boxes are designed to trap both coarse and fine sediments, filter nutrients, and capture hydrocarbons. They are relatively easy to maintain using conventional vactor equipment. Baffle boxes (also made by Bio Clean) should be placed along the CCH MS4 subsurface pipe network at accessible locations above outfalls. Bio Clean is presently working with CCH to install several baffle boxes on the MS4 servicing the Pearl City area.

The use of curb/grate inlets and baffles boxes on the same pipe network is somewhat redundant and not necessary. When a baffle box is placed near the outfall of a pipe network it will treat all the runoff entering the curb/grate inlets on the same pipe network and will essentially render the inlet structures obsolete. If baffle boxes are not installed, then it is strongly recommend that curb/grate inlets be installed. A general recommendation is to place inlet baskets on the most heavily used streets, near parking lots, and near areas where trash accumulates. Figure 2-9 depicts the recommended locations and priority for the baffle boxes installation.

Infiltration Trenches and Swales. Infiltration trenches and grass swales are recommended to reduce NPS pollutants and attenuate runoff generated off public and commercial parking areas and other impervious surfaces. Infiltration trenches and grass swales temporarily store runoff and remove fine sediments, are useful for controlling higher frequency flood events (generally less than the 2-year), and can be designed with a spillway outlet to handle large rainfall events. They should be constructed along and adjacent to parking lots where there is room and non-impervious surfaces. Specific areas for installation include CCH parcels such as the Wailupe and ʻĀina Haina Elementary Schools and public parks.

Modular Wetlands. Modular wetlands can be used to reduce NPS pollutants generated off parking lots and roadways. Modular wetlands are four-stage treatment storm water devices that are retrofitted to the MS4 pipe system in or adjacent to parking lots or roadways. These state-of-the-art products are a hybrid technology that combines traditional storm water separators and filters with plants grown in proprietary grow medium. Bio Clean manufactures a modular wetland that is appropriate for the hydrologic conditions of Wailupe Watershed. Figure 2-10 depicts the recommended locations for grass swales, infiltration trenches, and modular wetlands.

2.3.4 Stream Channel Management Unit

Management Measures: Channel stabilization; erosion protection of bare or exposed areas; flow restrictors/regulators; infiltration; instream sediment load control; retrofit opportunities; operation and maintenance; slope energy; stream bank preservation/enhancement; vegetative cover.

Management Practice: Natural/native vegetation; channel reinforcement mats, coir logs, articulated concrete mats, anchor pins, tie backs, drop structures.

Specific locations where channel erosion was noted during field inventories along Wailupe Stream have been identified and described by Mālama Maunalua (Prescott 2009). Prevention controls recommended for Wailupe Stream channel focus on rehabilitation, restoration and protection of the exposed banks using a combination of soft and hard engineering practices. Management measures are expected to reduce bank and stream bed erosion and facilitate remediation of NPS pollutants conveyed in runoff.

Stream Bank Protection. Meetings were held with SRGII, Mālama Maunalua and USACE to discuss potential strategies to control channel erosion, remediate NPS pollutants and provide for flood control along Wailupe Stream. USACE is taking the lead on developing engineering solutions to the issues identified above. Designs will consider the need to implement solutions that maintain channel flow conveyance for flood management and maintain a natural channel, to the extent possible, to provide for ecosystem functions.

Stream Bank Stabilization. Stream bank stabilization is defined as the stabilization of an eroding stream bank using practices that consist primarily of ‘hard’ engineering such as, but not limited to, turf reinforcement matting, concrete lining, rip rap or other rock, and gabions. The use of ‘hard’ engineering techniques is not considered a restoration or enhancement strategy but may be necessary in certain location where erosion threatens adjacent properties and the probability of success using soft engineering practices is low. Other sections along the channel banks can be treated with bioengineering and soft engineering practices, which can be expected to reduce bank erosion, increase site aesthetics, enhance instream habitat, and be less costly compared to hardened structures.

In Channel Treatment. When eroding stream banks are protected using a non-hardening pervious practice, they can serve as a filter for surface water runoff from upstream areas, or as a sink for nutrients, contaminants, or sediment present as NSP pollution in surface waters. Treatment potential within the stream channel can be enhanced with the use of vegetation as part of the remedial design. Use of native and/or endemic plants in channel stabilization designs that do not impair flow conveyance can enhance habitat structure and aesthetics, and phytoremediate NPS pollutants, especially elevated nutrient levels (Unser 2009). The practice of using coir logs with native sedges to stabilize stream banks and remediate nutrients has been tested and proven to be successful along two Oʻahu streams (SRGII 2009).

2.4 Pollutant Load Reductions

Suitable management practices for management units will address appropriate target parameters. Drawing from multiple guidebooks, Table 2-9 presents relative performance of management practices in addressing pollutant loading and storm water flow (LA-SMD 2000; USEPA 2003; Field et al. 2004; USEPA 2005; USEPA 2007; USEPA 2008; Bio Clean 2009). The table also identifies the complimentary benefits of various management practices. The load reduction potential qualitatively describes the potential reduction of loading achieved by implementing the practice. The actual reduction depends on the extent of the practice, existing loading levels, and local features like soil and hydrology. EPA, in their *Handbook for Developing Watershed Plans to Restore and Protect Our Waters*, recommends identifying the effectiveness of each management practice in reducing pollutant loading and addressing hydrologic impacts using a scale of high, medium, or low (USEPA 2008).

Pollutant load removal efficiency of selected management practices has been the subject of many studies. There are wide discrepancies in methods for evaluating and quantifying the effectiveness of management practices. Management practice performance is best described by how much storm water and associated runoff is treated and what effluent quality is achieved (Strecker et al. 2001). Storm water management practices by definition are specific devices, practices, or methods used to support the intensions of the storm water management measure (Field et al. 2004). However this term lumps widely varying techniques into a single category. Nonpoint sources of pollution are the biggest source of pollution into Wailupe Stream and the management practices recommended will, if implemented, reduce the loads. Since it was beyond the scope of this project to calculate loads of NPS pollutants generated from the various areas of the watershed, it is not possible to quantify how much load reduction can be achieved by installing measures at specific locations in the watershed. With this said, it is probable that placement of sediment detention basins designed to trap fine sediment on Wailupe Stream at or near the existing debris basin and on Kului Gulch near its confluence with Wailupe Stream will result in significantly reducing the load of fine sediments discharged into Maunalua Bay.

Table 2-9. Management Practices and Expected Load Reduction[39]

Pollutant Types and Relative Load Reductions of Management Practices								
Sediment	**Nutrient**	**Oxygen-Depleting Substances**	**Pathogens**	**Metals**	**Hydro-carbons**	**Organics**	**Storm water Flow**	**Management Practice**
H	H	H	M	H	M	H	L	Baffle box
M							L	Coir logs
H	H	H	M	H	H	M		Curb inlet baskets (with filter)
M	M			M			H	Extended detention basin
L	M	M	L	L	L	M	L	Good housekeeping practices
M	L	L	L	H			L	Grass swale
L	L	L	L				M	Green roof – Green grid
H	H	H	H	H			M	Infiltration trench
M	M		M				L	Invasive species control
H	H	H	H	H		H	H	Modular wetland
L	L		L				L	Natural/Native vegetation
M			M				M	Porous pavement
							L	Rain barrels
H	H	H	M	H	H	H	H	Subsurface storage
M								Turf reinforcement mats

[39] Numerical load reduction estimates for selected practices are contained in Appendix B.

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3. Implementation Strategy

The *Implementation Strategy* section provides the following information and tools to facilitate the implementation of the management practices recommended in Section 2, *Pollution Control Strategies*:

- An estimate of the technical and order of magnitude financial resources required to implement the recommended pollution control measures.
- A prioritization for implementing the recommended pollution control measures.
- Identification of potential entities responsible for implementing specific plan recommendations.
- Measurable milestones to aid in determining if pollution control measures are being implemented and if load reductions and load targets are being achieved.
- An adaptive management mechanism to address watershed plan recommendations should the load reductions and load targets not be achieved.

A comprehensive approach that considers the full set of pollution control strategies that should be employed when determining the reduction potential of each management practice. Each management practice will contribute to the overall success, but only in combination will success be ensured (i.e. significant net reductions of pollutant runoff loads from the watershed). Identifying key implementation strategies will ensure that the management practices identified in this WBP are developed and implemented with a solid foundation and oversight aimed ultimately at measureable reductions in pollutant loads.

3.1 Resources Required for Implementation

A watershed management approach to NPS pollution control requires systematic steps. The implementation of a management practice entails the identification of pollutant sources, selection of the appropriate practice to reduce the target NPS pollutants, identification of the locations for installation, and acceptance of responsibility by the sponsoring entity. The resources required to implement a management practice are determined by the complexity of design, site conditions, and regulatory and land owner requirements.

3.1.1 Technical Resources

Technical resources necessary to implement management practices are a function of the complexity of the engineering design, land ownership issues, permit requirements, preparation of biddable construction plans and drawings, and development of a post installation Operation, Monitoring, and Maintenance Plan. Engineering design includes, but is not limited to, assessing the physical condition of the installation site[40], evaluating design hydrology parameters following City and County of Honolulu (CCH) requirements, sizing and designing management practices, preparing construction plans and cost estimates, preparing detailed installation drawings, acquiring permits, and construction management. These are all collectively referred to as ‘Plans Specifications, and Estimates’. In addition to the engineering elements there are logistical issues associated with taking a management practice from the concept design phase to the implementation phase. Addressing logistical issues requires involvement of

[40] Assessing a site’s physical condition could include geotechnical analysis, locating utilities, inspecting structures (if the practice is a retrofit), and hydrologic analysis.

persons familiar with the technical elements of the design, the regulatory issues, and construction aspects of installation.

Contractors with expertise and knowledge of installing practices are a vital technical resource for the implementation of any practice. Since some of the recommended management practices have not been installed or have limited installations in Hawaiʻi, it will be important that the design and construction manger articulate the objectives and installation nuances to contracting crews, and provide detailed guidance to facilitate correct and expeditious installations.

3.1.2 Financial Resources

In general, costs to implement management practices include the following:

- Engineering design, including all plans, drawings, biddable plans and permit acquisition
- Product purchase, including shipping cost
- Construction installation
- Construction Management
- Annual maintenance

Financial resources required to implement the management practices can vary considerably; for example the cost of a complex technology such as a baffle box is higher than for a simple one such as a grass swale. Often the cost for implementing a single unit of a given technology appears relatively high compared with the net benefit provided. However economies of scale can be achieved through multiple installations as the cost to implement per unit management practice decreases as the number of units installed increases. As the number of units installed goes up, the net benefit in terms of NPS pollutant reduced increases not linearly but as a power function.

Various costs, including capital, Operations and Maintenance (O&M), and time and training requirements associated with installation and maintenance, will influence selection of recommended management practices. Comparison of cost to NPS pollutant reduction potential also affects selection of practices. Another consideration is initial cost to long-term maintenance cost.

Cost and equations to generate cost estimates to implement selected management practices are shown in Table 3-1. Costs should be considered provisional and order of magnitude estimates. Relative cost information on capital, O&M, and training for the recommended management practices in Wailupe Watershed is expressed qualitatively (high, moderate, and low). Relative cost relates the cost of the practice to its performance in terms of reduction of NPS pollutant the practice can be expected to achieve. "Low" indicates a cost ratio of less than one, meaning the cost of the practice is lower than the expected benefit, resulting in the practices being favorable to implement. A high relative cost would mean it costs more per unit reduction of NPS pollutant.

O&M cost refers to the amount of labor and expense required to maintain function of the management practice (relative to other management practices). A rating of "low" indicates that the practice does not require much maintenance, "moderate" implies an average amount of maintenance, and "high" indicates the management practice is labor-intensive or otherwise costly to maintain.

Training cost identifies the costs for time and materials needed to train staff on maintenance protocols to maintain the practices in good, safe and efficient operating condition. Some of the recommended practices are expected to require no post-installation maintenance (e.g., revegetation of upslope areas), while other practices will require ongoing routine maintenance (e.g., baffle boxes). The selection process considered the types of maintenance and equipment that would be necessary to maintain the various practices, and compared that to the current equipment and capacity of CCH and Hawai‘i Department of Transportation (HIDOT) departments responsible for municipal separate storm sewer system (MS4) maintenance. For example, baffle boxes can be cleaned using Vactor equipment presently owned by both CCH and HIDOT. Practices that would require the purchase of new maintenance equipment are not recommended.

Funding for implementation of management practices can come from a range of sources including Federal, State, local and private entities. In addition to resources at the local and State level that can be used to identify funding opportunities, the Environmental Protection Agency (EPA) has developed resources to enable watershed practitioners in the public and private sectors to find appropriate methods to pay for environmental protection efforts. Details are available at www.epa.gov/owow/funding.html and in the *Guidebook of Financial Tools: Paying for Sustainable Systems* (www.epa.gov/efinpage/guidbkpdf.htm).

Table 3-1. Costs Associated with Recommended Management Practices

Implementation Cost					
Management Practice	**Calculated Cost[41]**	**Relative Cost**	**O&M Cost**	**Training Cost**	**References**
Baffle box	$40,000/unit	Moderate	Moderate	Moderate	Vendor quote
Coir logs	$22.50/ft	Moderate	Low	Low	Vendor quote
Curb inlet baskets	$1800/unit	Low	Moderate	Low	(LA-SMD 2000; USEPA 2003; Field et al. 2004)
Extended detention basin	$C = 12.4V^{0.76}$; V in ft^3	Low	Moderate	Low	(Brown and Schueler 1997; LA-SMD 2000; Barr Engineering Company 2001)
Good housekeeping practices	N/A	Low	Moderate	High	(LA-SMD 2000)
Grass swale	$0.25 - $0.50/$ft^2$	Moderate	Moderate	Low	(Barr Engineering Company 2001)
Green roof – Green grid	$14 - $25/sq. ft	Moderate	Low	Low	(Greenroof 2010, LA-SMD 2000)
Infiltration trench	$C = 16.9V^{0.69}$; V in ft^3	Moderate	Low	Low	(Brown and Schueler 1997; LA-SMD 2000; Barr Engineering Company 2001)
Invasive species control	N/A	High	High	Low	(LA-SMD 2000)
Modular wetland	$32,000/unit	Moderate	Moderate	Moderate	Vendor quote
Natural/Native vegetation	N/A	Moderate	Low	Moderate	(LA-SMD 2000)
Porous pavement	$8 - $12/$ft^2$	Moderate	Moderate	Moderate	Vendor quote
Rain barrels	$60 - $135 each	Low	Low	Moderate	(Brown and Schueler 1997)
Subsurface storage	$C = 12.4V^{0.71}$; V in ft^3; $400 per cubic yard	High	High	High	(Brown and Schueler 1997)
Turf reinforcement mats	$2/$ft^2$	Moderate	Low	Low	Vendor quote

[41] Includes installation cost unless noted otherwise.

3.2 Implementation Priority

Sites that are generating and/or conveying the most NPS pollutants, and locations that are logistically favorable are given the highest implementation priority for management practices. For most of the recommended treatment practices, reduction of NPS pollutants occurs immediately or upon the first rainfall event that generates overland flow. The priority pollutants of concern identified in the Maunalua Bay Conservation Action Plan are land based pollutants, especially fine terrigenous sediment running off into Maunalua Bay (Mālama Maunalua 2006). As described in Section 2, *Pollution Control Strategies*, sediments are primarily generated from the upper watershed, adjacent slopes, and stream corridor management units. Thus, priority is given to management practices that are designed to reduce the generation and transport of fine sediments, and elevated when they also capture and reduce other NPS pollutants.

In the long run, the best solution to reducing the amount of land based pollutants reaching Maunalua Bay is to prevent generation and/or reduce generation to background levels. However in many instances these are not viewed as immediately feasible options due to high costs and long range time commitments (e.g. large scale erosion control projects). Since Maunalua Bay is in poor ecological health, and marine scientists contend there is not a lot of time to act before the Bay's ecology collapses completely, treatment controls that result in immediate benefits are ranked high priority for implementation. And although there may be a lag time before certain preventive controls, such as restoring vegetation, result in significant reduction of NPS pollutants, they too are recommended, albeit as a lower implementation priority.

Sediment "hotspot" locations are also ranked as a priority for treatment. An assessment was made to identify preferred locations for management practice installation along pathways by which sediment is routed into the stream and ocean. Since sediment is generated across numerous, diffuse locations, it is most efficient to treat where it enters the MS4 pipe network. The more management practices that are installed, the more NPS pollution is reduced. The installation of a range of practices is expected to result in complimentary treatment and greater reduction rates of the total pollution load moving through the system.

Management practices for implementation were also prioritized within each management unit. Similar to ranking the units for priority (see Section 2.3), sub-areas were evaluated and management practices for them prioritized. Units that are contributing the most sediment should, to the extent possible, be targeted first in order to reduce sediment delivery to the ocean in a timely manner. Table 3-2 presents relative implementation priorities for the recommended management practices based on an evaluation of their load reduction of potential and relative cost. Table 3-3 presents the management units in order of priority and the implementation priority of management practices within each unit.

The recommended management practices identified in this WBP can each be implemented independently. Due to the lack of quantitative data on the source and amounts of pollutants in the watershed, the prioritization is based on best estimates of where treatments are possible and which treatments will provide the most effective pollutant removal. However, in general the prioritization rules, criteria and rankings provided should be considered as guidelines, and if there is an immediate opportunity (e.g. via available funding, volunteer work), to implement a lower-ranking management practice that should be done. To reiterate, ultimately reduction of NPS pollution is a function of the types, numbers and extent of spatial coverage of the management practices installed.

Table 3-2. Relative Implementation Priorities

Management Practice	Load Reduction Potential	Relative Cost	Implementation Priority
Baffle box	High	High	High
Coir logs	Moderate	Moderate	Moderate
Curb inlet baskets	High	Low	High
Extended detention basin	Moderate	High	High
Good housekeeping practices	Moderate	Low	High
Grass swale	Low	Moderate	Low
Green roof – Green grid	Low	High	Low
Infiltration trench	Moderate	Moderate	Moderate
Invasive species control	Moderate	High	Low
Modular wetland	High	Moderate	High
Natural/Native vegetation	Low	Moderate	Low
Porous pavement*	Moderate	Moderate	Moderate
Rain barrels	Low	Low	Moderate
Subsurface storage	High	High	Moderate
Turf reinforcement mats	High	High	Moderate

Table 3-3. Priority Management Practices by Management Unit

Management Practice	Priority
Upland Forest Management Unit	High
Extended detention basin	High
Invasive species control	Low
Natural/Native vegetation	Low
Steep Slopes Management Unit	High
Baffle box	High
Coir logs	High
Infiltration trench	Moderate
Natural/Native vegetation	Low
Turf reinforcement mats	Moderate
Urban Management Unit	High
Baffle box	High
Curb inlet baskets	High
Good housekeeping practices	Low
Grass swale	Moderate
Green roof – Green grid	Low

Management Practice	Priority
Urban Management Unit (cont'd)	High
Infiltration trench	Moderate
Modular wetland	High
Natural/Native vegetation	Low
Porous pavement	Moderate
Rain barrels	Low
Subsurface storage	Moderate
Stream Channel Management Unit[42]	Moderate
Coir logs	Moderate
Natural/Native vegetation	Moderate
Turf reinforcement mats	High

3.2.1 Implementing Management Practices

A review of laws, ordinances, government programs and plans pertaining to NPS and point source pollutants was conducted to determine if the recommended practices are required to comply with a rule or law and/or program or plan (see Section 1.2). In many locations identified in this report where practices should be installed there are no regulations that require installation or implementation. However, installation of the recommended practices is compatible with, and often supported by programs, plans, and regulations addressing and governing NPS and point source pollution control. There are also legal issues and interpretations of laws governing NPS pollutants that are currently being discussed between regulatory agencies that will have bearing on the responsibility of NPS pollution control.[43]

An important component of an implementation strategy is identification of the entities responsible for implementing the range of management practices. Recommended management practices can be required under a regulatory program or implemented voluntarily. Often, overall implementation of a WBP is accomplished through the joint efforts of private and public entities. Responsibility for implementing management practices will often fall on landowners of the parcel or site where the practices will be installed. In many cases there will be more than one entity involved, particular at different stages of the process, so ongoing coordination will be needed and a lead entity needs to be identified. In Wailupe Watershed, entities that may implement the recommended management practices include: USACE, DLNR, HIDOT, CCH, commercial businesses, private land owners, community groups/volunteers.

3.3 Measurable Milestones

There are two types of milestones that can be used to evaluate whether pollution control measures are being implemented, and if load reductions and load targets are being achieved. The former relates to measuring the success of program implementation – are identified management practices being implemented in areas identified, in a timely fashion, cost-effectively, etc. The latter specifically addresses

[42] The USACE is currently working on a flood control project in Wailupe. As part of this project they will be developing detailed designs to control bank erosion and will likely be prioritizing sections of the channel for construction and the types of practices to install.

[43] CCH submitted a draft NPDES permit to HIDOH for review. HIDOH is addressing issues including the footprint and contributing area of the MS4, and whether NPS pollutants delivered into the MS4 become point source pollutants.

the effectiveness of the management practices in achieving reductions in identified pollutant loads, and related improvements to the overall health of the system. In the WBP for Wailupe Watershed, this refers to reducing sediment loading and discharge into the waterways, and improved health of Maunalua Bay.

3.3.1 Program Implementation

Factors such as funding availability, participation of managing and regulatory entities, and effectiveness of pollutant load reduction will influence feasibility of management measure implementation and the implementation timeline. Milestones for Wailupe Watershed can be assigned to management measures as a means to support scheduling and track tasks (Table 3-4). EPA gives three examples of times scales: short-term (1 to 2 years); mid-term (3 to 5 years); and long-term (5 to 10 years or longer).

Table 3-4. Implementation Timeframe for Management Measures

Management Measure	Implementation Timeframe
Bioengineered filtering system	Mid-term
Capture and filter sediment	Short-term
Channel stabilization	Short-term
Detention/retention	Long-term
Erosion protection of bare or exposed areas	Short-term
Flow restrictors/regulators	Long-term
Household generation	Short-term
Identify, prioritize, schedule retrofit opportunities	Short-term
Infiltration	Mid-term
Instream sediment load control	Long-term
Operation and Maintenance	Short-term
Restore natural systems	Long-term
Run-off interception/control	Mid-term
Slope energy	Short-term
Streambank preservation/enhancement	Mid-term

Development of an implementation strategy requires selecting practices, securing funds, establishing time-scales, and planning tasks. EPA suggests outlining tasks and the level of effort for each to establish a baseline for time estimates. It is also necessary to collectively discuss tasks and identify those that are feasible and identify the responsible parties (USEPA 2008). Table 3-5 identifies some of the required tasks for each of the recommended management practices. As the implementation process moves forward, additional work will be needed to fund the efforts and distribute work requirements. An implementation strategy for education and outreach activities is presented in Section 5.

3.3.2 Pollution Reduction Targets

Ideally, a WBP should identify specific targets for load reductions of identified pollutants (i.e., sediment). The practical reality of this WBP is that there is no baseline water quality data for use in establishing specific reduction targets. It will be difficult to quantify specific pollution reduction targets for Wailupe Watershed without this information.

Table 3-5. Management Practice Installation Tasks

Management Practice	Tasks
Baffle Box	– Location logistics – Drainage size – O&M
Coir logs	– Available material – Installation – O&M
Curb inlet baskets,	– Location logistics – O&M
Extended detention basin	– Drainage size – Permits – Construction – O&M
Good housekeeping practices	– Education/Outreach – Community acceptance
Grass swale	– Location logistics – Community acceptance – O&M
Green roof – green grid	– Location logistics – O&M
Infiltration trench	– Location logistics – Community acceptance – O&M
Invasive species control	– Develop and Implement plans
Modular wetland	– Location logistics – O&M
Natural/native vegetation	– Location logistics – Irrigation – O&M
Porous pavement	– Commercial/business support – Community acceptance – O&M
Rain barrels	– Education/Outreach – Distribution
Retention pond	– Location logistics – Community acceptance – O&M
Subsurface storage	– Location logistics – O&M
Turf reinforcement mats	– Available material – Installation – O&M

Monitoring efforts to evaluate whether management practices are reducing NPS pollutants are included in Section 4, *Evaluation and Monitoring*. An example indicator for measuring pollutant reductions by the management practices is the presence of sediments captured by the installed structures. The *Evaluation and Monitoring* section addresses both the current lack of available information and the need for ongoing monitoring to set targets and measure progress towards reducing pollutant loads. Indicators will provide quantitative measurements of progress toward meeting goals and will be easily communicated to target audiences. The indicators and associated targets will serve as triggers to indicate whether progress is being made and whether the implementation approach needs to be reevaluated (see Section 3.4). It is important to note that often, long and uncertain lag times occur between implementation and response at the watershed level. This timing is accounted for in the evaluation and monitoring framework.

3.4 Adaptive Management

Adaptive management is defined as a systematic process for continually improving management policies and practices by learning from the outcomes of past and current management activities. An adaptive management process will be used in the implementation of the WBP; for example it might be used to adjust priorities and actions should load reductions and load targets not be achieved. Adaptive management recognizes that there is a level of uncertainty about the ‘best’ policy or practice for a particular management issue, and requires that each management decision be revisited in the future to determine if it is providing the desired outcome. The approach builds upon prior results, both positive and negative, and allows managers to continually reassess and incorporate new knowledge into management practices.

Management actions in a WBP guided by adaptive management can be viewed as hypotheses and their implementation as tests of those hypotheses. *A priori* planning and test design can allow managers to better determine if actions are effective at achieving a management objective. For example, monitoring before and after installation might assess the effectiveness of a pollution control method. Once an action has been completed, the next, equally important, step in an adaptive management protocol is the assessment of the action’s effectiveness (results). A review and evaluation of the results allows managers to decide whether to continue the action or to change course. This investigational approach to management means that regular feedback loops guide managers’ decisions and ensure that future strategies better define and approach the objectives of the WBP.

Adaptive management is a powerful way to approach a methodology for effectively achieving load reductions and meeting load targets, but it is also time and personnel intensive. Designing a plan that incorporates adaptive management takes more time initially, but can lead to shorter implementation times and greater efficiency later. An adaptive management plan requires an extensive review of current scientific literature and existing management practices, and consultations with experts in the field. It also requires that the implementation of management practices and evaluation protocols be thoughtfully designed, and it must include feedback mechanisms for reassessing management strategies and changing them, if necessary. As additional information about agents and processes impacting Maunalua Bay becomes available, priority pollutants of concern could shift, with corresponding adjustments to management practices required. The WBP is a living document that will benefit from regular review and updating, to remain current and to support effective management. Section 4, *Evaluation and Monitoring*, illustrates how adaptive management will be used in the plan’s implementation.

4. Evaluation and Monitoring

The objective of the *Evaluation and Monitoring* section is to provide guidance for monitoring and evaluating the effectiveness of the recommended management practices in reducing NPS pollutants once they are installed. This section presents guidelines and methodologies that will provide qualitative and quantitative assessments that can be used to determine effectiveness of the practices and adaptively apply the findings to other watersheds.

4.1 Monitoring Logistics

4.1.1 Drivers for Monitoring

Monitoring is conducted for both regulatory and non-regulatory purposes, although in many cases it is driven by regulations even if the regulation itself does not “require” monitoring. Section 208 of the 1972 Clean Water Act (CWA) requires every state to establish effective practices to control NPS pollution. Urban areas must meet requirements of municipal separate storm sewer system (MS4) permits, and many industries and institutions such as state departments of transportation must also meet National Pollutant Discharge Elimination System (NPDES) storm water permit requirements. Even if monitoring is not required under the NPDES permit, operators of regulated MS4s are required to develop a Storm Water Management Plan (SWMP) that includes measurable goals and states their intention to implement needed storm water management controls (management practices). MS4 operators are also required to assess controls and the effectiveness of their storm water programs and reduce the discharge of pollutants to the “maximum extent practicable.”

In many cases, the recognition of CWA Section 303(d) listing and the subsequent development of Total Maximum Daily Loads (TMDL) for that water body triggers a water quality monitoring program. Under CWA Section 303(d), the EPA requires that each state develop a list of waters that fail to meet established water quality standards. Waters that are on the 303(d) list of impaired water bodies are defined as water bodies having beneficial uses but that are impaired by one or more pollutants. The law requires that states establish priority rankings for waters on the list and develop TMDLs for these waters. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive, also known as the loading capacity, so that the water body will meet water quality standards. The TMDL allocates that load to point and nonpoint sources, which includes both anthropogenic and natural background sources of pollutants. If the TMDL identifies nonpoint sources of pollutants as a major cause of impairment, states can apply for EPA funded grants, called Section 319 grants. These grants can be used to fund state programs for nonpoint source assessment and control as well as individual projects.

4.1.2 Monitoring Program Administration

The City and County of Honolulu (CCH) and the Hawaiʻi Department of Transportation (HIDOT) are required to undertake a comprehensive water quality monitoring and activity tracking/reporting program to comply with NPDES Permits No. HI S000002 and HI S000001, respectively. Both permits describe in Part E the preparation of an Annual Monitoring Plan, the development of a Waste Load Allocation (WLA) Implementation and Monitoring Plan, and development of Implementation and Monitoring Plans for additional WLA’s as adopted by DOH. These requirements are addressed in the SWMPs developed by CCH and HIDOT (CCH-ENV 2007; HIDOT 2007). There are no specific monitoring requirements or WLAs for Wailupe Stream or the nine other streams that drain into Maunalua Bay.

Emphasis in both the CCH and HIDOT WLA Monitoring Plans is on actions in the Ala Wai Canal, Kawa Stream, and Waimanalo Stream; all of which are currently on the 303(d) list of impaired waters and have established TMDLs. In response to waste load reduction goals set by USEPA and HDOH, HIDOT worked jointly with CCH to propose implementation and monitoring plans for each of these water bodies (see Oahu SWMP Appendices M.2, M.3, M.4). The WLA Monitoring Plans are specific to water quality monitoring and activity tracking to demonstrate efforts towards compliance. The scope of work outlined in these plans includes drainage area characterization and water quality monitoring to develop a monitoring approach and configure monitoring locations. The U.S. Geological Survey (USGS) is also involved in the program through a separate contract with HIDOT Highways to conduct in-stream and outfall monitoring. The SWMP includes the development of baseline data and a database to record field collection and sampling. HIDOT and CCH will use the databases to estimate the reduction of pollutants once permanent management practices are installed.

Wailupe Stream is not currently on the 303(d) list of impaired water bodies and therefore no TMDL has been developed for it. TMDL monitoring is only done after the water body is 303(d) listed and daily loads of the impairing water constituents are established. This is relevant to Wailupe Stream since it means that routine monitoring will not occur under CWA unless there is a specific compliance reason to conduct the monitoring (e.g. spill of pollutant that requires post clean up monitoring). All water bodies in the State are required to adhere to water quality standards, however, most streams are not routinely sampled and determining if a stream is compliant with standards is difficult. It is likely that Wailupe Stream is not compliant during moderate to high discharge events, due to elevated levels of sediments. Maunalua Bay is listed on the 303(d) impaired water body list, but the streams terminating in the Bay are not listed.

4.1.3 Monitoring and Data Collection Responsibility

4.1.3.1 Existing Monitoring Efforts in Wailupe Watershed

Currently the USGS, the National Weather Service (NWS), and Mālama Maunalua are the only entities that are routinely and systematically collecting hydrologic data in Wailupe Watershed (see Section 4.1.4). The USGS maintains a stream flow gage on Wailupe Stream that continuously records stream flow and a suspended sediment sampler to collect samples during moderate to high flows. There is no water quality sampling program for other parameters in the watershed, and as a result there is very little available data to characterize baseline water quality conditions. The NWS maintains a weather station at Wailupe Valley School, collecting data on a variety of meteorological variables including rainfall and temperature. Mālama Maunalua installed two rain gages in Wailupe Watershed along the headwater ridgeline on top of the pali and Wiliwilinui ridge above ‘Āina Haina neighborhood during the spring of 2010.

4.1.3.2 Management of Wailupe Watershed Monitoring

At present there is no single entity responsible for collecting and maintaining data and information on water quality and/or and watershed conditions in Wailupe Watershed. This WBP has characterized the watershed conditions and made recommendations to on how to reduce NPS pollutants generated from the watershed and discharged into Wailupe Stream and the ocean. This is an essential first step towards improving the health of the watershed and its receiving waters, Maunalua Bay. However, there is still a need to develop a water quality monitoring program that can provide baseline data and numeric criteria to evaluate the expected changes of water quality following implementation of some or all of the management practices recommended in Section 2: *Pollution Control Strategies*. There needs to be an identified entity conducting baseline monitoring in the watershed, even if not required. Similarly, monitoring the effectiveness of the practices once they are installed is not necessarily required under the CWA, but should be conducted. It is recommended that Mālama Maunalua take the lead on managing, collecting and analyzing the information recommended as part of implementation, baseline and effectiveness monitoring for Wailupe Watershed. Mālama Maunalua's prior collaborative relationships with various government agencies and private and public partners uniquely qualify this organization to spearhead this effort.

In order to maximize the effectiveness of data and information collected and to increase its exposure and usefulness to larger stakeholder groups, a central repository should be developed to house the data collected by the various parties. A geo-database would be the most desirable platform for storage of the various data collected in Wailupe Watershed (see Section 4.4.3).

4.1.4 Maunalua Mauka Watch Community Volunteer Monitoring Programs

Within this WBP a site-based monitoring regime is identified for each of the recommended actions. In addition, Mālama Maunalua has begun community efforts through the *Maunalua Mauka Watch* program that address related needs for region-wide monitoring across all watersheds. Three volunteer based monitoring programs for water quality, rainfall and pollutant source inventories have been established. A summary of each is below. Full descriptions of the programs are found in the *Mauka Watch Volunteer Monitoring Program Plan* (Mālama Maunalua 2009) and associated Quality Assurance Project Plan (QAPP). Data now being gathered are helping to develop a baseline for Maunalua's streams; and the hope is that in future years citizen data will also assist in evaluating the effectiveness of NPS pollutant/sediment reduction measures that are implemented in the watersheds.

4.1.4.1 Volunteer Water Quality Monitoring Program

This mainstay of the *Mauka Watch* program was launched in 2009, with 20 volunteers trained for citizen water quality monitoring. Bi-weekly monitoring was conducted at the first two sites (Wailupe and Kuliʻouʻou) through February 2010, at which time the program was expanded to include an additional 15 volunteers and three additional sites. Volunteers presently contribute approximately 40 hours per month to this activity. Tests and observations collected in the field include turbidity, conductivity, DO, pH, nutrients and trash. Additional monitoring sites and parameters may be added in 2011-12. Data will soon be available for public viewing via an interactive online map at www.malamamaunalua.org.

4.1.4.2 Stream Team Program

In June 2009, a survey instrument ('stream reconnaissance survey') derived from the Unified Stream Assessment and Unified Subwatershed and Site Reconnaissance Assessment was deployed.[44] Nine volunteers were trained and all Maunalua region streams were surveyed between August 2009 and September 2010. Neighborhood and Reach (channel) assessments were conducted to identify potential pollutant types and impact sites. A report of findings has been produced for Wailupe and Kuliʻouʻou Streams, and a detailed map and report of the remaining streams is in progress and expected be completed by December 2010. Mālama Maunalua will use the survey data to pinpoint outreach and education needs (mainly for nonstructural measures) for each watershed, and as a tool for initiating identified green infrastructure projects with federal, state and local agencies.

[44] Available from the Center for Watershed Protection, www.cwp.org.

4.1.4.3 Volunteer Rainfall Monitoring (Rain Gage) Project

This new project creates partnerships between schools, agencies, and residents to install two rain gages per watershed for each of the region's 10 watersheds. Historical rainfall data for the region is nearly nonexistent and the goal of this program is to create a dataset that can be used to support watershed planning and management. Five gages have been installed by volunteers and staff; an additional five are scheduled to be installed by the end of 2010; and the remaining ten gages will be installed during 2011. A rainfall data system connected with Mālama Maunalua's online web map is expected to be in place by December 2010 with data available for view by March 2011.

4.2 Types of Monitoring

Monitoring is a process that provides feedback to managers and stakeholders to verify if pollution control strategies are being installed and working as designed, and if water quality is improving. Some level of monitoring is necessary to verify and justify the installation of practices and provide support for future installation of management practices. Measurable progress is critical to ensuring continued support of watershed management efforts, and progress is best demonstrated through monitoring data that accurately reflects improved water quality conditions relevant to the identified problems. Other applications of monitoring data include: analyzing long-term trends; documenting changes in management and pollutant source activities; measuring performance of specific management practices; calibrating or validating models; filling data gaps; tracking compliance; and providing information to educate stakeholders.

Monitoring includes quantitative and qualitative methods that can range from visual verification of a practice in the field to complex statistical approaches requiring experimental designs. Quantitative monitoring methods are used to quantify pollutant responses to installed management practices and could include sampling of water quality, measurements of solids sequestered, vegetation density, channel morphology, and hydrology. Qualitative approaches often utilize repeated visits to the location of a practice installation or reference area that the practice is designed to improve and taking photographs that show the practices in use or changes to the reference area over time. The level of effort for monitoring can vary significantly, and practical considerations such as availability of funds and the training and background of the persons conducting the monitoring need to be considered when designing the monitoring program. In many instances implementation monitoring is the minimum level of effort that can be performed. This level is often is all that is needed to ensure that some level of pollutant reduction is occurring by simply documenting the pollution control practices are installed.

There are seven types of monitoring used in watershed management (see Box 1 and Table 4-1) (USEPA 1996). There can be considerable overlap and some redundancy between the seven and there is no strict definition or standards that define them.

Box 1. Types of Monitoring

Trend monitoring. Use of the adjective "*trend*" implies that measurements will be made at regular, well-spaced time intervals in order to determine the long-term trend in a particular parameter. Typically the observations are not taken specifically to evaluate management practices (as in effectiveness monitoring), management activities (as in project monitoring), water quality models (as in validation monitoring), or water quality standards (as in compliance monitoring), although trend data may be utilized for one or all of these other purposes.

Baseline monitoring is used to characterize existing water quality and watershed conditions, and to establish a database for planning or future comparisons. The intent of baseline monitoring is to capture much of the temporal variability of the constituent(s) of interest, but there is no explicit end point at which continued baseline monitoring becomes trend or effectiveness monitoring.

Implementation monitoring assesses whether activities, actions or installation of practices were carried out as planned. The most common use of implementation monitoring is to determine whether management practices were implemented as recommended. Typically, this is carried out as an administrative review and does not involve any water quality measurements. Many believe that implementation monitoring is the most cost-effective means to reduce NPS pollution because it provides immediate feedback to the managers on whether the practices installation are being carried out as intended.

Effectiveness monitoring. While implementation monitoring is used to assess whether a particular activity was carried out as planned, effectiveness monitoring is used to evaluate whether the specified practice activities had the desired effect. Confusion arises over whether effectiveness monitoring should be limited to evaluating individual practices or whether it also can be used to evaluate the total effect of an entire set of practices on water quality and watershed condition.

Monitoring the effectiveness of individual practices, such as the capture of fine sediments by a baffle box, is an important part of the overall process of controlling NPS pollution. However, in most cases the monitoring of individual practices is quite different from monitoring to determine whether the cumulative effect of all or portion of the practices result in reducing the generation and transport of NPS pollutant to receiving waters. Evaluating individual practices may require detailed and specialized measurements best made at the site of, or immediately adjacent to, the management practice. In contrast, monitoring the overall effectiveness of practices is usually done at reference locations along the stream channel or in the ocean. Thus, it may be difficult to relate the measurements at reference locations to the effectiveness of individual practices.

Project monitoring assesses the impact of a particular activity or project, such as good housekeeping practices.

Validation monitoring refers to the quantitative evaluation of a model that is used to estimate pollutant load reductions or achieve some other objective. The intensity and type of sampling for validation monitoring should be consistent with the output of the model being validated.

Compliance monitoring is used to determine whether specified water-quality criteria are being met. The criteria can be numerical or descriptive. Usually the regulations associated with individual criterion specify the location, frequency, and method of measurement.

Table 4-1. General Characteristics of Monitoring Types

(USEPA 1996)

Type of Monitoring	Location of Monitoring	Frequency of Measurements	Duration of Monitoring	Intensity of Data Analysis
Trend	Reference Site	Low	Long	Low to moderate
Baseline	Installation & Reference Site	Low	Short to medium	Low to moderate
Implementation	Installation site	Variable	Duration of project	Low
Effectiveness	Installation & Reference Site	Medium to high	Usually short to medium	Medium
Project	Variable	Medium to high	Greater than project duration	Medium
Validation	Installation & Reference Site	High	Usually medium to long	High
Compliance	Installation Site	Variable	Dependant on project	Moderate to high

This plan focuses on three types of monitoring: implementation, baseline and effectiveness. These three monitoring types best address the intent of the *Evaluation and Monitoring* requirements and will provide the necessary information to determine if NPS pollutant reduction is occurring in Wailupe Watershed and to help refine future selection of practices for other watersheds.

4.2.1 Implementation Monitoring

Implementation monitoring documents information about the installation of management practices including: which management practices are being implemented; where they were installed; when they were installed; the entity that installed them; and what pollutants they are targeting. An implementation monitoring program is a mechanism to track progress and provide verification that a recommended practice was installed successfully. The normal sequence of events leading up to implementation monitoring is that a need for a practice to reduce NPS pollutant(s) and the entity responsible for its implementation are identified. The responsible entity then develops detailed engineering designs, generates a cost estimate to install the design and installs the design. In reality, this "normal" sequence often involves a considerable amount of time between the identification of the need and installation of the practice. The biggest reason for this lag time is the lack of funding to design and install the practice. An implementation monitoring plan can be used to document and identify the phases of the process that result in delays to installation to help develop solutions to expedite the process. Implementation monitoring is described in detail in the USEPA report *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures - Urban* (USEPA 2001).

4.2.2 Baseline Monitoring

Baseline and effectiveness monitoring are temporally linked by pre- and post-implementation of a practice. Baseline monitoring is the initial pre-project collection of data and information, this transitions to effectiveness monitoring following installation of a practice or beginning of an activity. Baseline monitoring documents existing water quality and watershed conditions and is used to compare changes to a parameter being sampled following implementation of a practice. Water quality baseline data is usually collected at representative locations such as confluence of channels, storm water outfall locations and at the mouth of streams.

The main objectives of baseline monitoring are to document existing conditions in a watershed by: identifying locations where pollutants are generated; sampling water quality in surface runoff, streams and ocean waters; and mapping flow transport pathways of pollutants. This allows a characterization of the extent of NPS pollution problems in the watershed and its water bodies that can be used to determine the stressors to the aquatic system and assess changes (i.e. post-implementation of management practices). This characterization can be used to tailor the management practice design and identify pollutants that are impairing water quality and to identify location to install practices. Before new data are collected, available historical data, as well as data currently being collected should be identified and consolidated and have their validity and usability assessed.[45] Existing data can help in deciding what other data sets need to be collected, and how to expand the original data set by either continuing with existing protocols or developing new ones that can utilize the existing data. Pooling individual studies assists in identifying trends in environmental conditions and comparing effectiveness of implemented management practices.

Baseline measurements of pollutants in water bodies are often collected to determine whether violations of water quality standards are occurring. Once a problem is identified, determining its spatial scale and geographical and temporal extent helps to focus management efforts. Determining the causes and sources of the impairments are often more difficult than determining its presence because there are often many potential sources with overlapping influences.

Controlling for influencing factors such as climate is necessary if baseline monitoring is to be used as a reference point for trend analysis and management decisions. The ability to relate water quality responses to land management depends on the quality and quantity of data collected prior to any changes of land management practices.

4.2.3 Effectiveness Monitoring

4.2.3.1 Definition and Purpose

Effectiveness monitoring is used to determine whether management practices, as designed and implemented, are functioning as planned and improving water quality. This type of monitoring is essential for determining how effective the practices are once they are installed. The information obtained from effectiveness monitoring can be used to adjust design of the practices, change the types of practices if the installed practices are not effective, identify locations for future installations, and document

[45] Data validity implies that individual data points are considered accurate and precise with known field and laboratory methods. Data usability implies that a database demonstrates an overall temporal or spatial pattern.

reductions of NPS pollutants. Effectiveness monitoring is the subject of the USEPA guidance document *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA 1996).

Water quality monitoring is an integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses (ITFM 1995). An important water quality monitoring element for NPS pollutants is relating the physical, chemical, and biological characteristics of receiving waters to land use characteristics. The most desirable scenario for conducting effectiveness monitoring is to have a robust set of water quality baseline data to compare to the post-practice installation water quality. This scenario will allow a statistical analysis on post-practice load reductions and water quality improvement. When baseline data is unavailable the probability of computing load reductions is low, making load monitoring difficult. Load monitoring requires considerable effort and should follow protocols documented in *Urban Storm Water BMP Performance Monitoring: A Guidance Manual for Meeting the National Storm Water BMP Database Requirements* (GeoSyntec and ASCE 2002). Due to potentially high variability of discharge and pollutant concentrations in Wailupe Watershed impacted by both point and non-point sources, collecting accurate and sufficient data from a significant number of storm events and base flows over a range of conditions (e.g., season, land cover) is important.

4.2.3.2 Sampling Locations

Effectiveness monitoring is primarily conducted at the location where the pollutant control management practice is installed and on areas along the flow pathway down gradient. Baseline data collected prior to the installation of a practice will provide a reference condition for which to make post installation comparisons against and compute NPS pollutant load reductions. Selection of reference sampling sites that are representative of the flow network is an important step in the monitoring system design. Effectiveness monitoring is the easiest and most accurate way to evaluate if the practice is working as designed. Effectiveness monitoring can also be conducted at representative locations on the water bodies or surface areas located down the flow gradient from the installed practice. However, it is often difficult to correlate the changes measured at sites located away from the practice installation due to unknown inputs and outputs that occur between the installed and sampling sites. In addition, when multiple practices are installed, ascribing changes to one practice becomes difficult and usually the reference sample value is representative of the cumulative impacts derived from all the practices. For this reason some watershed scientists divide monitoring into two categories based on the sampling location following installation of management practices. Samples collected at the installation site are defined as effectiveness monitoring and those collected at reference locations are classified as trend monitoring. In general the monitoring output of these two monitoring types are positively correlated: if a practice is effective (i.e. shown to be trapping fine sediment), then the trend in water quality at a down gradient stream sampling reference site will likely show a decrease in turbidity. The effectiveness monitoring methods identified in Section 4.3.3 and Table 4-3 are focused on monitoring effectiveness at the installation locations of the management practices.

4.2.3.3 Methods

Effectiveness monitoring can be carried out using quantitative and/or qualitative methods. Qualitative methods are generally easy to conduct, less costly, and do not require significant training to carry out compared to quantitative methods. Qualitative methods are however prone to subjective analysis. Protocols should minimize opportunities for bias and subjectivity during monitoring activities. When utilizing volunteers to conduct monitoring providing sufficient subject matter background is recommended.

Quantitative methods range in complexity, level of effort to carry out, and cost. Selection of the quantitative method should in part be based on the minimum level of effort needed to determine if the installed practice is functioning effectively and meeting regulatory compliance requirements. For example, it may be sufficient to measure the amount of sediment trapped in a baffle box periodically to determine how much sediment was captured per unit time. This would allow calculation of the amount of sediment removed from storm water that entered the baffle box, and would equate to a reduction of sediment delivered to the receiving waters. The baffle box would be considered 'effective' since it captured sediment. A more involved monitoring scheme would be needed to determine the efficiency of a baffle box and compute the load reduction for a storm event. For example, measurements of flow into and out of the baffle box during a storm event would need to be collected and the concentration of sediment in each measured. This sampling approach allows computation of the efficiency of the baffle box and the pollutant load reduction. It requires more equipment, labor, and total cost to implement compared to simply measuring the sediment in the baffle box.

The reduction in pollutant concentration that a baffle box or other installed treatment device provides can be quantified by sampling water entering and leaving the device and comparing the change. The three commonly used measures are concentration grab samples, total contaminant load conveyed over a specified duration (i.e. storm event), or event mean concentration (EMC). An understanding of how the monitoring data will be analyzed and evaluated is essential to determine the collection methods. Methods of estimating water quality concentration for various pollutants require significant time, persons with technical skills and adequate funds. They are not recommended as part of the effectiveness monitoring presented in Section 4.3.3, but rather presented as specific examples of rigorous numeric methods that could be conducted.

- Pollutant concentration measured at individual points in time can be useful to determine concentration as a function of time or if the "first flush" phenomenon occurred during a specific storm event. This type of monitoring is best when focusing on outflow monitoring.
- Contaminant loads are typically calculated by using an average concentration multiplied by the total volume over the averaging period. Accurate flow measurement or modeling is essential for load estimation. This method can be used to determine dry weather flows that can contribute substantially to long-term loading.
- EMC is a method for characterizing pollutant concentrations in receiving water from a runoff event. The value is determined by compositing (in proportion to flow rate) a set of samples, taken at various points in time during a runoff event, into a single sample for analysis. The primary aim is to analyze rain storm events at a site. It often provides the most useful means to quantify the pollution level resulting from a runoff event.

In many instances the proper operation and maintenance (O&M) of a management practice is as important as the proper design and installation. Regular maintenance and inspection of a management practice insures the practice is functioning at full effectiveness. Deferred maintenance can adversely affect a practices' performance and can result in pollutants bypassing or moving through the structure without reduction. Inspections can also identify repair needs or retrofits, as well as areas that require additional management resources. Effectiveness monitoring can be coordinated with routine maintenance schedules and if possible personnel performing maintenance can be enlisted to conduct the effectiveness monitoring.

4.3 Monitoring in Wailupe Watershed

4.3.1 Implementation Monitoring for Wailupe Watershed

For each management practice installed in Wailupe Watershed, the following information should be collected. The information should be maintained in a GIS database and/or relational database (see Section 4.4.3). Information on implementation should be conveyed to DOH, HIDOT, CCH, USGS, U.S. Army Corps of Engineers, and other entities to be determined.

- Details on specific type of management practice
- Management unit
- Location installed
- Construction start date
- Construction completion date
- Entities involved
- Purpose and targeted pollutants
- Expected performance (if applicable)
- Issues and delays before implementation (if applicable)

4.3.2 Monitoring of Environmental Conditions in Wailupe Watershed

4.3.2.1 Baseline Data for Wailupe Watershed

In general, there is a lack of quantitative data for Wailupe Watershed to develop numerical estimates on the concentration of pollutants in runoff water across the watershed. There is sufficient qualitative information to make informed inferences regarding where pollutants loads are generated, what types of pollutants are being generated, and the flows paths that the pollutants use as they are transported off the watershed and into Wailupe Stream and the ocean (see Section I: *Watershed Characterization*). In addition, there are data sets generated from water quality samples collected in Maunalua Bay that support the hypothesis that land based pollutants are the source of pollutants found in the Bay. Baseline data collected in all ten of the watersheds that drain into the Bay would be extremely useful in narrowing down the pollutant constituents that each watershed is generating, as well as the watersheds that are contributing the highest pollutant loads.

Four management units have been delineated in Wailupe Watershed for focusing NPS pollutant types and control methods (see Section 2, *Pollution Control Strategies*). A baseline data monitoring plan is needed for each of these management units. Monitoring methods to collect baseline information that address the identified priority NPS pollution parameters are identified in Table 4-2. Baseline data is not necessary to evaluate the effectiveness of the management practices that are recommended for installation in this WBP. However, establishing baseline sampling (reference) sites across the four management units will provide data and information that can be used for baseline and trend monitoring. Trend monitoring can supplement effectiveness monitoring and can be used to correlate the management practice installation and trends in water quality and watershed conditions.

Table 4-2. Baseline Monitoring Parameters

Monitoring Location	Monitoring Objective	Method
Upland Forest		
Exposed faces beneath ridgelines	Estimate exposed surface area and potential sediment loss.	Measure surface area, establish photo points, establish erosion pins
Ridge line utility access road, and upland trails	Inventory condition to determine specific locations for BMPs to reduce sediment production.	Ground based survey of road and trails
Upland forested plots (to be determined)	Determine percent ground cover and vegetation types for use in erosion models and assessing ungulate impacts.	Vegetation transect to compute percent cover and species composition
Confluence of three major tributaries of Wailupe Stream above the detention basin	Determine baseline water quality, use for long term trend monitoring	Collect and analyze water samples at routine intervals.
Steep Slopes		
Upper, middle and toe area of slope on west side of ʻĀina Haina below Wiliwilinui ridge.	Determine percent ground cover, erosion rates; identify erosion hotspots locations for coir log or other erosion control structure installation.	Establish transects parallel to slope, measure vegetation density, install erosion pins, establish photo points, and assess condition of gulches draining slopes for erosion hotspot inventory.
Urban		
Collect water samples at four storm water pipe outfalls along Wailupe Stream and four at ocean.	Determine baseline water quality of storm water runoff, can be used for long term trend analysis and identifying pollutant hotspots to remediate.	Collect grab samples during runoff events and analyze at lab.
Throughout residential and commercial areas.	Determine attitudes and views of stakeholders; assess willingness to alter behavior to reduce generation of NPSP.	Survey a subset of residents to determine activities and uses that generate NPSP.
Stream Channel		
Establish 6 reference monitoring locations on Wailupe Stream 1. Stream mouth (0+00) 2. + 600 ft. upstream 3. + 1800 ft. upstream 4. + 4330 ft upstream 5. + 6110 ft. upstream 6. + 8550ft. upstream	Determine baseline water quality, geomorphic, vegetation conditions that can be used to evaluate trends in variables following installation of practices, and to identify locations for installing future practices	Establish water quality stations collecting water samples concurrently at routine intervals, establish flow rating curves, establish cross section and longitude profiles, install erosion pins, install vegetation transects, establish photo points, conduct pebble counts, survey aquatic invertebrates

Establishment of and data acquisition from baseline sampling locations is expected to provide information that can be used to refine or identify new locations to install practices. A better understanding of the condition of the watershed through baseline data will lead to better decision-making regarding the type and locations to install practices. Two types of baseline monitoring sampling stations should be installed: (1) at specific NPS pollutant generating sites; and (2) at reference locations along Wailupe Stream and in the ocean near the stream's mouth.

The overall goals of implementing storm water management practices pertain to preventing pollution at the source, improving storm water outfall discharge quality, reducing pollutants loads to receiving waters, restoring ecosystem functions for beneficial uses and erosion protection, and complying with water quality standards. The priority parameters that monitoring of Wailupe Watershed will focus upon are 1) fine terrigenous sediments and 2) other NPS pollutants (see Section 1, *Watershed Characterization* and Section 2, *Pollution Control Strategies*).

4.3.3 Monitoring Effectiveness of Management Practices in Wailupe Watershed

This section provides information and guidance on monitoring the effectiveness of management practices once they are installed. Guidance is provided in the form of basic protocols. Results of effectiveness monitoring efforts should be maintained in a GIS database and/or relational database (see Section 4.4.3).

Table 4-3 summarizes information on effectiveness monitoring parameters for management practices in Wailupe Watershed. The protocols were developed based on the assumption that Mālama Maunalua volunteers would be conducting the effectiveness monitoring.

- **Analysis Type**: Specifies whether analysis will be quantitative or qualitative.
- **Protocol**: Identifies the type of protocol to be used for sampling
- **Target NPS**: Identifies the NPS pollutants being addressed by the management practice
- **Frequency**: Recommended frequency of monitoring efforts
- **Entity**: Persons or organization responsible for monitoring

Table 4-3. Effectiveness Monitoring for Management Practices

Practice	Monitoring Objective	Protocol	Target NPS Pollutants								Frequency
			Sediments	Nutrients	ODS	Pathogens	Metals	Hydrocarbons	Organics	Storm water flow	
Baffle box	Qualitative/ Quantitative	Visual assessment; sediment volume; grab sample	X	X	X	X	X	X	X		Biennially or prior to vault cleanout
Coir logs	Qualitative/ Quantitative	Photo point; sediment volume	X							X	Biennially
Curb inlet baskets	Qualitative	Debris type and volume	X	X	X	X	X	X	X		Concurrent with routine or as needed maintenance
Extended detention basin	Qualitative/ Quantitative	Visual assessment; sediment volume	X	X			X			X	Storm/runoff event; concurrent with routine maintenance
Good housekeeping practices	Qualitative	Survey		X	X				X		Annually
Grass swale	Qualitative	Visual assessment	X				X			X	Annually; storm event
Green roof – Green grid	Quantitative	Storm water volume								X	N/A
Infiltration trench	Qualitative	Visual assessment	X	X	X	X	X			X	Annually; storm event
Invasive species control	Qualitative/ Quantitative	Collaboration	X	X		X					N/A
Modular wetland	Qualitative/ Quantitative	Visual assessment; grab sample	X	X	X	X	X		X	X	Quarterly; storm events
Natural/Native vegetation	Qualitative/ Quantitative	Vegetation survey	X	X		X					Annually
Porous pavement	Qualitative	Visual assessment	X			X				X	Annually; storm event
Rain barrels	Quantitative	Interview								X	Annually
Subsurface storage	Quantitative	Storm water volume	X	X	X	X	X	X	X	X	Annually; storm event
Turf reinforcement mats	Quantitative	Visual assessment	X								Biennially; storm event

4.3.3.1 Protocols for Effectiveness Monitoring

This section identifies the type of practice, the objective(s) of monitoring efforts, monitoring protocols, and recommended monitoring frequency for each management practice.

4.3.3.2 Baffle Box

Practice Description: A baffle box is designed to capture pollutants three ways: trapping gross solids using a mesh grate, settling of particles in one of the chambers, or absorption onto a skimmer boom.

Monitoring Objective: (1) Qualitatively assess the amount of vegetation and rubbish trapped in the entry grate. (2) Quantify the amount of sediment deposited per unit time in the boxes' chambers. (3) Identify the chemical makeup of the substances contained in the deposited sediments.

Protocol: Access to the inside of a baffle box is obtained via ports or manholes located above each of the boxes' chambers. (1) Visual assessment of the type and quantity of gross solids (e.g., vegetation, rubbish, and other materials) should be made and recorded. (2) The volume of sediment particles in each of the chambers is the product of the average sediment layer thickness in each chamber and its area. The volumetric measure can be converted to mass by multiplying the volume times an average particle density. Thickness of the deposition layers can be determined using a graduate rod or other measuring instrument. To account for variability of the thickness of the deposition layer, four samples located at middle point along each of the chamber's walls should be collected and a mean thickness computed. (3) Sediment grab samples can be collected and sent to a laboratory to determine composition.

Frequency: Biennially or prior to vault cleanout.

4.3.3.3 Coir Logs

Practice Description: Coir logs are used to reduce slope length and are installed on the ground perpendicular to the slope. Runoff and material carried is dammed when it encounters the log; water eventually passes through the porous log while particles settle on the upslope side.

Monitoring Objective: Evaluate if the coir log is trapping sediment.

Protocol: Qualitative evaluation is conducted by establishing photo points and taking periodic pictures of the upslope face of coir log to visually assess presence of deposited sediment. Quantitative evaluation requires measurements of the volume of sediment on the upslope side of sediment. Volume is computed as the product of the thickness of deposit and it length and width along the face of the coir log.

Frequency: Biennially

4.3.3.4 Curb Inlet Baskets

Practice Description: Mesh grates placed inside curb inlets used to capture gross solids.

Monitoring Objective: Evaluate if gross solids are being captured.

Protocol: Document type and estimate volume of gross solids contained on mesh grate during cleaning inspections. Record composition of debris and estimate the dominant debris type.

Frequency: Concurrent with routine or as needed maintenance.

4.3.3.5 Extended Detention Basin

Practice Description: An excavated basin along a waterway fitted with a dam structure is used to temporarily impound runoff and allow particles in the water to settle out of suspension. Extended detention basins attenuate flow out of the basin and trap sediments entering into the basin.

Monitoring Objective: (1) Validate that storm water runoff is being retained. (2) Quantify amount of sediment trapped either per unit time or per storm event. Objective 2 requires surveillance of storm events and rapid mobilization of crews.

Protocol: (1) Visually inspect the basin during storm water runoff to confirm basin fills. (2) The volume of sediment is the product of the average sediment layer thickness in the basin and its area. Measure the thickness and area of sediment deposits to compute total volume of sediment trapped.

Frequency: Validation of the design to store water can be made during periodic storms that generate overland flow. Quantification of sediment amounts trapped can be done concurrent with routine maintenance to compute a quantity per unit time, or can be conducted immediately after a runoff event to compute quantity per unit time, and quantity per runoff event.

4.3.3.6 Good Housekeeping Practices

Practice Description: Actions and activities conducted by watershed dwellers that reduce the generation of NPS pollutants and runoff from their properties.

Monitoring Objective: To determine if behavioral changes or occurring, to what level and if they are reducing the generation of NPS pollutants.

Protocol: Conduct survey to document type, location, perceived effectiveness of implemented good housekeeping practices, and effectiveness of educational and outreach methods.

Frequency: Annually

4.3.3.7 Grass Swale

Practice Description: A shallow excavation lined with grass along a waterway that slows flow, temporarily impounds a portion of flow, and filters a portion of pollutants.

Monitoring Objective: To validate design is working.

Protocol: Visually inspect swales during runoff events to assess if water is retained and following event to verify that stagnant water conditions do not occur.

Frequency: Annually for one rain event

4.3.3.8 Green Roof – Green Grid

Practice Description: A multi layered assembly covered with plants that is used to reduce roof temperature, retain rainfall, and reduce runoff volume and contaminants in it from the roof area.

Monitoring Objective: Quantify the amount of runoff captured on roof area.

Protocol: An estimate of the amount of rain water that can be held in the grow medium of the structure is made as part of a green roof design. This estimate can be used to quantify the volume of rainfall can be sequestered on the roof.

Frequency: N/A

4.3.3.9 Infiltration Trench

Practice Description: A shallow trench that is backfilled with high rock or sand installed along an overland flow path used to promote runoff infiltration. Design is used to reduce overland flow concentration and capture pollutants into the subsurface.

Objective: To validate design is working.

Protocol: Visually inspect during runoff events to assess if retention of water is occurring and following event to verify that stagnant water conditions do not occur.

Frequency: Annually for one rain event

4.3.3.10 Invasive Species Control

Practice Description: Program that identifies actions and activities to prevent, reduce and remove invasive species from the ecosystem in order to enhance native ecological systems.

Monitoring Objective: To validate program implementation.

Protocol: The scope of evaluating an invasive species program is extensive and would be best approached by collaborating with university researchers, government agencies and/or other entities exploring invasive species management programs and assessments.

Frequency: N/A

4.3.3.11 Modular Wetland

Practice Description: A close-contained structure that mimics a natural wetland and uses natural processes to treat runoff generated from impervious surfaces in a watershed. The wetland is used to slow runoff and reduce pollutant loads.

Monitoring Objective: Evaluate the wetland during runoff event to verify it is sized and working properly.

Protocol: Collect a sample of water entering and exiting the wetland during runoff events. Analyze samples to determine the concentration of target pollutants and the percent reduction of each. Evaluate the structure to determine that over flow is not occurring and the system is functioning per its design. Inspect plants growing in the wetland to evaluate vigor and growth.

Frequency: Quarterly, for four separate rain events

4.3.3.12 Natural/Native Vegetation

Practice Description: Installation of native plant species along runoff paths, on exposed surfaces, or on areas following restoration activities (i.e. stream channel modifications).

Monitoring Objective: Determine success and survival rates of plants.

Protocol: Conduct vegetation surveys for small plots in which each plant is counted at periodic intervals to get a value of percent survival. Establish vegetation transects for large plots.

Frequency: Annually

4.3.3.13 Porous Pavement

Practice Description: Pavement supporting high usage by pedestrian and vehicular traffic that allows for rainfall infiltration into the subsurface.

Monitoring Objective: Verify that rain water infiltrates into the subsurface and runoff is minimized.

Protocol: Observe the porous pavement site during rainfall event and confirm rainfall infiltration into ground.

Frequency: Annually for one rain event

4.3.3.14 Rain Barrels

Practice Description: A device used to capture and store runoff generated from roof, slabs, and other impervious surfaces around residential and commercial buildings.

Monitoring Objective: Verify use by building owners and verify storage capacity of barrel.

Protocol: Interview property owners.

Frequency: Annual

4.3.3.15 Subsurface Storage

Practice Description: These are water storage devices that are installed in an excavated trench below ground and normally covered with fill. Most common uses are to incorporate the storage tank into surface landscaping or place beneath an area such as a parking lot. Water is removed either by gravity (flowing out openings in the base of the reservoir or out an overfill pipe), or by pumping. Subsurface storage reduces overland flow generated from impervious surfaces for use as irrigation water or for slow release into ground water.

Monitoring Objective: Verify installation and operation.

Protocol: Measure depth of water inside tank at access port immediately after rain event that generates overland flow. The volume stored and reduced as overland flow is the product of the depth of the water and the inside area of the reservoir.

Frequency: Annually for one rain event

4.3.3.16 Turf Reinforcement Mats

Practice Description: Turf reinforcement mats are made of synthetic fabric and are used to line a channel to protect the channel bed and bank from erosion. They allow water to infiltrate in substrate and provide for hydraulic connectivity to ground water.

Monitoring Objective: Verify installation is functioning.

Protocol: Following rain events that generate runoff, visually assess the stream reach with the mat to determine if cloth is intact.

Frequency: Biennially, for two separate rain events

4.3.3.17 Restrictions on Sediment Sampling

Storm water runoff is generated when water from rainfall events flows over land or impervious surfaces (paved streets, parking lots, and building rooftops) and does not percolate into the ground. As it travels, runoff accumulates debris, chemicals, sediment or other pollutants. During this process, some of the chemicals and pollutants can become adsorbed or deposited into sediments and concentrated in areas where settling occurs (i.e. streambed or ocean) or where a management practice has been implemented. For example, a baffle box installed in a storm drain within the urban area may retain sediments contaminated with chemicals or other pollutants. These pollutants (or contaminants) can include heavy metals, petroleum hydrocarbons, pesticides, herbicides, and polychlorinated biphenyls (Field et al. 2004). Many of these contaminants are known to pose a human health risk at elevated concentrations.

Tier 1 Environmental Action Levels (Tier 1 EALs) are concentrations of over 150 contaminants in soil, soil gas and groundwater below which the contaminants are assumed to not pose a significant threat to human health or the environment (State of Hawaii 2009). During the sampling or handling of sediments, a human health risk can result from direct exposure to contaminants via incidental ingestion, dermal absorption and inhalation of vapors or dust in outdoor air. Exceeding the Tier 1 EAL does not necessarily indicate that contamination poses environmental hazards; however, it does indicate that additional evaluation is warranted (State of Hawaii 2009). This can include additional site investigation and a more detailed evaluation of the tentatively identified environmental hazards. State of Hawaii (2009a), accessible at http://hawaii.gov/health/environmental/hazard/eal2005.html, and Section 13 of State of Hawaii (2009b), accessible at http://www.hawaiidoh.com/, provide a detailed discussion of the development of the Tier 1 EALs and their use.

There are currently no data to confirm or disconfirm the presence of contaminants in sediments from urban runoff in Wailupe Valley or whether their respective concentrations exceed the Tier 1 EALs. Given the lack of data and the potential presence of listed contaminants in sediments, sampling and chemical analysis of retained sediments for practice effectiveness monitoring should be conducted by personnel with proper training and expertise in handling these materials. This training may include Hazardous Waste Operations and Emergency Response (HAZWOPER) training as required by the Occupation Safety and Health Administration. The need for HAZWOPER-trained personnel may be reevaluated once analytical data is available to support easing the restriction on sampling and handling of sediments. If and when analytical data becomes available, Tier 1 EALs should be used as a screening mechanism to determine whether sediments pose a human health risk for sampling personnel.

The HAZWOPER standard applies to five distinct groups of employers and their employees. This includes any employees who are exposed or potentially exposed to hazardous substances -- including hazardous waste -- and who are engaged in one of the following operations as specified by 29 CFR 1910.120(a)(1)(i-v) and 1926.65(a)(1)(i-v). Individuals in any of the groups described below should receive HAZWOPER training:

- clean-up operations — required by a governmental body, whether federal, state, local, or other involving hazardous substances — that are conducted at uncontrolled hazardous waste sites;
- corrective actions involving clean-up operations at sites covered by the Resource Conservation and Recovery Act of 1976 (RCRA) as amended (42 U.S.C. 6901 et seq.);
- voluntary clean-up operations at sites recognized by Federal, State, local, or other governmental body as uncontrolled hazardous waste sites;
- operations involving hazardous wastes that are conducted at treatment, storage, and disposal facilities regulated by Title 40 Code of Federal Regulations Parts 264 and 265 pursuant to RCRA, or by agencies under agreement with USEPA to implement RCRA regulations; and
- emergency response operations for releases of, or substantial threats of releases of, hazardous substances regardless of the location of the hazard.

4.4 Data Management, Evaluation, and Reporting

Identifying specific approaches for accurate collection and analysis of data is essential for determining the effectiveness of implemented management practices. Monitoring storm water management practices tends to generate a considerable amount of data and information. A well designed and implemented data management program is valuable for the development of comprehensive and ongoing monitoring of management practices.

4.4.1 Quality Assurance and Quality Control

An integral part of any monitoring program is quality assurance and quality control (QA/QC). Development of a quality assurance project plan (QAPP) is the first step in incorporating QA/QC into monitoring. The QAPP is a critical document for the data collection effort as it integrates the technical and quality aspects of the planning, implementation, and assessment phases of the project. The QAPP documents how QA/QC elements will be implemented during sample collection, data management, and data analysis. It contains statements about the expectations and requirements of those for whom the data is being collected (i.e. Mālama Maunalua, DOH, NOAA) and provides details on project-specific data collection and data management procedures designed to ensure that these requirements are met. A thorough discussion of QA/QC is provided in Chapter 5 of USEPA's *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA 1996). Many of the elements and aspects of a QA/QC program are similar across program types, and the elements listed below are general in nature. The implementation of each management practice that will involve the collection and analysis of environmental data should be accompanied by the development a QAPP according to the guidance provided in *EPA Requirements for Quality Assurance Project Plans for Environmental Data Objectives* (USEPA 1994). Additional information can be found at www.epa.gov/quality/qapps.html. EPA requires four types of elements in a QAPP that include (with some examples):

1. Project Objectives and Management
   - Project/task organization
   - Problem definition/background
   - Project/task description
   - Quality objectives and criteria for measurement data
   - Special training requirements/certification
2. Measurements and Acquisition
   - Sampling process design
   - Sampling handling and custody requirements
   - Analytical methods requirement
   - Quality control requirements
   - Instrument/equipment testing, inspection, maintenance requirements
   - Instrument calibration and frequency
3. Assessment/Oversight
   - Assessment and response action
   - Reports to management
4. Data Validity and Usability
   - Data review, validation, and verification requirements
   - Validation and verification methods
   - Reconciliation and user requirements

4.4.2 Data Management

A central data management system should be maintained by Mālama Maunalua with careful consideration for what level of quality control the data should be held to, where and how the data will be held, who will maintain the database, and how much will data management cost. Before initiating monitoring, it is important to establish data management procedures to enable efficient storage, retrieval, and transfer of monitoring data. These procedures should be identified in the QAPP with specifications related to a central filing system, field forms, electronic database, contractor instructions, and computer backup guidelines. The International Storm Water Best Management Practice Database uses a combination of data entry spreadsheets in Microsoft Excel and a master database in Microsoft Access (WWE and Geosyntec 2009). Both the spreadsheets and the master database can be downloaded from www.bmpdatabase.org.

4.4.3 Geographic Information Systems

Geographic Information Systems (GIS) are useful for characterizing the features of watersheds and maintaining data on management practice implementation. The spatial relationships among the locations of pollutant sources, land uses, water quality data, trends in land cover and development, installed management practices, and many other features can be represented graphically. Non-graphical data on characteristics of management practices (e.g., sizing of pipes and storm water inlets, materials used in infrastructure, dates of inspections, and water quality results) can be incorporated into the GIS database and layer attribute tables.[46] A GIS database can be an extremely useful tool for management practice tracking and for detecting trends in implementation, land use changes, and virtually any data related to management practices and water quality. It is also valuable for communicating data to a wider audience. In order to guarantee data integrity and availability, as well as security, guidance for access and control should be laid out in the QAPP. A central GIS database for Wailupe Watershed should be developed and maintained. Mālama Maunalua has contracted a consulting group (Geospatial Consulting Group International, LLC) to develop a geodatabase and protocols for data entry to house geospatial data for projects in the Maunalua Bay region. Collaboration with past efforts and building onto existing databases would be an efficient means for utilizing GIS in monitoring efforts in Wailupe Watershed.

4.4.4 Data Evaluation

Evaluation of management practices includes statistically summarizing and analyzing collected data. Data analysis begins in the monitoring design phase and QAPP when the goals and objectives for monitoring and the methods to be used for analyzing the collected data are identified. Data analysis typically begins with screening and graphical methods, followed by evaluating statistical assumptions, computing summary statistics, and comparing groups of data. The development of a statistically relevant experimental design for data collection is strongly recommended and would benefit from consultation with a statistician during the design phase. Statistical analysis and sampling designs are addressed in detail in Chapter 3 of USEPA's report, *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures – Urban*, and data analysis and interpretation are addressed in detail in Chapter 4 of EPA's *Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls* (USEPA 1996; 2001).

4.4.5 Presentation of Monitoring Results

Management practice monitoring results should be presented in a practical and comprehensible form. The target audience(s) (scientists, school groups, policy makers, etc.), format (written or oral), and style (graphics, table, etc.) are factors in the selecting the appropriate means for presentation. Presentation of results will be built around the information that was collected, the statistical findings, and the process of the data collection (i.e. experimental design). Technical quality and completeness of results will ensure adequate decision making for management decisions for evaluating the effectiveness of installed management practices. Techniques and recommendations for quality presentations can be found in Chapter 6 of USEPA's report, *Techniques for Tracking, Evaluating, and Reporting the Implementation of Nonpoint Source Control Measures – Urban* (USEPA 2001).

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[46] The attribute table of a GIS mapping layer is a relational database that is linked to a geographic feature and stores characteristics of that feature in tabular format.

4.5 Evaluating Program Effectiveness

To ensure the most effective pollution control strategies for Wailupe Watershed, the success of management practices to limit generation and transmission of pollutants in the watershed must be regularly evaluated. This section describes challenges to monitoring storm water quality and methods that can be used to ensure that management practices are achieving stated goals and objectives.

4.5.1 Storm Water Quality Monitoring Challenges

Storm water quality at a given location varies greatly both among storms and during a single storm event. Significant temporal and spatial variability of storm water flows and pollutant concentrations are challenging to effectively sample. For example, the intensity of Hawaiʻi's rainfall varies seasonally and is often irregular and dramatic. Variations in rainfall affect the rates of runoff, pollutant wash-off, in-channel flow, pollutant transport, sediment deposition and resuspension, channel erosion, and numerous other phenomena that collectively determine the pollutant concentrations, pollutant forms, and storm water flow rate observed at a given monitoring location at any given moment. In addition, the transitory and unpredictable nature of many pollutant sources and release mechanisms (e.g., spills, leaks, dumping, construction activity, landscape irrigation runoff, vehicle washing runoff) contribute to inter-storm variability (GeoSyntec and ASCE 2002). In general, many measurements (i.e., many samples taken during a single storm event) are necessary to obtain enough data to be confident of actual management practice performance. Available resources, such as budget and staff, should be considered when determining the number of samples required to obtain a statistically valid assessment of water quality. A well-designed monitoring program will need to collect enough storm water samples to result in a high level of statistical confidence when determining management practice effectiveness. A small number of samples are not likely to provide a reliable indication of storm water quality at a given site or the effect of a given management practice.

4.5.2 Monitoring Program Progress

Regular monitoring must occur in order to determine if progress is being made towards meeting stated goals and objectives. A status report should be developed every year to document progress, challenges, and next steps. Next steps will consist of a list of priority management practices to occur the next year, along with a realistic schedule that reflects available funding, equipment purchases, and personnel time. Comparison of the projected schedule with the actual schedule will enable better timeline estimates for future projects and will help determine if the scale and scope of the management practices slated for the following year(s) are appropriate.

Information in the GIS and associated databases will be essential for developing this report so data can be objectively analyzed and compared between years. Notes on problems encountered with management practices, interesting outcomes, successes, and ideas for improving management practices in the future should be kept on a linked document, to allow for easy cross-reference.

The principles of adaptive management require regular review of the program and revision of management goals, objectives, actions, and techniques, to improve the performance of the program. The Wailupe WBP should be reviewed (yearly) and updated (as needed) regularly. Future reporting and results of monitoring activities will be essential to providing information on the pollutant loads in the watershed and the effectiveness of management practices.

5. Education and Outreach

The goals of the Wailupe WBP education and outreach strategy are:

1. **Build general public awareness** about polluted runoff, including its negative effects on coastal and marine environments, and actions individuals can take to reduce discharges to the receiving water of Maunalua Bay, a 303(d) listed waterbody.

2. **Build early community support** for a holistic approach to planning for Wailupe Stream and for implementation of structural and nonstructural management measures and practices identified in the WBP.

3. **Engage the community** in do-it-yourself workshops, monitoring, and pilot NPS-reduction projects in Wailupe Watershed, in order to promote participation in installation, monitoring and maintenance of projects.

4. **Increase agency support** for, and participation in, actions to reduce NPS pollution in Wailupe Watershed.

Activities to be undertaken in order to accomplish these goals are described below. A timetable of activities is included as Table 5-1.

5.1 Goal 1: Build General Public Awareness

Build general public awareness about land-based pollution.

In 2010 Mālama Maunalua began developing a new outreach campaign, *Every Drop Counts* (EDC). This regional awareness campaign targets residents and business owners to increase understanding and adoption of best practices for managing storm water runoff and the pollutant loads it carries into Maunalua Bay. Presently under development are outreach materials including a 'Pollution Reduction' homeowner booklet; wallet-sized informational cards for boaters, fishers, divers, surfers, and homeowners; and informational web pages on best practices and sources of materials and technical support.

Associated with this, Mālama Maunalua also is developing user-friendly, web-based maps depicting the storm water conveyance network, stream and neighborhood reconnaissance data, water quality monitoring sites and data, rain gauge sites and data, and other community watershed monitoring efforts. Targeted at residents of the area, the maps will provide a useful outreach tool to convey information about specific threats and remedial actions that can be taken by an individual in his/her neighborhood or block. The EDC campaign will be piloted in Wailupe Watershed ('Āina Haina) and several other locations.

5.2 Goal 2: Build Early Community Support

Build early community support for implementation of management measures and practices identified in the WBP, and for a holistic approach to Wailupe Watershed management.

To build early community support for the implementation of the Wailupe WBP, Mālama Maunalua and partners will hold an initial series of small pilot community meetings. The intent of these meetings is to present information and get feedback from Wailupe Watershed residents in order to lay the groundwork for the planned larger scale community participatory process. These pilot meetings, to take place in early 2011, will roll out the content of the WBP as well as review research, planning, monitoring and management efforts to date, and the content and strategy of the EDC campaign. Participants will be asked to provide their feedback on the content and delivery of information, and their ideas regarding integration of the goals of the WBP into USACE's ongoing planning effort for Wailupe Stream Flood Reduction. Feedback received from these meetings will be shared among Mālama Maunalua's partners and used to inform the broader community participatory process. Participants will also be asked to volunteer to disseminate information to neighbors and to various constituent groups including surfers, fishers, paddlers, condominium associations, neighborhood associations, and business owners.

5.3 Goal 3: Engage the Community

Engage the community in do-it-yourself workshops, *Mauka Watch* monitoring, and in pilot NPS-reduction projects in Wailupe Watershed, in order to promote participation in installation, monitoring and maintenance of projects.

5.3.1 Workshops

Mālama Maunalua will work with partners to produce and disseminate printed materials on residential management practices for reducing runoff and pollution and host 'how-to' homeowner workshops for a variety of practices such as rain barrels and mulching. 'Early adopters' who create a demonstration effect will be recognized through public announcements and signage. In addition, Mālama Maunalua will investigate sources of funding to help subsidize homeowner projects.

5.3.2 Monitoring

Mālama Maunalua has established three types of community monitoring efforts under the *Mauka Watch* program: water quality monitoring, stream/neighborhood surveys, and rainfall monitoring. . These ongoing activities support the implementation of the Wailupe WBP by:

- Providing data for management efforts.
- Serving a key outreach function. In educating residents about watershed function and impairments, and providing hands-on activities, the programs instill knowledge and a sense of responsibility and stewardship for a place.

Summaries of the three programs are included in this report (see Section 4.1.4), and full descriptions can be found in the *Mauka Watch Volunteer Monitoring Program Plan* (2009) and associated Quality Assurance Project Plan (QAPP), available by request. The data from these programs is being stored in a newly-created Mālama Maunalua GIS database and will be shared with DOH, NOAA and other entities. The data will also be depicted in a user-friendly, web-based geospatial format, to provide a visual map of results by site for water quality, precipitation and pollutant source inventories (see Section 5.1).

5.3.3 Pilot Projects

It is also important to involve the community in implementing 'green infrastructure' and other early opportunity demonstration projects for Wailupe Watershed. Mālama Maunalua and SRGII will work together in 2011-12 to implement two high-visibility NPS-reduction pilot projects for Wailupe Watershed that will provide opportunities for local residents and business owners to observe and/or participate in installation and maintenance. The projects are an upland erosion control project to reduce sediment inputs from the upper Wailupe Watershed, and the installation of a storm water biofiltration measure (vegetated swale) at Wailupe Beach Park. Volunteers will be recruited to assist both with installation and outreach for the projects. Periodic site visits/tours will be provided and progress updates will be posted via email and on Mālama Maunalua's website. Management efforts in Wailupe Watershed will be highlighted at the Maunalua Bay Heritage Festival, a region-wide celebration of Maunalua's environmental and cultural resources scheduled for April 2011.

5.4 Goal 4: Build Agency Support

Build agency support for, and participation in, actions to reduce NPS pollution in Wailupe Watershed.

Mālama Maunalua will continue to seek new cooperative partnerships to address regional and watershed management needs and expand community and government interest in improving Maunalua Bay. The Wailupe WBP provides technical guidance and a set of priority implementable actions that can be taken to reduce NPS pollution inputs into Maunalua Bay. Since these actions do not fall within the responsibility of any single agency, implementation will require collaborative efforts among multiple entities. The community can act as intermediary to build essential networks and partnerships among USACE, EPA, DOH, DLNR, CCH-DES, CCH-DFM (Department of Facility Maintenance) and others, and facilitate integration of improved water quality management practices into existing agency management plans and practices.

To date, Mālama Maunalua's largest collaborative effort has been participation in the planning process for Wailupe Stream by the USACE, DLNR, and CCH. This plan is in process and predates the WBP (see Section 1.1.2). The USACE is developing a project that will address the flood risk and propose measures to reduce impacts to ecosystem function. The objectives of the project are currently being refined but may include:

- **Flood Risk Management:** Reduce flood risks to property and life safety.
- **Ecosystem restoration:** Enhance, preserve, restore, or reverse the degradation of natural watershed function and processes, where possible, throughout the watershed, including the urban areas.
- **Water Quality:** Improve management of stormwater, sediments and other pollutants from the watershed to minimize degradation of nearshore waters.

The goals of the Wailupe WBP are consistent with those of the Flood Reduction Project. Mālama Maunalua supports all objectives of the USACE project and has pledged to provide technical and in-kind match assistance, and community coordination, to support its goals. Mālama Maunalua also has developed other types of partnerships with the CCH to expand the scope of agency support, for example by participating in the City's Green Infrastructure project and creating formal agreements such as Adopt-A-Stream (with CCH-DFM) and Adopt-A-Park (with CCH-Department of Parks and Recreation).

Mālama Maunalua will continue to develop additional types of partnerships and new NPS reduction plans for the remaining watersheds of the region through partnerships, as recommended in the *Maunalua Regional Watershed Strategy* (2009). As part of this effort Mālama Maunalua also will help to develop funding partners to address long-range funding needs for land-based pollution reduction across the region.

Table 5-1. Timetable: Education & Outreach Activities

Activity	Who	Duration
Develop EDC messaging, presentations and materials	MM and partners	September-December 2010
General Education Campaign, i.e., EDC	MM, Partners Residents, Businesses	December 2010-July 2011
Volunteer Water Quality Monitoring	MM Volunteers	2009-ongoing
Volunteer Rainfall Monitoring	MM Volunteers	January 2010-ongoing
Volunteer Stream / Neighborhood Reconnaissance Monitoring	MM Volunteers	July-September 2009; and ongoing as needed
Prepare summary documents and other outreach materials for the pilot WBP meetings	MM	December 2010
Hold a series of three pilot community meetings	MM	January-March 2011
Conduct outreach to key agencies for Wailupe and adjacent areas	MM, USACE, EPA, NOAA CCH, DLNR, DOH,	
Hold a series of EDC presentations	MM	January-March 2011
Disseminate news pieces/updates on Wailupe Stream plans and management	MM, USACE	March-June 2011
Engage residents in pilot projects (i.e. filtration swale at Wailupe Beach Park and Wailupe erosion reduction project)	SRGII, MM & Volunteers	March 2011- May 2012
Feature Wailupe pilot projects and resident management practices at the Maunalua Bay Heritage Festival	MM	April 2011
Report back to community on progress of pilot projects, and invite public to visits/tours at these sites	MM	April 2011-December 2012
Conduct three do-it-yourself workshops on residential storm water runoff management practices and homeowner self-assessments	MM & Partners	June-December 2011
Prepare outreach materials for large-scale all-Wailupe community meetings	MM, USACE, others	July-September 2011
Hold all-Wailupe community meetings to engage residents in USACE and MM planning process	MM, USACE, CCH, DLNR, Wailupe Residents	September 2011-March 2012 as needed
Meet with ‘Āina Haina Community Association and other community groups and businesses	MM & Partners	April 2011-August 2011

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Geospatial Data

Geospatial data was obtained primarily from public data sources (government agencies) and non- profit groups (Mālama Maunalua).

City and County of Honolulu (CCH), Department of Planning and Permitting (DPP), Honolulu Land Information System (HoLIS) files, NGA 1 Ft Imagery (Oahu) and associated metadata are available for download at http://gis.hicentral.com/. HoLIS files are in the following projection: Universal Trans Mercator, Zone 4, NAD 83.State Plane Hawai‘i, Zone 3, NAD 83 HARN.

Department of Business, Economic Development & Tourism (DBEDT) files and associated metadata are available for download at http://www.Hawaii.gov/dbedt/gis/download.htm. DBEBT files are in the following projection: Universal Trans Mercator, Zone 4, NAD 83.

Hawai‘i Gap Analysis Program (HI-GAP) files and associated metadata were from HI-GAP at ftp://ftp.gap.uidaho.edu/products/Hawaii/. HI-GAP files are in the following projection: Universal Trans Mercator, Zone 4, NAD 83.

Natural Resources Conservation Service (NRCS) files and associated metadata are available for download at http://soildatamart.nrcs.usda.gov/. Zipped file (containing all files for the soil shapefile for the Island of O‘ahu, including metadata) is current as of April 2010. NRCS files are in the following projection: State Plane Hawai‘i, Zone 3, NAD 83.

NOAA/DOC/NOS/NCCOS/CSC files and associated metadata are available for download from *National Oceanic and Atmospheric Administration* (NOAA) (See shapefile and associate .txt file for contact information for source; More information can be found at http://www.csc.noaa.gov/ccap/pacific/honolulu/index.html and http://www.sanctuaries.noaa.gov/). NOAA files are in the following projection: State Plane Hawai‘i, Zone 3, NAD 83.

Mālama Maunalua files and associated metadata were obtained from their GIS database. Mālama Maunalua files are in the following projection: Universal Trans Mercator, Zone 4, NAD 83.

U.S. Geological Survey (USGS) files and associated metadata are available for download at http://hawaii.wr.usgs.gov/oahu/data.html. Zipped file (containing .jpg and metadata) is current as of April 2010. USGS files are in the following projection: Universal Trans Mercator, Zone 4, NAD 83.