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

Draft Report

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Acronyms

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

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Executive Summary

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

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

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

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

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

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

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

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

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

Watershed Characterization Report

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1 Introduction

1.1 Purpose

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

The watershed approach, which has been adopted and is supported by the Environmental Protection Agency's (EPA) National Water Program, is a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically-defined geographic areas, taking into consideration both ground and surface water flow.[1]

1.2 Overview of Project Area

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

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

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

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

1.3 Summary of Previous Reports and Information

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

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

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

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

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

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

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

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

2 Watershed Components

A complete watershed characterization utilizes a multi-disciplinary scientific approach to collect information about the ecosystem processes, resource conditions, and historical changes due to cumulative effects of management practices. A series of concepts and categories, as presented in EPA’s *Handbook*

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

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

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

2.1 Population and Land Use

2.1.1 Anthropogenic Impacts on Wailupe Watershed

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

Historical Anthropogenic Impacts on Wailupe Watershed Hydrology

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

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

2.1.2 Land Use

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

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

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

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

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

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

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

Land Cover

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

[6] Per Hawai‘i Revised Statutes Chapter 183, and Hawai‘i Administrative Rules Title 13, Chapter 104.
[7] Data derived from the Office of Planning, State of Hawai‘i DBEDT GIS Program, ‘Major Landowners'.

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

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

2.2 Physical and Natural Features

2.2.1 Watershed Boundaries

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

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

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

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

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

2.2.2 Topography

Wailupe Watershed has topography that is typical of many Hawaiian watersheds. Deep valleys have been cut by running water that destabilize the slopes by tearing away rock fragments, including local collapses, and debris remains in talus slopes or is carried downstream by floods (Lau and Mink 2006) (see Figure 9). Elevations range from 2,600 feet msl at the crest of the *pali* to sea level, with an average elevation of 560 feet msl.[11] Slopes range from 68% in the steep *pali* sections to near flat in the coastal zone area with an average of 24%. When viewed from above Wailupe Watershed appears roughly rectangular, and its topographic boundaries are distinct due in part to the two ridges that bound it along its longest axis, The toe of these ridges end *mauka* of the shoreline. The coastal plain, the more *mauka* portions of the watershed that contain the Aina Haina neighborhood, butts up against the toe and extend slightly up the base of the steep slopes that fall from the ridges. A result of the topography is that rainfall and surface runoff derived on most of the watershed drains towards the urban area.

2.2.3 Climate

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

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

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

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

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

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

2.2.4 Hydrology

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

Hydrologic Cycle

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

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

Watershed Hydrology

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

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

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

Along their longitudinal profile streams have sections where ground water drains into the stream increasing surface flow volume in the channel, and other sections where the channel loses water through its bed and banks. Since the surface water regime in Wailipe Watershed's urban area, and to a lesser degree in the conservation uplands, has been altered, there is likely more surface runoff and less infiltration during and following storm events than historic values. The reduction of water infiltrating into the ground during rain events reduces the volume of water that returns to the stream following storms. As a result, it is possible that baseflow values in Wailupe Stream are lower now than in the past. During rainy years the stream likely flows for longer periods when compared to low rainfall years. Under natural or pre-urbanized conditions only a small percentage of the rainfall that reaches the ground results in runoff. This is due to infiltration of water into the soil, detention of water on surfaces such as plants, and retention of water in small depressions common in natural landscapes. A portion of water infiltrates into the soil and recharges ground water, some of which makes its way slowly though subsurface flow paths into the streams as baseflow. Under natural conditions the volume of runoff is attenuated and the contaminants contained in it remediated along the flow path or sequestered on the watershed. Ground water recharge rates and subsequently stream baseflow have likely decreased across the urban area of the watershed due to extensive covering of the land with impervious surfaces.

Wailupe Stream Hydrology

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

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

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

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

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

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

Impacts of Urbanization on Wailupe Watershed Hydrology

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

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

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

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

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

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

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

Changes to Hydrology of Upland Areas

Although the upland conservation areas in the Wailupe Watershed have not been urbanized, they have been adversely impacted by human activities. Non-native plants, introduced either on purpose or inadvertently, have displaced native plants that evolved on the island over millions of years. Some scientists hypothesize that non-native vegetation does not function as well as native plants in controlling erosion and that it uses more water than its native counterparts. There are no definitive papers that support these hypotheses and research into the ecohydrology of Hawaiian watersheds continues.

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

Floodway Issues

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

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

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

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

ZONE	DESCRIPTION
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas; no depths or base flood elevations are shown within these zones.
AE	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. In most instances, base flood elevations derived from detailed analyses are shown at selected intervals within these zones.
B, X	Areas outside the 1-percent annual chance floodplain, areas of 1% annual chance sheet flow flooding where average depths are less than 1 foot, areas of 1% annual chance stream flooding where the contributing drainage area is less than 1 square mile, or areas protected from the 1% annual chance flood by levees. No Base Flood Elevations or depths are shown within this zone. Insurance purchase is not required in these zones.
D	Areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted. Flood insurance rates are commensurate with the uncertainty of the flood risk.

2.2.5 Geomorphology

Geomorphology is a sub-discipline of geology that discusses the processes that shape the earth surface. Fluvial geomorphology refers to the subset of processes shaped by water. The morphology or shape of a stream channel is a function of the geological stratum it is in contact with, slope, hydrology (rainfall, flow volume, and their frequency), as well as landscape features (groundcover, slope angles, and soil types) that control overland flow and runoff to the channel. In general steeply sloped channels are more entrenched than low slope channels.[20] In general, channels with steep profiles usually have sufficient energy to transport fine materials through their reaches, and as a result the rock particles along their bed and banks are usually coarse gravel size or larger.[21]

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

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

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

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

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

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

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

2.2.6 Soils

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

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

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

Closer to the stream mouth and entrance to the bay the soil turns to Waialua (WKA) and Honouliuli (HxA) both of which are fertile alluvial soils found in the lowlands of Oʻahu that are very fine and halloysitic nature.[23] Both are characterized as well drained, slow to medium runoff with moderately slow permeability. Clay soils contain very small void spaces, which retain moisture for long periods using capillary action and chemical bonds. These small voids are prone to compaction and reduction of pore volume from mechanical actions that exert shear stress on the soil horizons, resulting in reduction of infiltration rates and water holding capacities. The susceptibility of these soils to compaction can often lead to erosion problems by reducing infiltration and creating concentrated surface runoff and flow along the compacted surface.

2.2.7 Biotic Environment

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

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

Invasive plant and feral animals in the upper conservation areas of Wailupe Watershed pose a threat to the watershed and its water resources. Habitat destruction and the introduction of invasive species have been the prominent causes of the loss of biodiversity in Hawaiʻi for over a century (El-Kadi, Mira et al. 2008). In Hawaiʻi feral pig populations thrive, with the greatest densities typically existing within wet forest

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

habitat due to the availability of food and water (Cuddihy and Stone 1990). In the 20th century pig population densities began to increase and the negative impacts associated with their presence were observed. Expansion resulted from an increase in area disturbed by humans and the expansion of non-native plants preferred by pigs, which in turn are spread by pig grazing and browsing (Cuddihy and Stone 1990). There are no known counts of pigs in the upper portion of Wailupe Watershed, however pigs are known to frequent the area and pig damage can be readily observed. The strong correlation between alien plant presence and feral pig activity leads Aplet et al. (1991) to suggest the possibility that field observations of plant composition could be used to estimate the relative amount of pig activity. Although the effects of feral pigs on native ecosystems are wide ranging, there is emerging evidence that their presence alone may be linked to increases in runoff and soil loss (Browning 2008). To date there are no efforts for ungulate control in Wailupe's preservation area with the exception of the upper reserve designation as State hunting grounds.

2.2.8 Waterbody Monitoring Data

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

Water Quantity

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

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

Water Quality

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

2.3 Waterbody and Watershed Condition

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

Maunalua Bay

Marine waters in the project area are designated 'Class AA, open coastal waters' by the State of Hawaiʻi (DOH 2006). The objective of Class AA waters is: "…that these waters remain in their natural pristine state as nearly as possible with an absolute minimum of pollution or alteration of water quality from any human-caused source or actions. To the extent practicable, the wilderness character of these areas shall be protected" (DOH 2004). Maunalua Bay's flat reef and reef communities are protected under 'Class II' designation for which existing or planned harbors may be located within nearshore reef flats showing degraded habitats and only where feasible alternatives are lacking and upon written approval by the director, considering the environmental impact and public interest (DOH 2004). All flat reefs and reef communities around the State of Hawaiʻi are protected with the objective that no action shall be undertaken that would substantially risk damage, impairment, or alteration of the biological characteristics of the areas.

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

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

Wailupe Stream

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

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

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

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

Wailupe Watershed

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

2.4 Pollutant Sources

2.4.1 Point Source and Non-Point Source Pollutants

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

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

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

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

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

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

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

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

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

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

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

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

2.4.2 Storm Water Rules and Wailupe Watershed's MS4 System

MS4 Regulatory Information

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

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

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

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

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

Wailupe MS4 System

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

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

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

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

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

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

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

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

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

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

3 Identification of Data Gaps and Future Priorities

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

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

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

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

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

Appendix A. Figures

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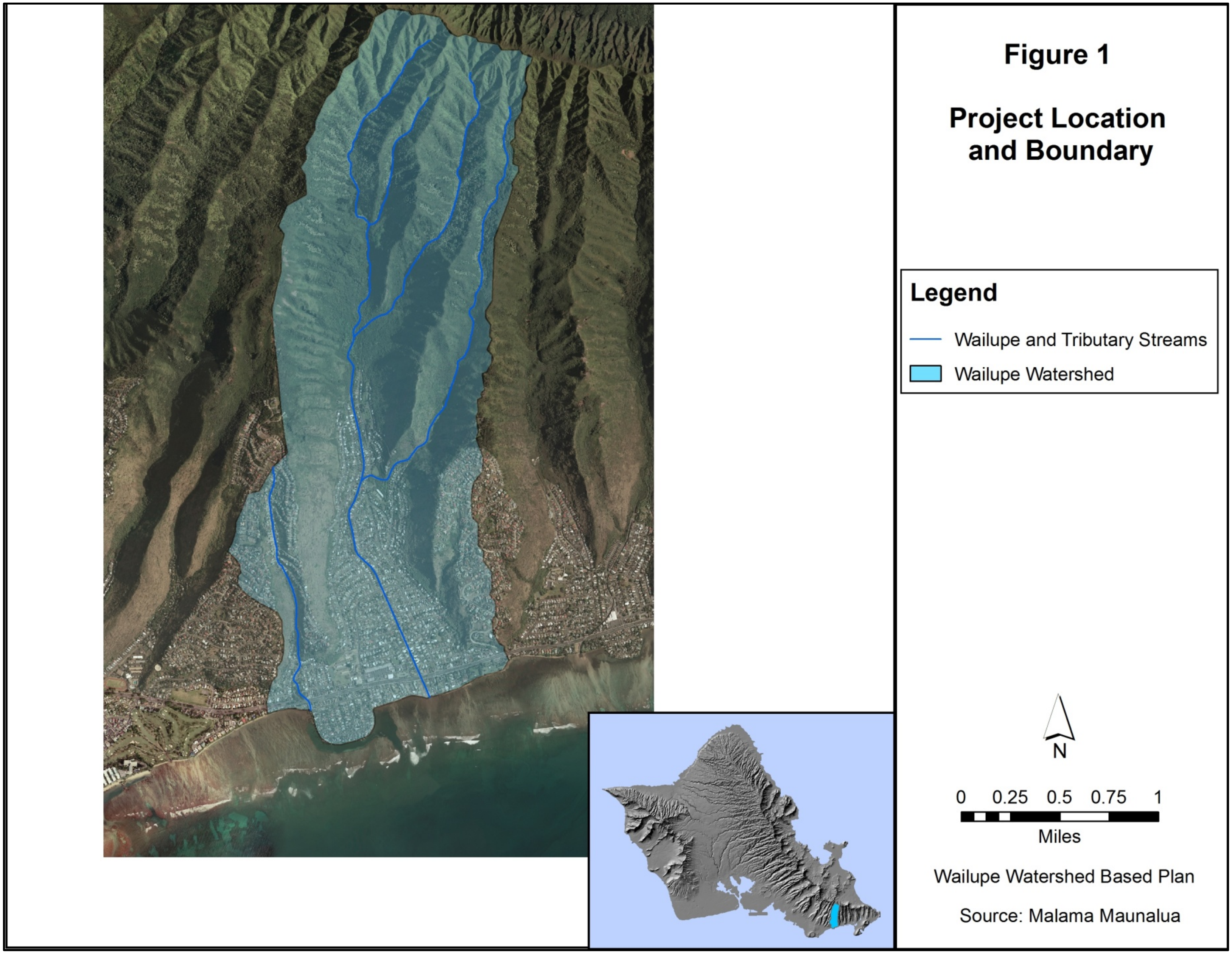


Figure 1

Project Location and Boundary

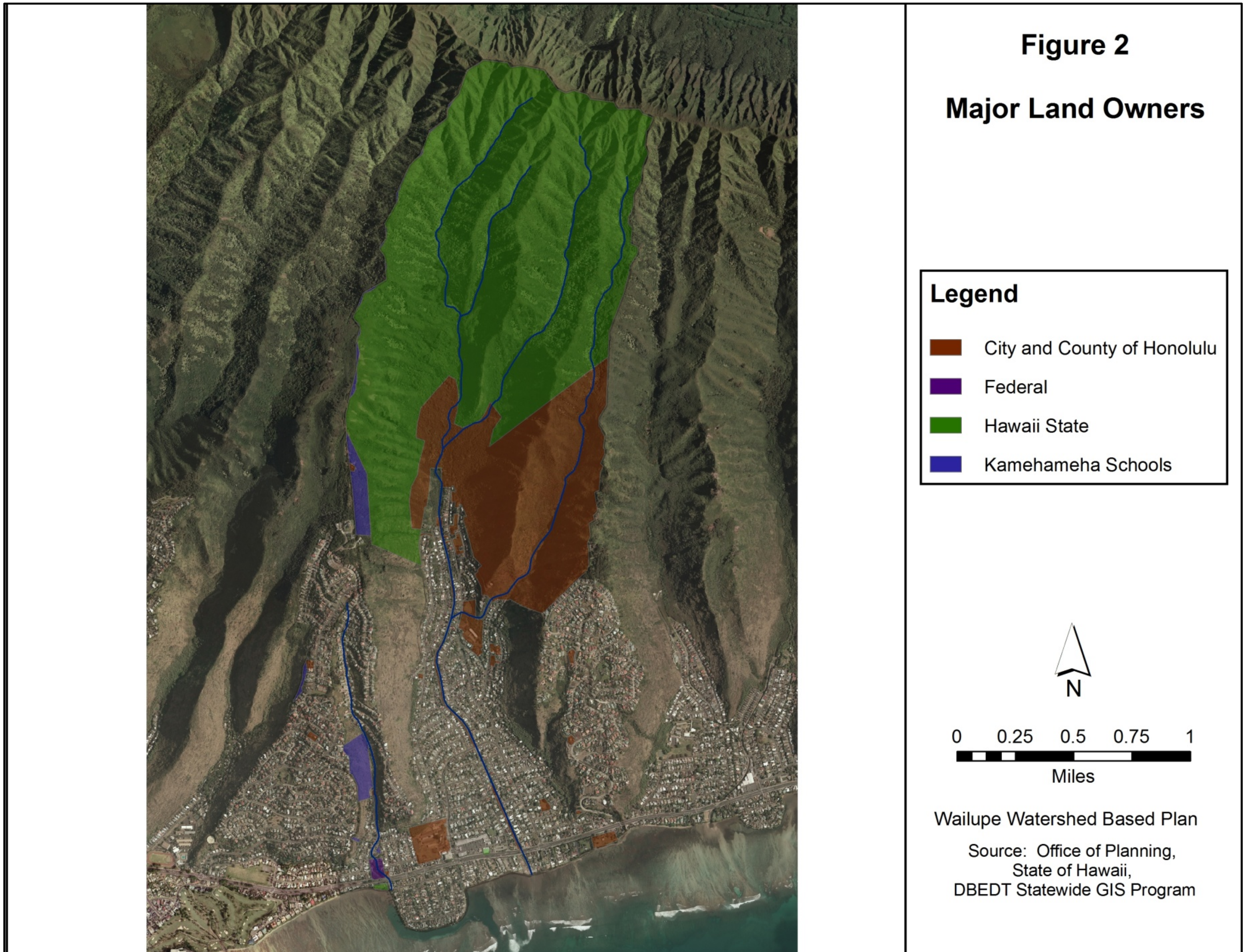


Figure 2
Major Land Owners
Legend
City and County of Honolulu
Federal
Hawaii State
Kamehameha Schools
N
0 0.25 0.5 0.75 1
Miles
Wailupe Watershed Based Plan
Source: Office of Planning,
State of Hawaii,
DBEDT Statewide GIS Program

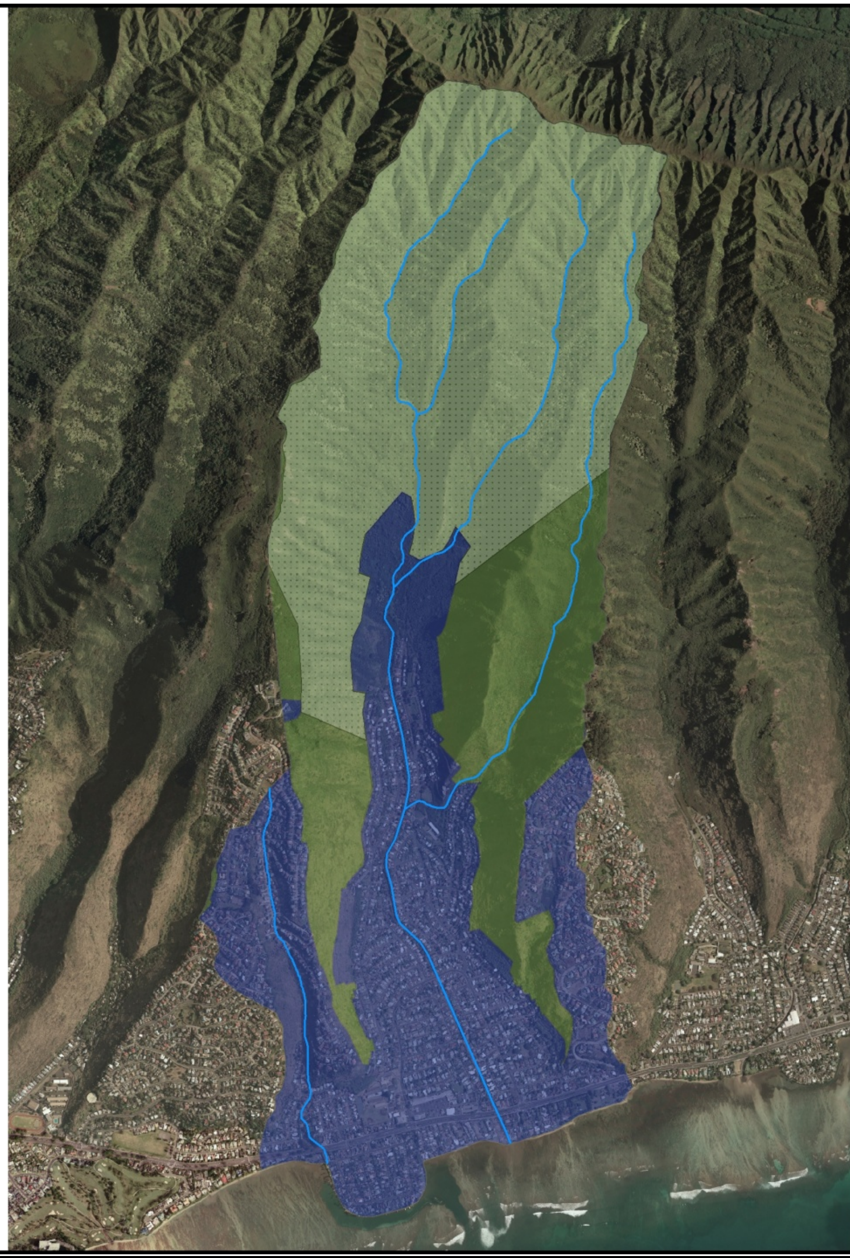


Figure 3

Hunting Areas

Legend

Hunting area

State Land Use Districts

Conservation

Urban

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

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

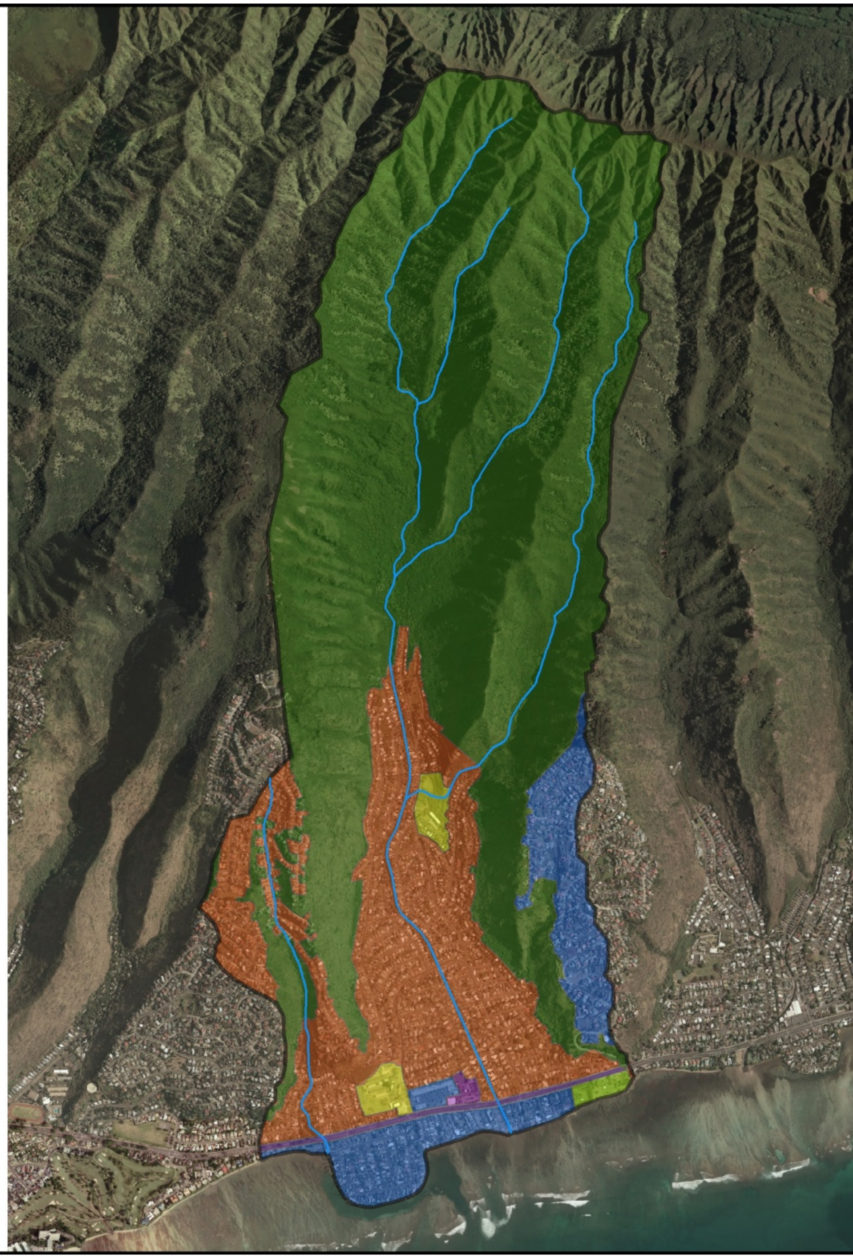


Figure 4

Land Use
USGS NAWQA

Legend

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

N

0 0.25 0.5 0.75 1
Miles

Wailupe Watershed Based Plan

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

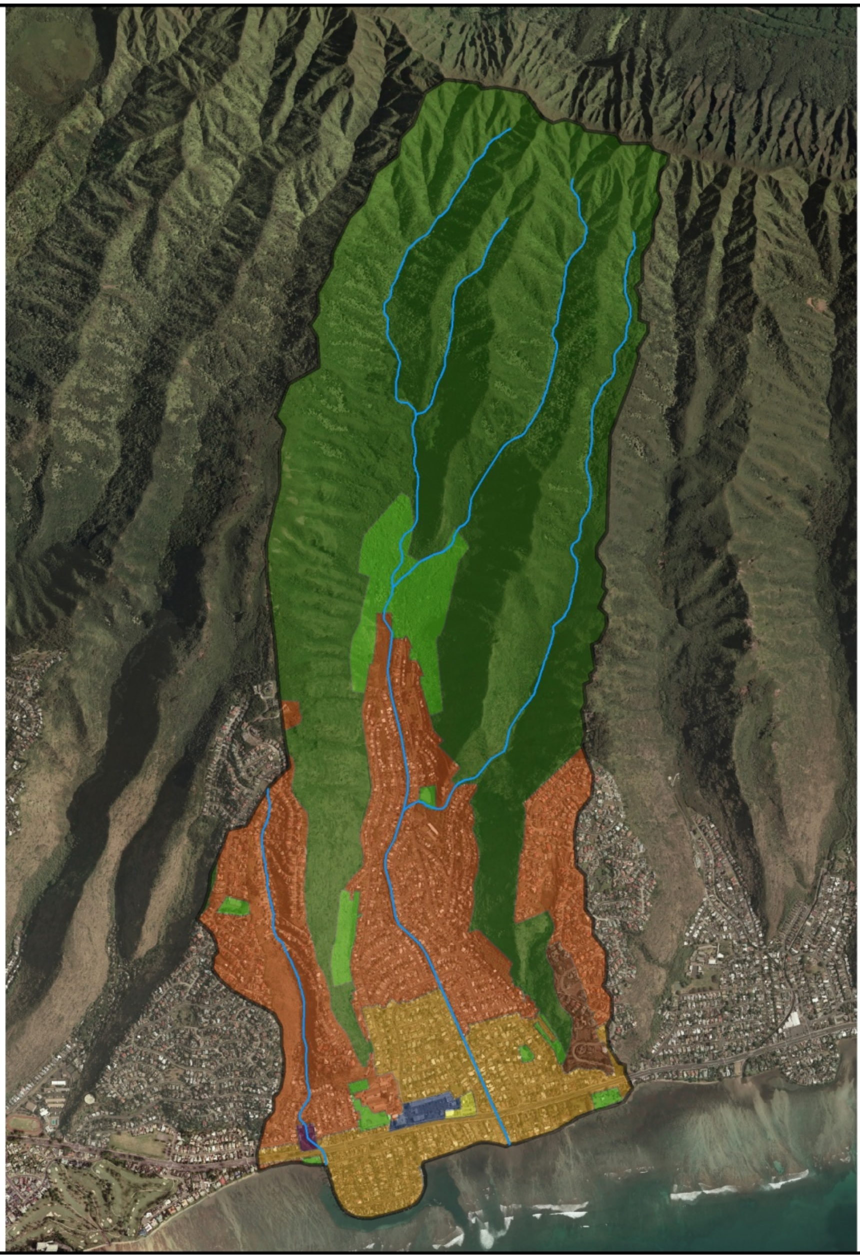


Figure 5

City and County of Honolulu Zone Descriptions

Legend

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

Wailupe Watershed Based Plan

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

Figure 6

Impervious Surfaces

Legend

Impervious Surface

N

0 0.1 0.2 0.3 0.4

Miles

Wailupe Watershed Based Plan

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

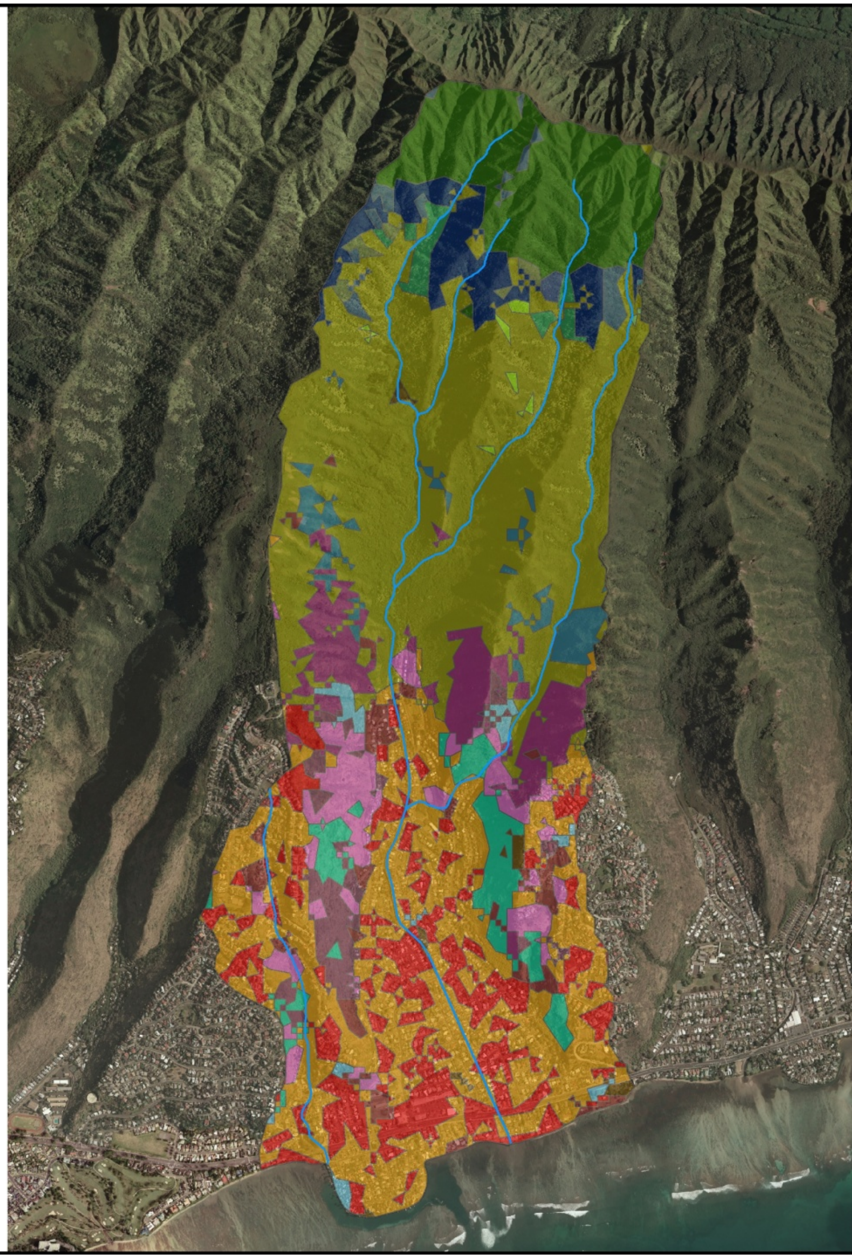


Figure 7

Vegetation Cover

Wailupe Watershed Based Plan

Source: Hawaii Gap Analysis Program (HI-GAP)

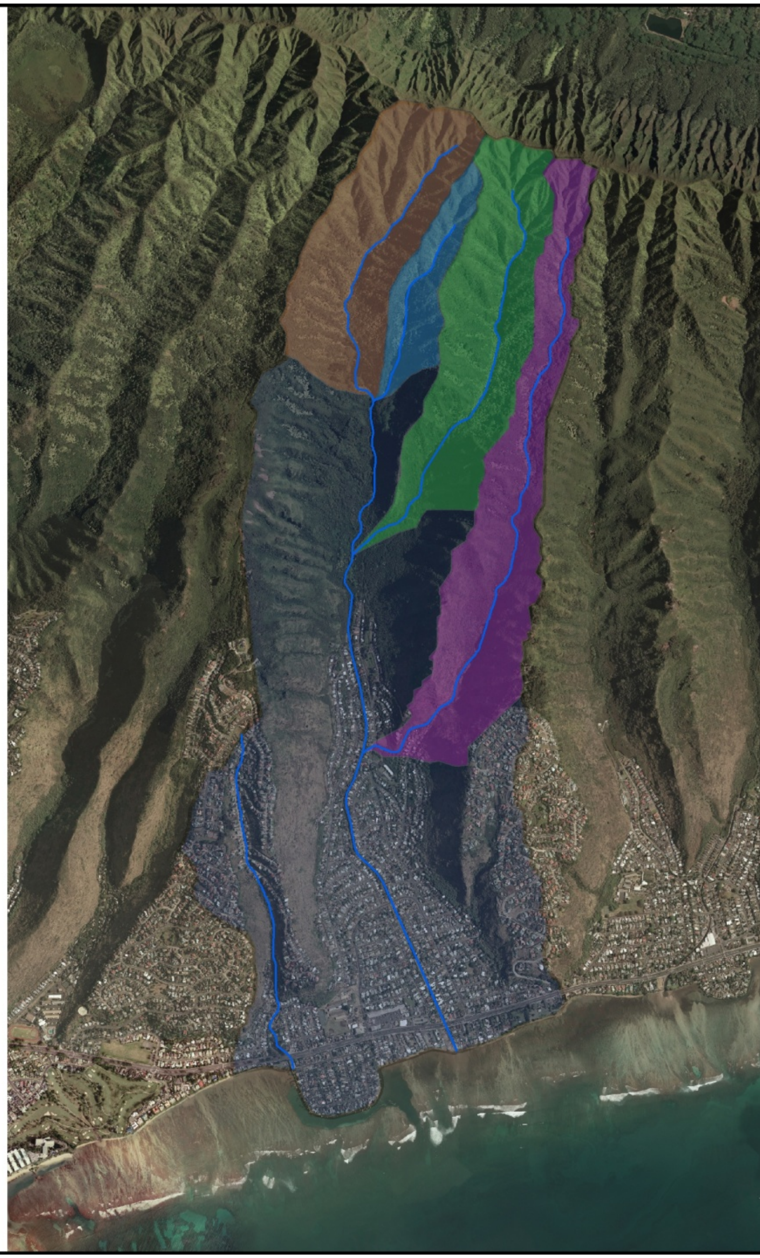


Figure 8

Upper Wailupe Sub-Watersheds

Legend

- Kului
- Laulaupoe
- Wailupe East
- Wailupe West

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

Source: SRGII

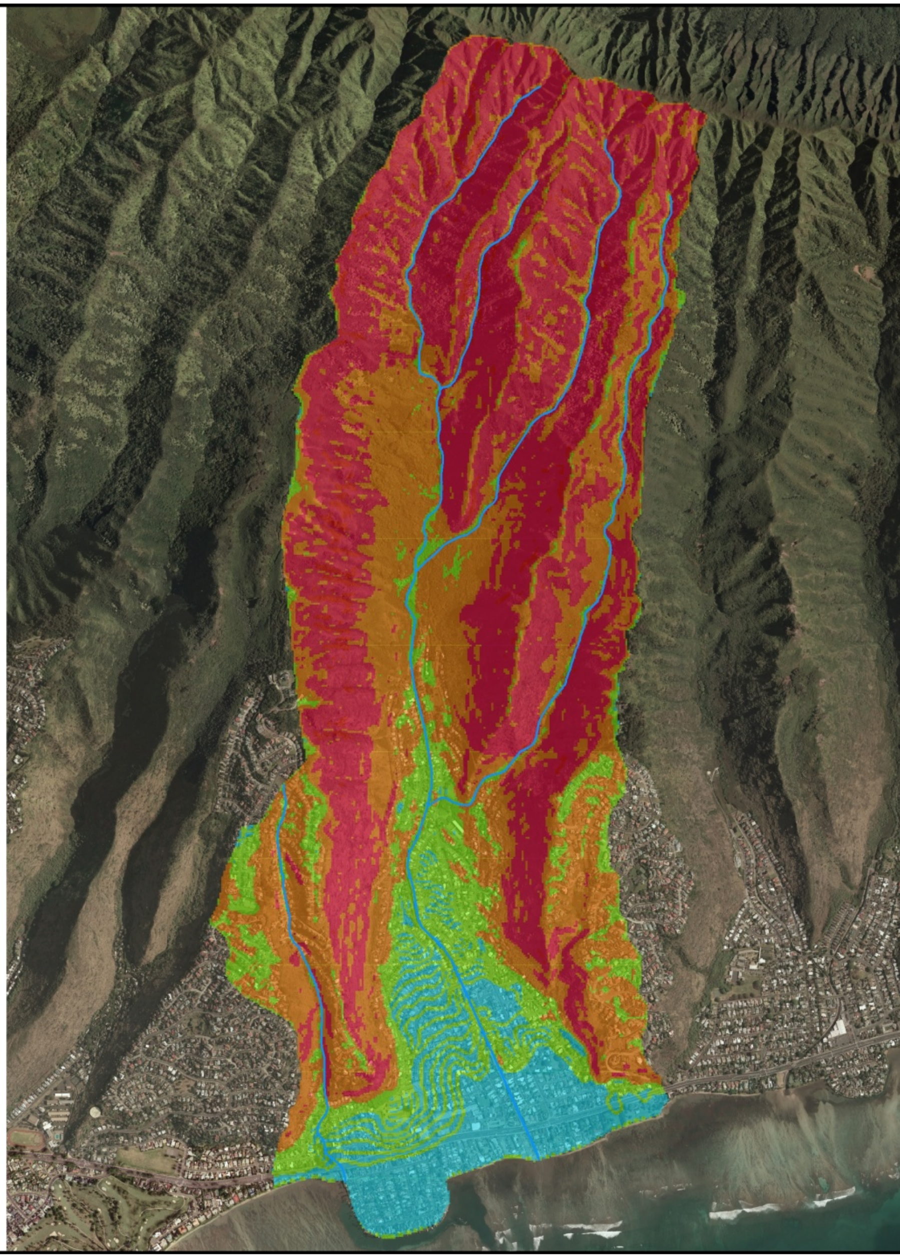


Figure 9

Topography

Legend

Slope (percent value)

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

N

0 0.25 0.5 0.75 1

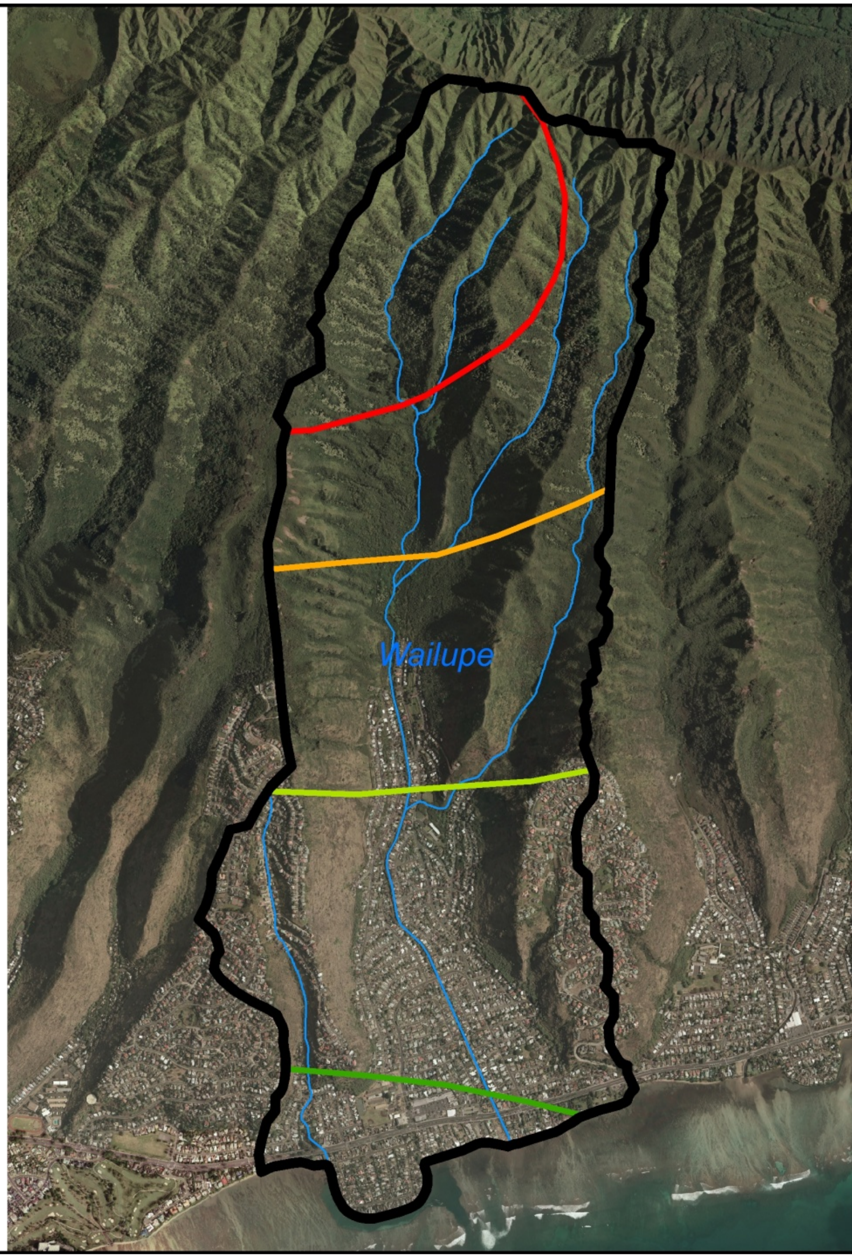
Miles

Wailupe Watershed Based Plan

Source: SRGII

Figure 10

Rainfall



Legend

Median Annual Rainfall (in.)

- 32
- 39
- 59
- 79

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

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

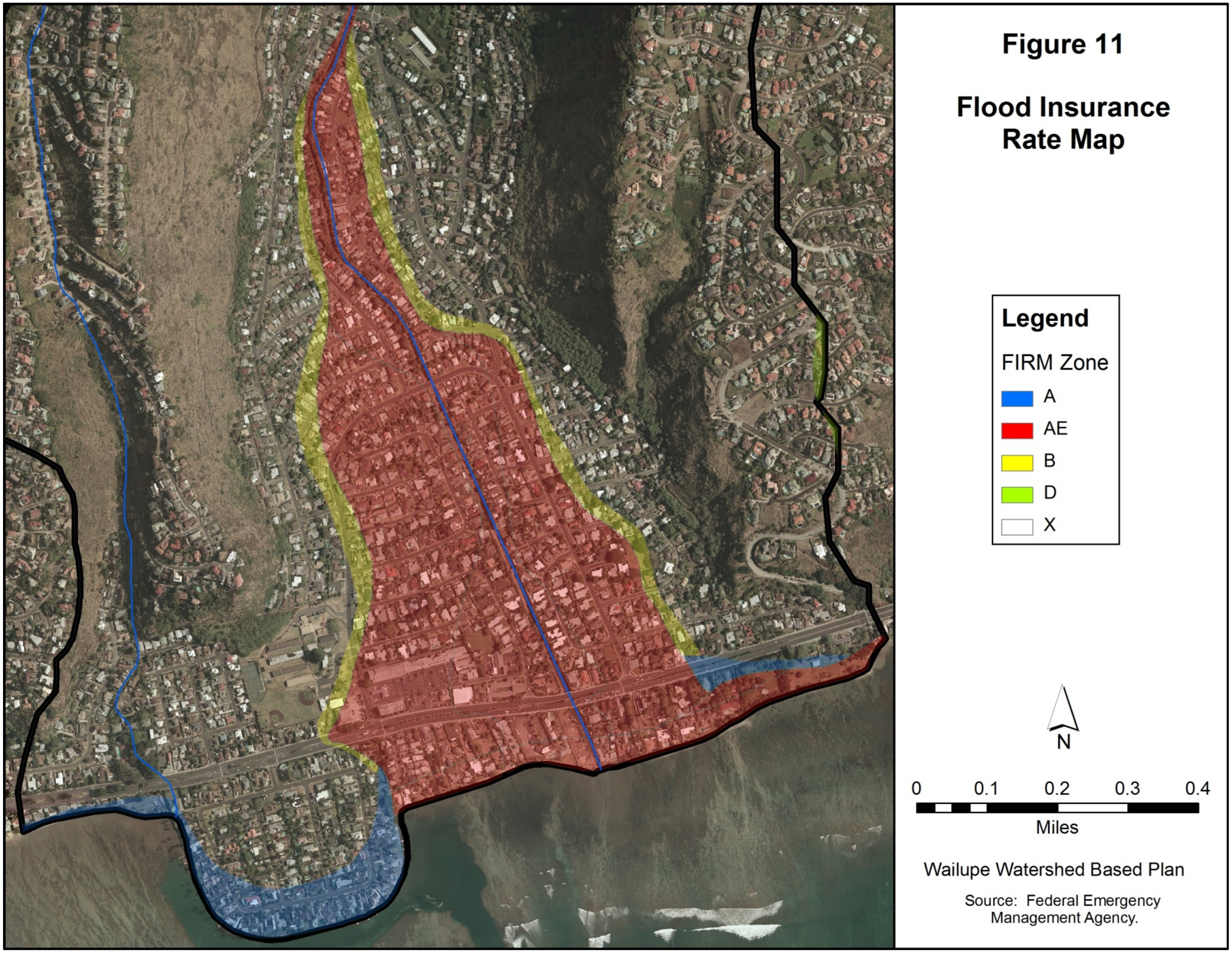


Figure 11
Flood Insurance Rate Map
Legend
FIRM Zone
A
AE
B
D
X
N
0
0.1
0.2
0.3
0.4
Miles
Wailupe Watershed Based Plan
Source: Federal Emergency Management Agency.

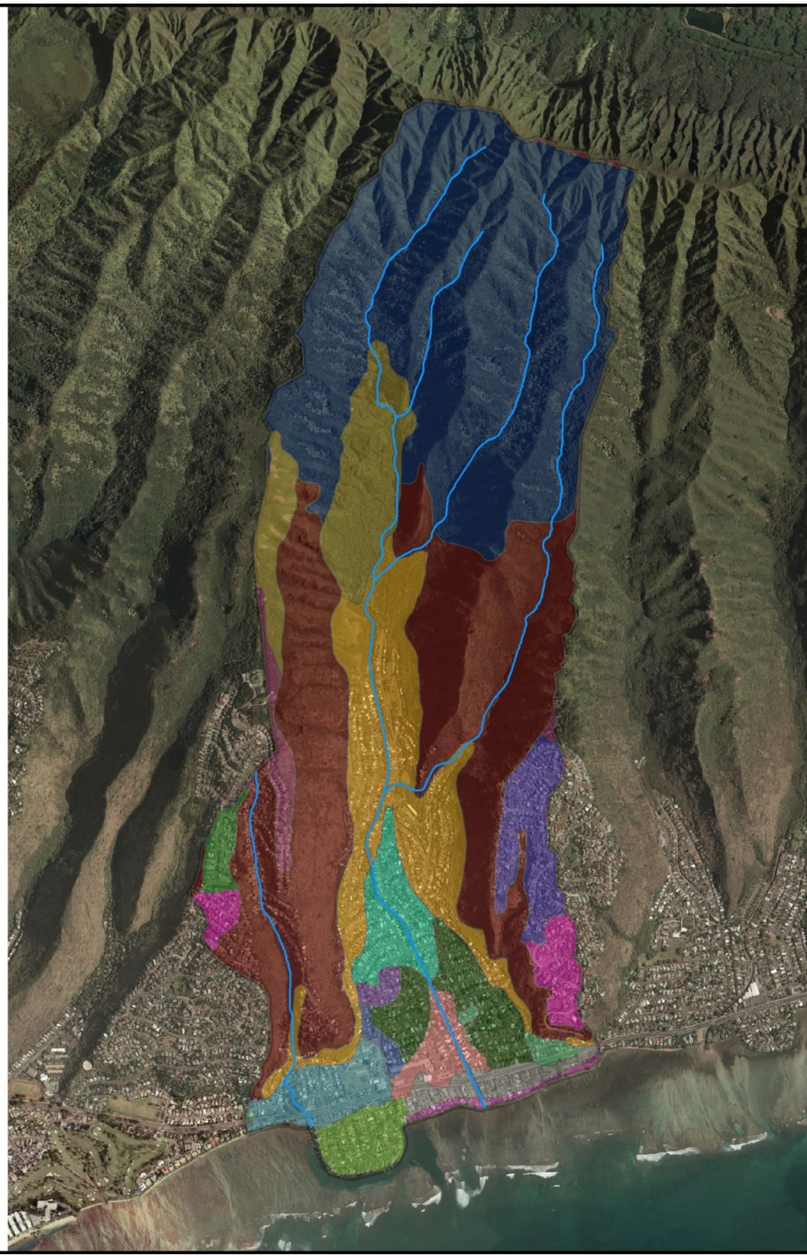


Figure 12

Soil Types

Legend

- CR
- FL
- HLMG
- HxA
- JaC
- KlA
- KlaA
- LPE
- LaB
- LaC
- LaC3
- LuA
- MnC
- Mt
- PID
- W
- WkA
- rRK
- rRO
- rRT

N

0 0.25 0.5 0.75 1

Miles

Wailupe Watershed Based Plan

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

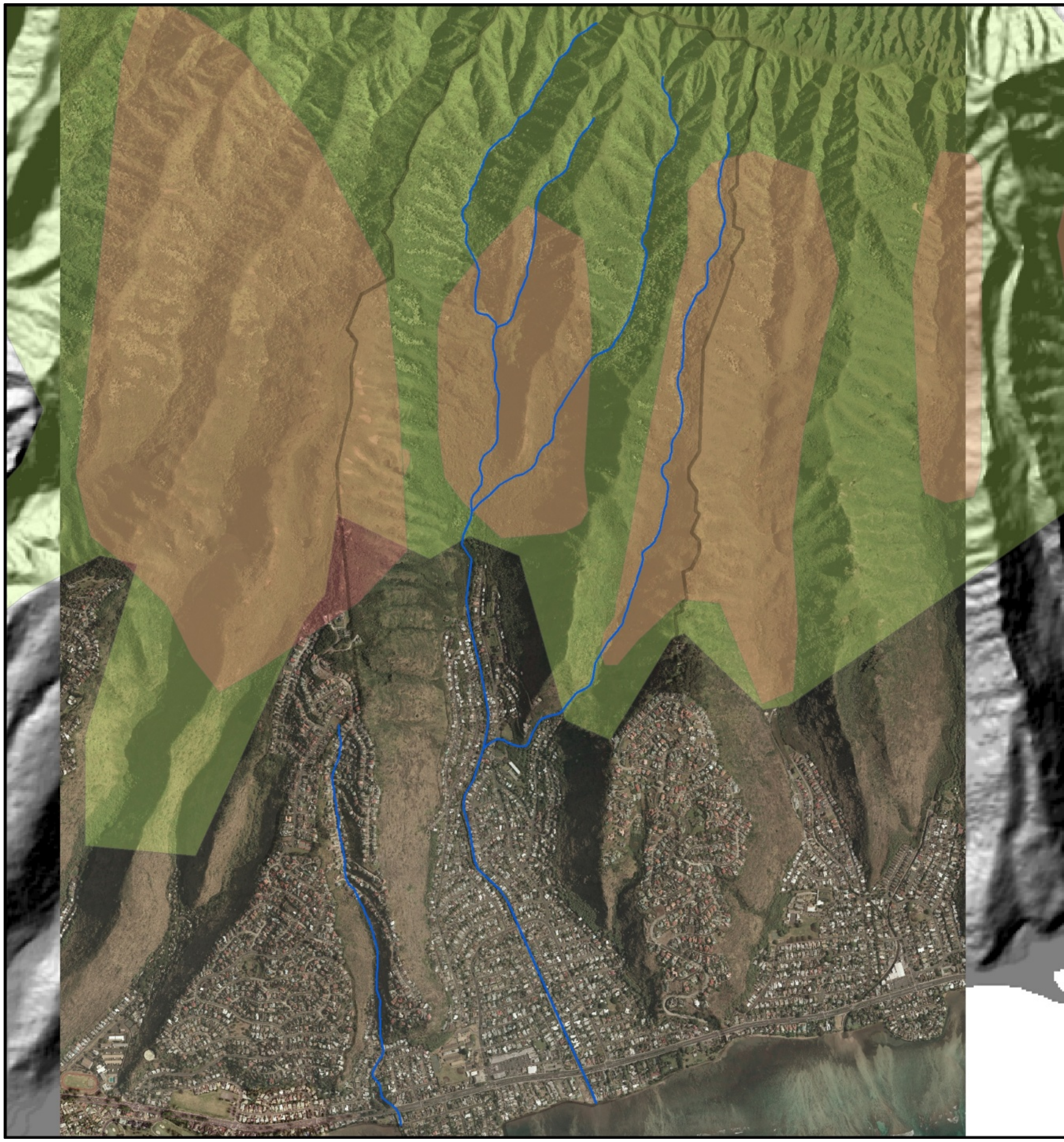


Figure 13

Distribution of O'ahu 'Elepaio (*Chasiempis sandwichensis ibidis*)

Wailupe Watershed Based Plan

Source: U.S. Fish and Wildlife Service. Pacific Islands Ecoregion. Honolulu, HI; Hawaii Natural Heritage Program, Natural Diversity Database.

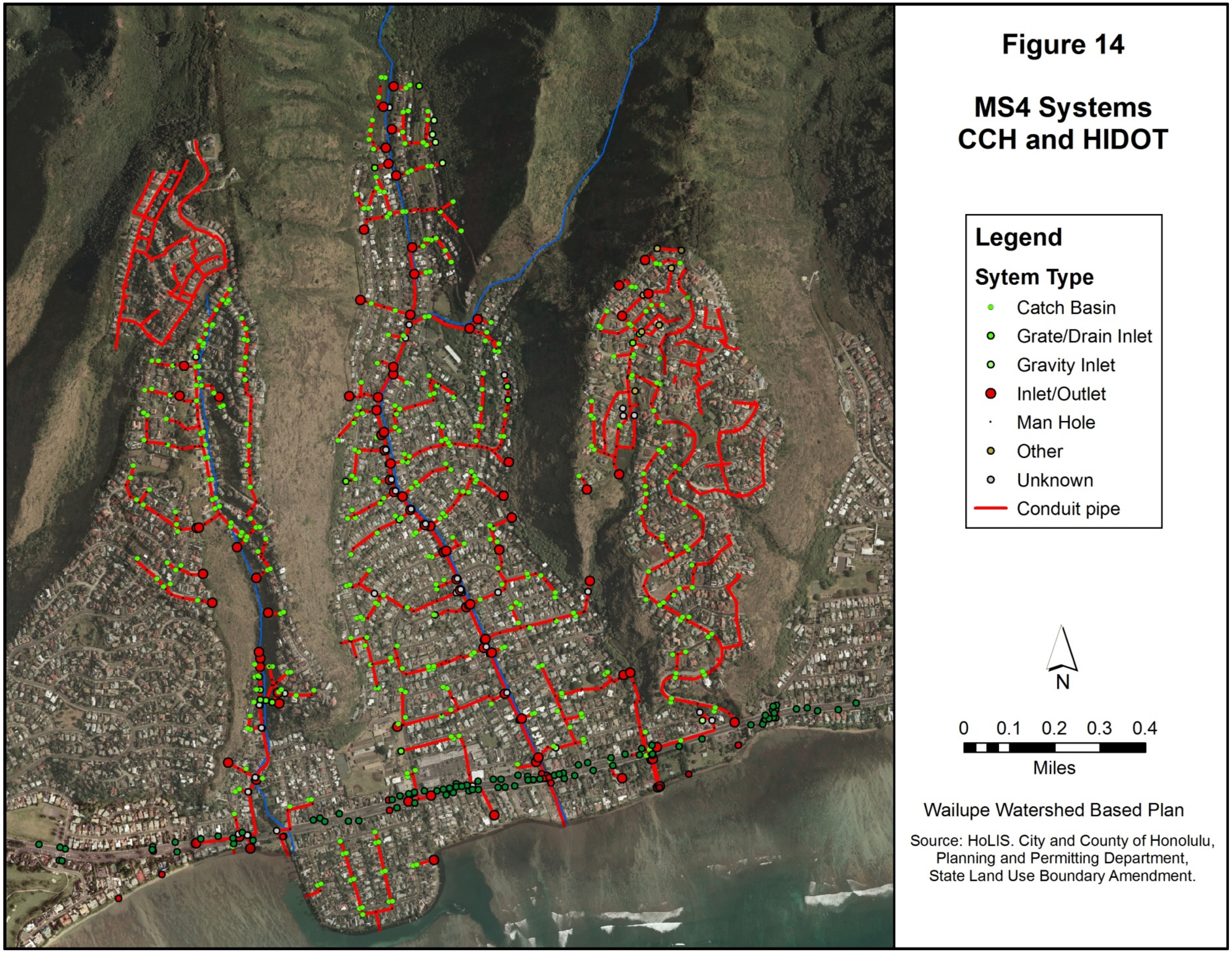


Figure 14

MS4 Systems CCH and HIDOT

Wailupe Watershed Based Plan

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

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

Pollution Control Strategies Report

Draft

June 2010

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Table of Contents

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1 Introduction

The goal of the *Wailupe Watershed Based Plan* is to characterize and assess the condition of the watershed and to identify management objectives and pollutant control strategies to reduce generation and discharge of non-point source (NPS) pollutants into the receiving waters of Wailupe Stream and Maunalua Bay. A watershed characterization is presented in the *Watershed Characterization Report*. The objectives of this *Pollution Control Strategies Report* 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 necessary to 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 Defining Management Measures

Management measures are defined in Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 as economically achievable measures 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.[1] 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's stream 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. 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

[1] 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.

presented should not necessarily be excluded. A primary consideration when selecting management measures was to choose 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, preventative or treatment control. Preventative measures focus on controlling or eliminating the pollutant at its source. From a watershed science perspective, preventative source control is the best way to address NPS pollutants. However, preventative measures are not always technically feasible or cost-effective, and it often takes considerable time after they are installed for benefits to be realized. In some cases, a treatment control, which involves treating the NPS pollutant along its pollution stream[2] will be the most effective and immediate means to reduce pollutant loads. Both types of controls can be achieved through structural (hard) and nonstructural (soft) type practices. Structural or hard engineering practices generally rely on the use of structures made of concrete or synthetic materials, (e.g. storm water basins and hydrodynamic separators). Soft engineering practices, such as bioengineering, utilize vegetation and materials made from synthetic and natural fibers and designs based on ecologic practices. In many situations hard and soft engineering practices are used to maximize the best elements of each approach. Selection of the 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 report identifies practical and implementable measures to be installed or practiced across the watershed that are expected to reduce NPS pollutant delivery into Maunalua Bay. The management practices recommended in this report address existing watershed impairments and/or features that generate and transport NPS pollutants in the watershed, and are not management practices targeting 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 what measures to implement. Prior to implementation the management practices will require varying levels of detailed design 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 the *Implementation Strategy Report*.

3 Delineating Management Units

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

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

Table 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

The units were ranked based on 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 generation and transport, proximity to receiving waters, NPS pollutant sources and pathways, and land use and cover. The dominant criterion was the probability that the unit generates and transports fine terrigenous sediments to the marine environment. The rationale for making this the dominant criterion is the identification of fine sediment as the priority threat to the health of Maunalua Bay (Mālama Maunalua 2009). Primary pollutant types that are generated from each management unit are identified in Table 2.

Table 2. Storm Water Pollutant Generation Types for Management Units

Pollutant Type[3]	Management Unit (✓ = Pollutant Applies)			
	Upland Forest	Steep Slopes	Urban Footprint	Stream Corridor
Sediment	✓	✓	✓	✓
Nutrient	✓	✓	✓	✓
Oxygen-Depleting Substances	✓	✓	✓	
Pathogens	✓	✓	✓	✓
Metals			✓	
Hydro-carbons			✓	
Organics			✓	
Storm Water Flow[4]		✓	✓	

Management measures for implementation were prioritized within each management unit. Similar to ranking the units for priority, specific areas and management measures were evaluated and prioritized. The priority for implementation should not be considered rigid, and if a land owner or entity responsible for a particular parcel has resources to implement a management measure that is lower priority, the opportunity should be taken. Any installation of a management measure is a positive gain towards reducing NPS pollution regardless of order. Units that are contributing the most sediment should, to the

[3] Pollutant types are described in detail in the *Watershed Characterization Report*, Table 3.
[4] Storm water flow refers to runoff per unit area that, for current conditions, is estimated to be greater than historic or background levels.

extent possible, be targeted first in order to reduce the largest contribution of sediment to the ocean in a timely manner.

3.1 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 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 and 3 show areas where an 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 2003). Mass wasting and erosion are both natural processes, as evidenced by the steep valleys that dominant the watershed. However, when human activities or other introduced agents alter ground cover, reduce slope stability or generate concentrated over flow to areas where it would not naturally occur, the outcome is increased rates of erosion and occurrence of 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 as 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 *Watershed Characterization Report*). 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).

3.2 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 Aina Haina neighborhood.

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

Description: Adjacent to the developed urban zone are steep, exposed slopes with scarce vegetation consisting of 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. This management unit has a lower mean annual rainfall 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 that can form rills along slopes, causing the surface to weaken and increase the chance of slope failure. There are numerous large gullies that extend from the ridgelines down to the outer boundary of the urban unit. Sediment and runoff derived from these steep slopes and transported in the gullies is routed directly into the municipal separate storm sewer system (MS4) located at the base of the steep slopes.[5] The NPS 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 in 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. Figure 4 depicts the steep side slopes with the cutoff ditch located on the west side of the Aina Haina neighborhood.

Pollution Type: The primary NPS pollutant concern from the steep slopes is the runoff containing soil particles of various sizes classes that wind up in ditches and drainage inlets that are conveyed into the stream channel via the MS4. Although the rate of erosion from this steep slope unit has not been quantified, there is evidence of significant erosion. For example, there are sediment deposits at the toe of the slopes and the existence of cutoff ditches maintained by the CCH at the downslope area of Wiliwilinui ridge above the Aina Haina community and at the base of the slopes below Hawaii Loa Ridge. These cut-off 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.

3.3 Urban Management Unit

Site: Residential and commercial footprint within the Aina Haina, Wiliwilinui, and Hawaii Loa neighborhoods, and Kalanianaole Highway.

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

Description: The urban footprint in Wailupe Watershed is comprised of the Aina 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, as well as the commercial district and Kalanianaole Highway. Land use in this region ranges from residential to commercial and includes a school district, public parks, and a highway system (see *Watershed Characterization Report* for further details on land use). This range of land use practices generates a variety of pollutant types from numerous sources throughout the urban region.

Land coverage, 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 MS4 systems, 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 Kalanianaole Highway. Rainfall for all but the smallest of storms generates overland flow that is quickly transported

[5] *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.

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 an increase in the generation of contaminants when compare to pre-urbanized conditions. This increase in frequency of 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 draining 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, material 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: Based on the conditions observed across the management unit and the land uses that take place within it, it is hypothesized that the urban management unit generates the largest diversity of NPS pollutants and for some of the NPS pollutant types (i.e. metals), the highest loads. The exception is fine sediments, which are primarily generated from the upland forest and steep slope management units. The types of pollutants that diminish water quality and negatively impact aquatic ecosystems can oftentimes be traced to residential and commercial activities and practices. The urban region presents 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 (see Table 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 have been linked to the degradation of urban waterways (USEPA 2005).

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 (see Tables 4 and 5). Large impervious surfaces (i.e. commercial parking lots) essentially function as water harvesting surfaces and generate high magnitude runoff containing by-products of the numerous vehicles that use them. None of the parking lots in the unit were found to be fitted with management measures to attenuate runoff volume or timing or remediate NPS pollutants. A few parking lots at the Aina Haina School border grassy areas and in some cases it appeared that storm water runoff would discharge onto the grass, however, this did not appear to be intentionally designed. 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.

Table 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 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

Constituent	Primary Sources
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 5. Mean Pollutant Concentration in Runoff from Urban and Rural Highways
(Driscoll, Shelley 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

3.4 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 (see *Watershed Characterization Report*, Section 2.2.5). There are two sections between the existing debris basin near the *mauka* end of Hao Street and the ocean that are lined with concrete-rubble masonry walls; below the debris basin for approximately 1,000 ft and also from Kalanianaole Highway downstream to the mouth. This section is bounded by the urban management unit. 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 potential upland sapprolite failures (collapse of large mass of weathered residual rock) 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 bull dozer 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 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 Kalanianaole 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 for all the outfalls carries with it untreated storm water runoff.

At several locations 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 ultimately becomes 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.[6]

As described in the *Watershed Characterization Report*, flooding is a major concern in the region, and flood control 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 versus the infrequent high magnitude events.

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

4 Management Measures for Implementation

The development of a run-off management program is guided by management measures. Management measures establish performance expectations and, in many cases specify practices that can be taken to prevent or minimize NPS pollution. Management measures for targeted pollutants and priority concerns for each management unit are shown in Table 6. Recommend priority practices and technologies for improvement purposes in each management unit are presented in Table 7. Examples of management practices are presented in Appendix B.

There are numerous publications and resources to guide land managers in the selection, acquisition, and installation of management measures to control storm water runoff and remediate NPS pollutants. During preparation of this section literature reviews, interviews, and site inspections were conducted to narrow the list of recommended management measures 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 measures 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.

4.1 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.

The upland forest management unit likely generates the most fine sediments of the four management units due primarily to its size, the rainfall regime, and steep topography. Lowering erosion rates would result in significant reduction of fine sediment generation from this unit. However, a preventative strategy to control erosion rates in this steep and somewhat inaccessible and passively managed unit presents logistical and regulatory challenges. After reviewing the regulatory and management plans for the unit, considering the challenges that reforestation activities face, and noting the lack of direct funding programs for preventative measures, it was concluded that while preventative measures would be recommended, they would not be the priority for this unit.

Table 6. Management Measures Applicable to Management Units

Management Unit (✓ = Management Measure Applies)					**Objective**	
Upland Forest	**Steep Slopes**	**Urban**	**Stream Channel**	**Management Measure**	**Preventative**	**Treatment**
✓		✓		Bioengineered Filtering System		✓
	✓	✓		Capture and Filter Sediment		✓
			✓	Channel Stabilization	✓	
✓		✓		Detention/Retention	✓	✓
	✓		✓	Erosion Protection of Bare or Exposed Areas	✓	
	✓	✓		Flow Restrictors/Regulators	✓	
		✓		Household Generation	✓	
✓	✓	✓	✓	Indentify, Prioritize, Schedule Retrofit Opportunities		✓
	✓	✓	✓	Infiltration		✓
✓			✓	Instream Sediment Load Control		✓
✓	✓	✓	✓	Operation and Maintenance		✓
✓	✓		✓	Restore Natural Systems	✓	
	✓	✓		Runoff Interception/Control	✓	
	✓	✓	✓	Slope Energy	✓	
			✓	Streambank Preservation/Enhancement	✓	
✓	✓		✓	Vegetative Cover	✓	✓

Table 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		✓		✓

Extended Detention Basins. The recommended priority measures are treatment controls that are expected to have immediate positive impacts on reducing transport of fine sediments and other NPS pollutants upon implementation. 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. When properly designed and maintained, ED basins can reduce fine sediment concentration in suspension; trap large particles resulting in protection and maintenance of downstream channel geometry and flow conveyance; reduce downstream peak flows decreasing in channel erosion rates; enhance ground water recharge; and assist USACE in achieving their 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 sustain certain flow events or low flow in the basin is compatible with USACE flood reduction project ideas.

The 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 5 and 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 Ko'olau mountains is currently being studied by government entities, private entities (i.e. Ko'olua Mountain Watershed Partnership) and public institutions (i.e. University of Hawai'i). 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.

4.2 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 methods due to the extremely steep topography and direct connection of runoff into the MS4 at several locations. Recommended preventative 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.

Revegetation. Prevention practices will decrease the rate of overland flow and 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 are recommended to provide ground cover on exposed areas and decrease slope length and trap sediments. Covering exposed areas with an erosion mat and seeding the mat with species such as dry land Pili grass (*Heteropogon contortus*), the drought tolerant a'ali'i (*Dodonaea viscose*), and alahe'e (*Psydrax odorata*) are practices that have been successfully implemented during restoration efforts on the island of Kaho'olawe. Figure 7 depicts locations where coir logs could be placed along contours of the slopes to slow overland flow and trap sediments.

Baffle Boxes. Treatment practices 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 system 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 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 Aina 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 were 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 water. 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. These include filters, screens, perforation holes, and energy dissipaters at the outlet of the ditch.

4.3 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.

Recommended management measures and practices in the urban unit focus on reducing a range of 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 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 preventative 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 general good housekeeping practices (see

Table 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. The program should include specific recommendations on how each individual could contribute to towards the goal of reducing contaminants that create NPS pollution.

Storm Water Capture. Field observations made in the urban management unit found that many houses were 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). This higher volume of runoff increases the frequency and efficiency by which NPS pollutants are carried to MS4 inlets. Rainfall 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 *Watershed Characterization Report*). Mālama Maunalua has initiated a program called Every Drop Counts that is focused on reducing storm water runoff from urban areas. A low tech, moderately low cost solution is to harvest runoff generated off roofs and other elevated surfaces and store it in rain barrels 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. 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. 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 potentially use excess 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 applications 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* in December 2008 (DLNR 2008). This publication is a useful guide on methods and practices to harvest rainwater. Although the intent of the publication was not remediation of NPS pollution, many of the practices will assist in remediating NPS pollutants.

Table 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 grass areas, install rain gardens.

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 Hawai‘i and reports having the lowest installation time and highest rated catch basin insert for performance and maintenance (Bio Clean 2009). MS4 inlets on both MS4s targeted for curb basket inlet retrofits are located in areas that receive high traffic volume (i.e. commercial parking lots, school pick-up zones) and inlets adjacent to areas where vehicles stop frequently (i.e. stoplights along Kalanianaole Hwy). There are 489 inlets on the CCH MS4 system and it was not possible to identify or prioritize installation locations.

Baffle boxes are designed to trap both coarse and fine sediments, filter nutrients, capture hydrocarbons and are relatively easy to maintain using conventional storm inlet 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 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 Aina 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 10 depicts the recommended locations for grass swales, infiltration trenches, and modular wetlands.

4.4 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 were 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. During preparation of this report meetings were held between 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 issues 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, 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 streams located on O‘ahu (SRGII 2009).

5 Pollutant Load Reductions

Suitable management practices for management units will address appropriate target parameters. Drawing from multiple handbooks and management practice guidebooks, Table 9 screens management practices for their relative performance in addressing pollutant loading and storm water flow (LA-SMD 2000; USEPA 2003; Field, Tafuri 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 umbrella term lumps widely varying techniques and objections into a single category. There is great variability in storm water quality and hydrology of the runoff. Since nonpoint sources are recognized as the major contributor to pollution in Wailupe Stream, the recommended management practices are the primary tool to be used to mitigate the deleterious effects of NPS pollution on the receiving coastal resources of Maunalua Bay.

Table 9. Management Practices and Expected Load Reduction

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

Appendix A

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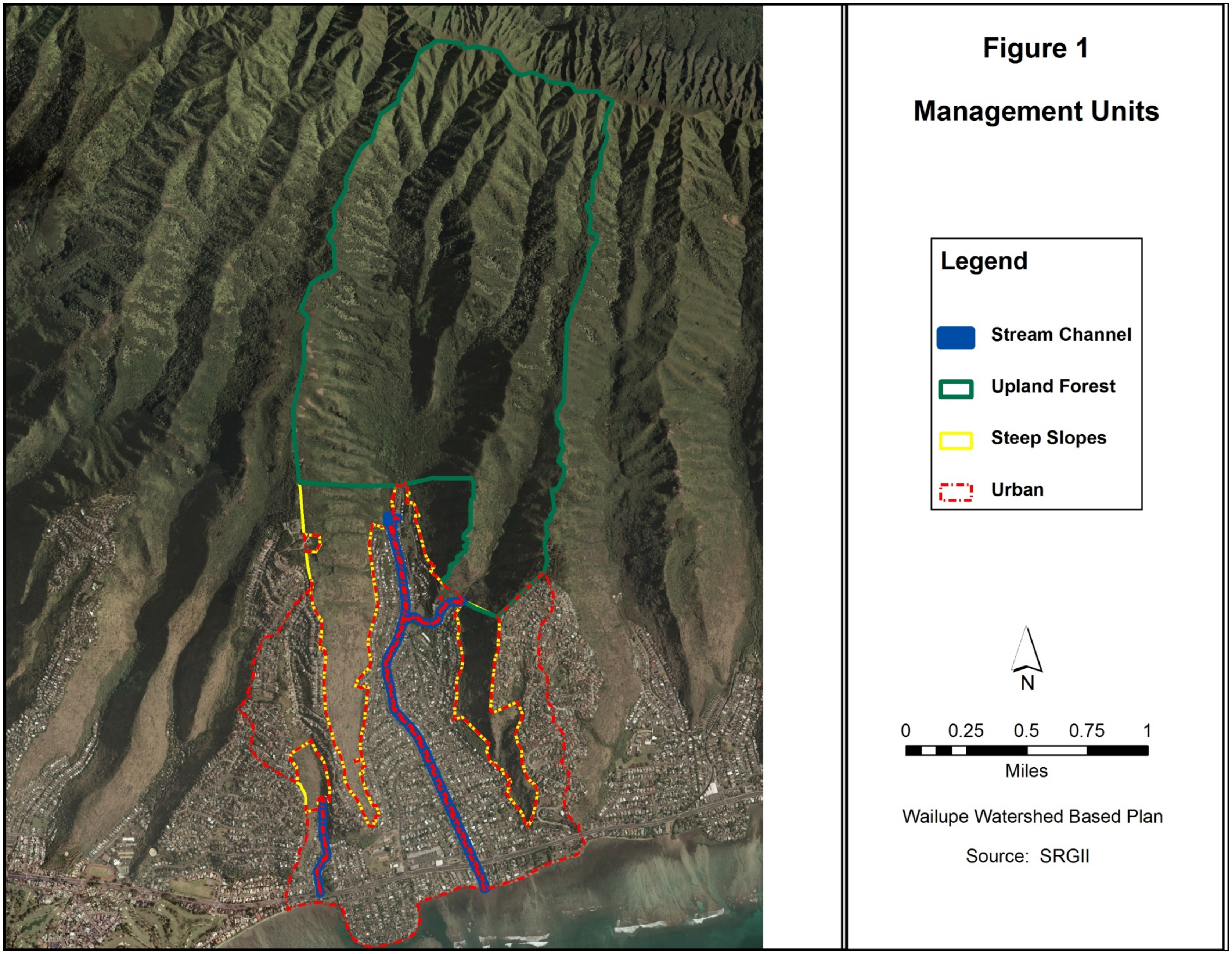

Figure 1

Management Units

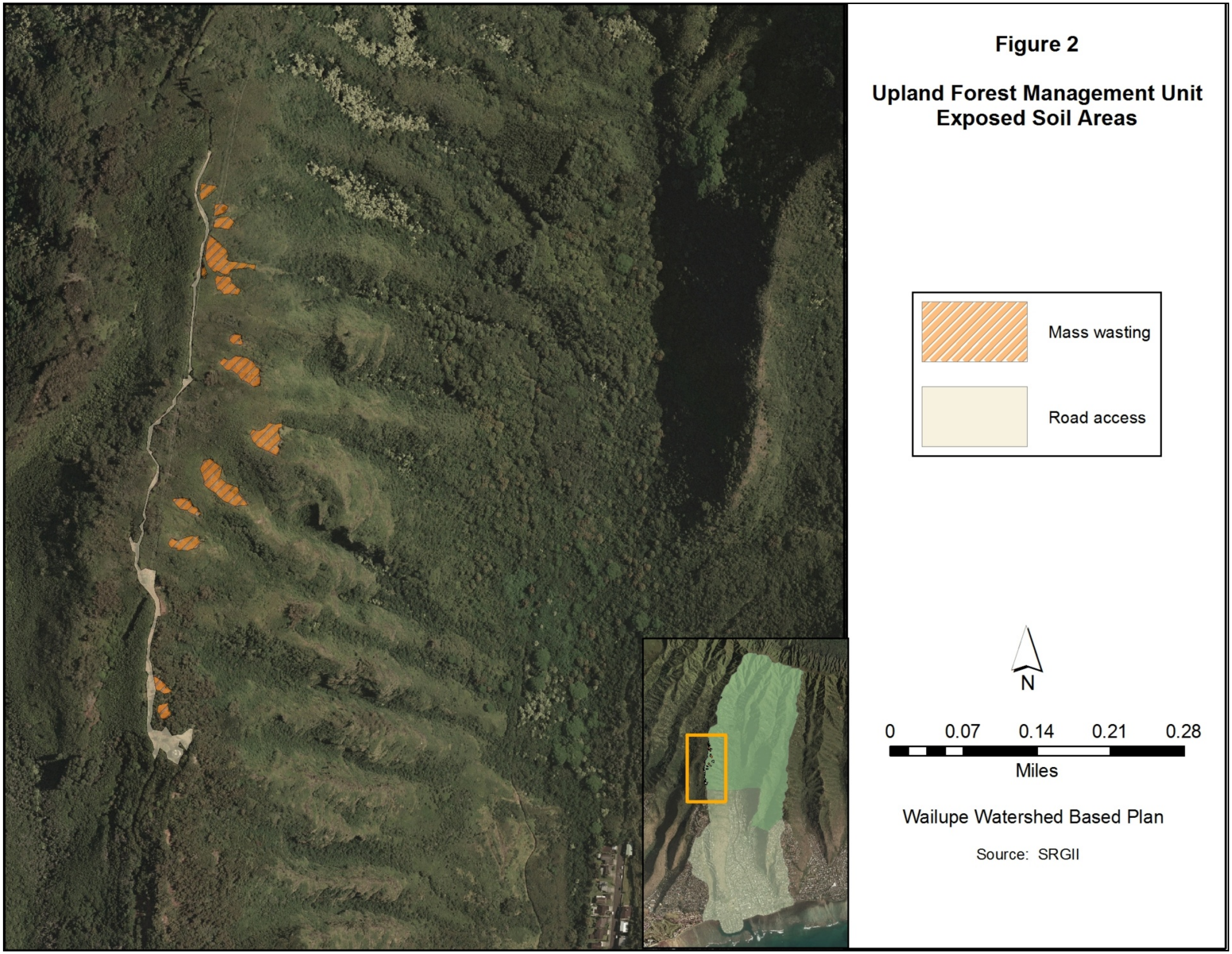

Figure 2
Upland Forest Management Unit
Exposed Soil Areas
Mass wasting
Road access
N
0
0.07
0.14
0.21
0.28
Miles
Wailupe Watershed Based Plan
Source: SRGII

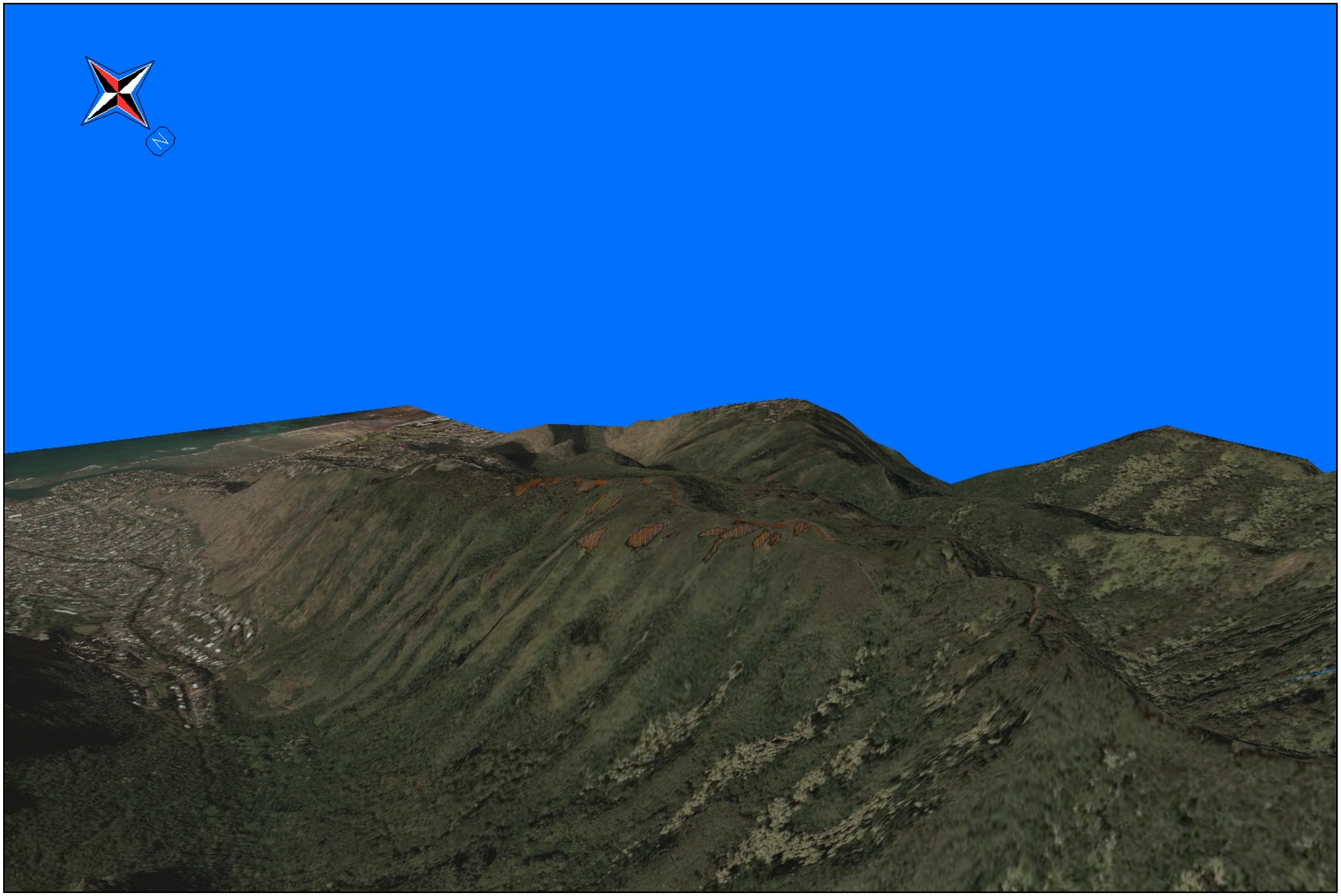

Figure 3. Upland Forest Management Unit: Exposed Soil Areas (3D)

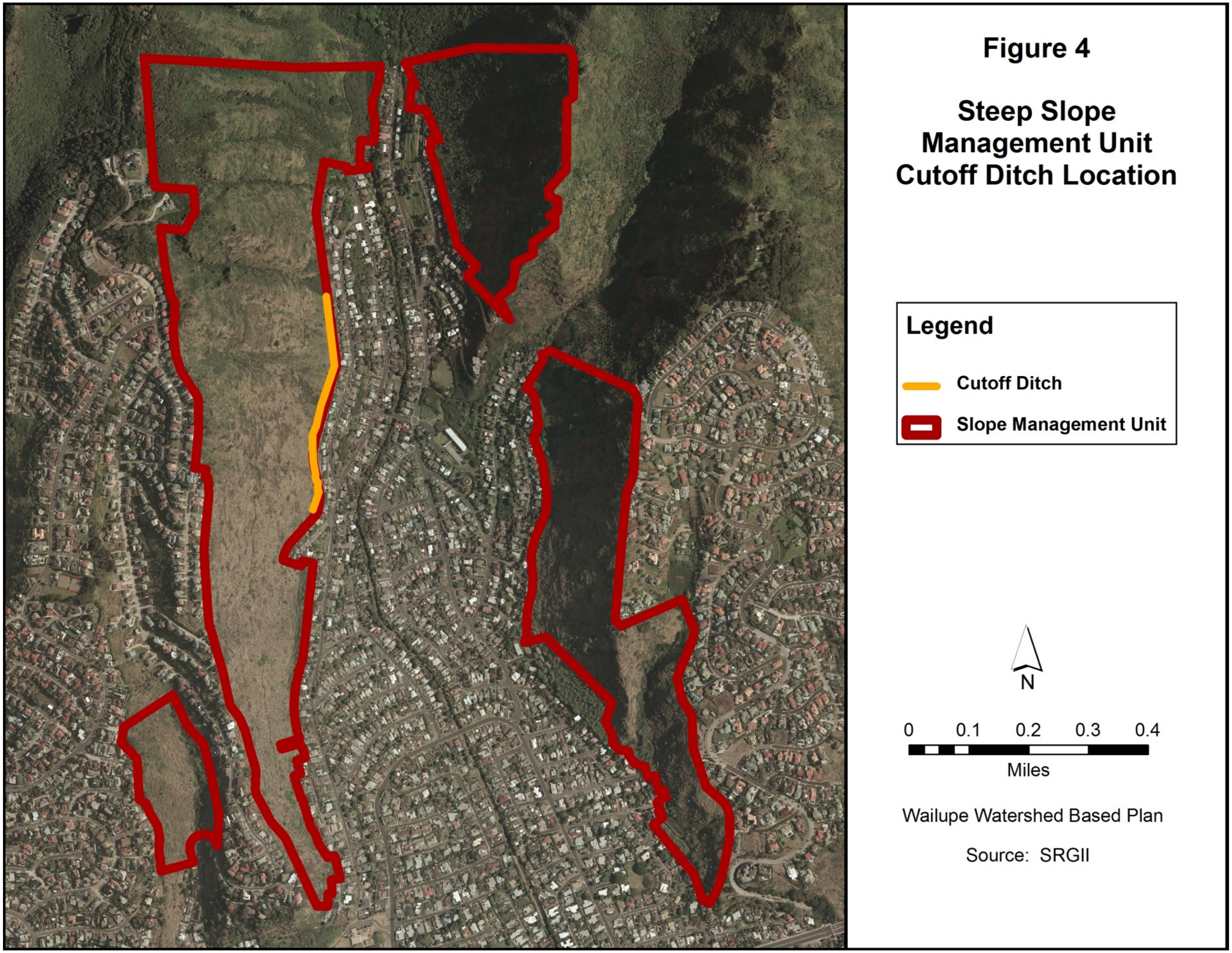

Figure 4

Steep Slope Management Unit Cutoff Ditch Location

Wailupe Watershed Based Plan

Source: SRGII

Figure 5

Upland Forest Unit Extended Detention Basins

Legend

- **Existing Debris Basin Retro Fit**
- **Extended Detention Basin**
- **Wailupe Stream**

N

0 0.06 0.12 0.18 0.24

Miles

Wailupe Watershed Based Plan

Source: SRGII

Figure 6. Upland Forest Management Unit: Extended Detention Basin Locations (3D)

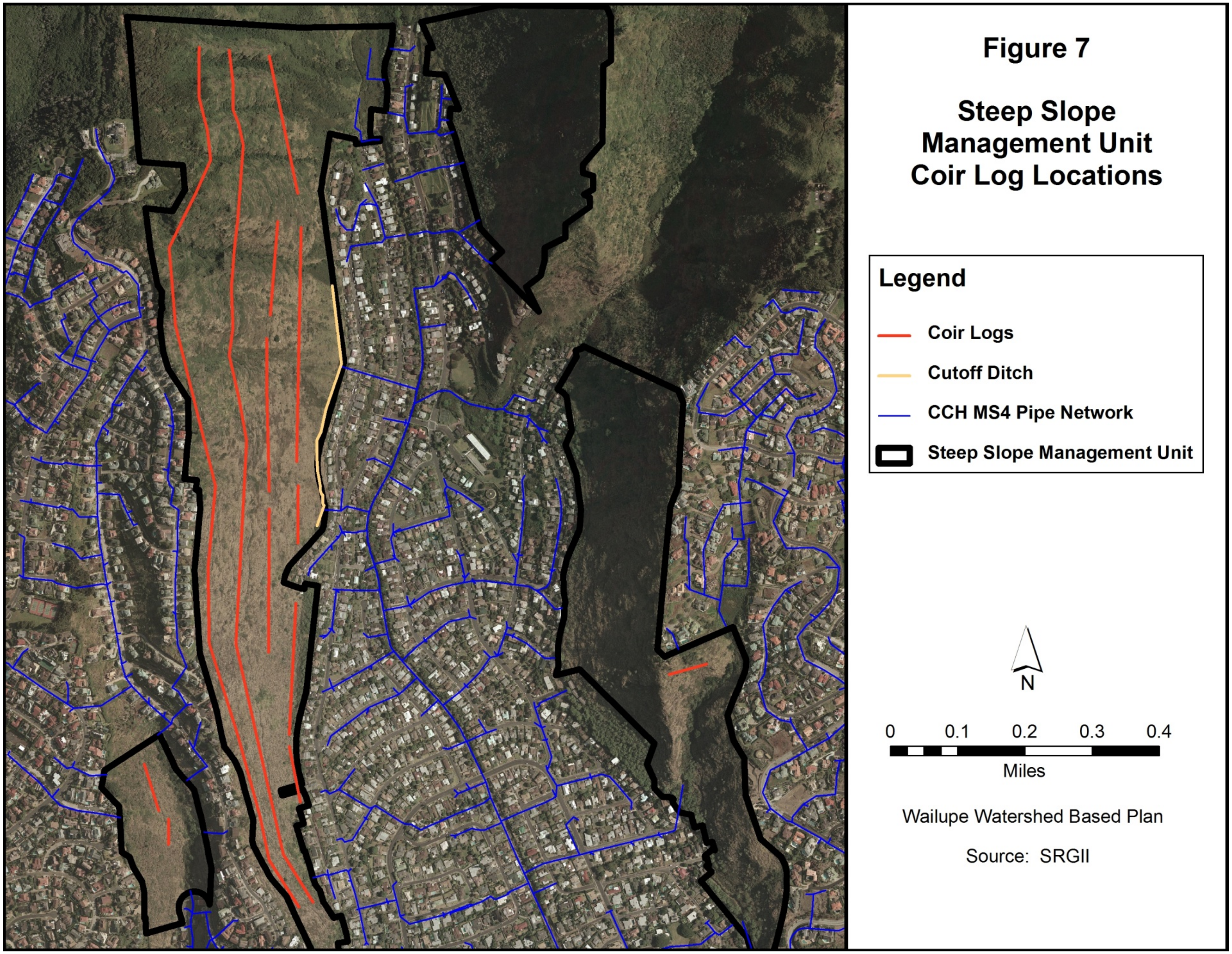

Figure 7
Steep Slope
Management Unit
Coir Log Locations
Legend
Coir Logs
Cutoff Ditch
CCH MS4 Pipe Network
Steep Slope Management Unit
N
0
0.1
0.2
0.3
0.4
Miles
Wailupe Watershed Based Plan
Source: SRGII

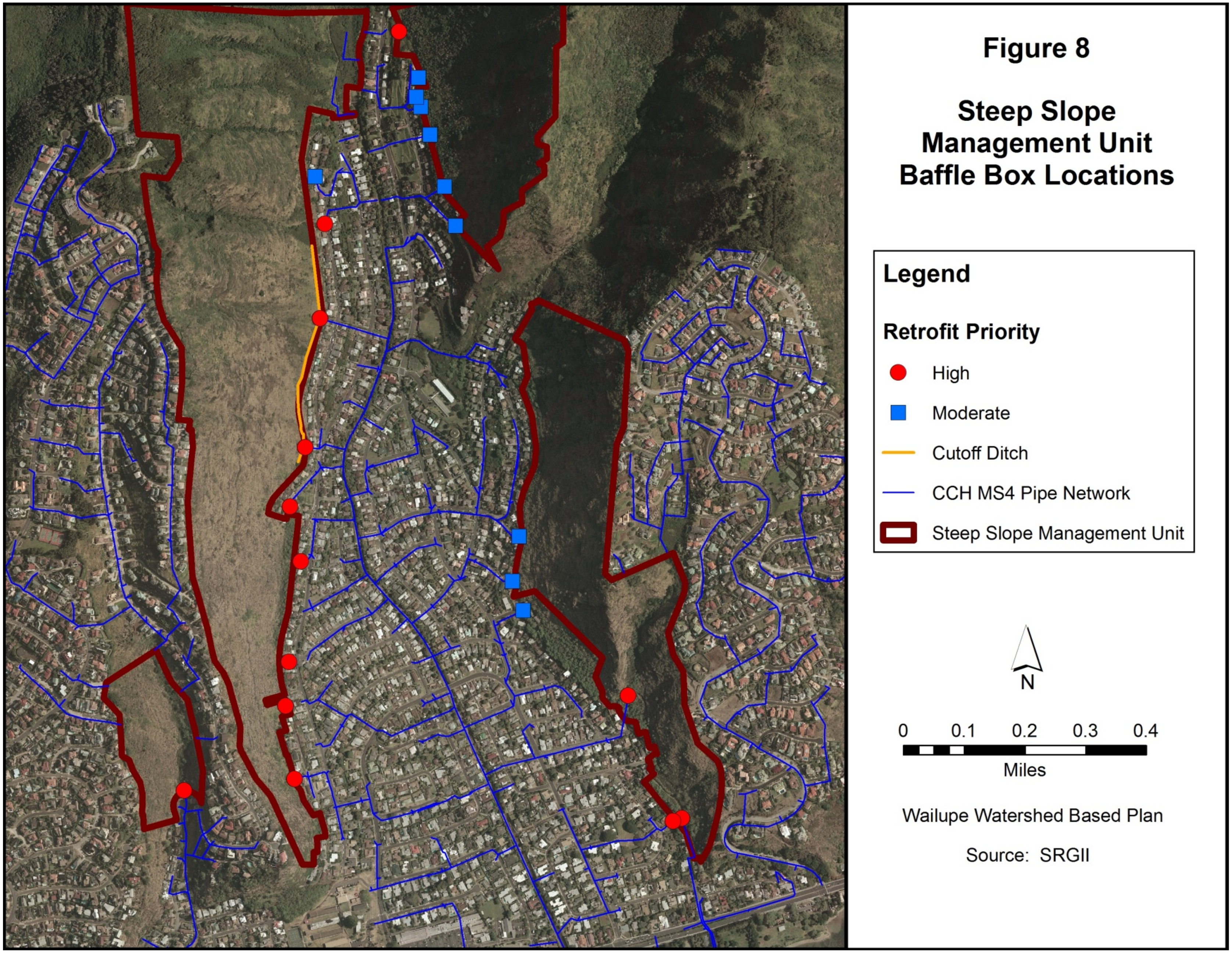
Figure 8
Steep Slope Management Unit Baffle Box Locations
Legend
Retrofit Priority
High
Moderate
Cutoff Ditch
CCH MS4 Pipe Network
Steep Slope Management Unit
N
0 0.1 0.2 0.3 0.4
Miles
Wailupe Watershed Based Plan
Source: SRGII

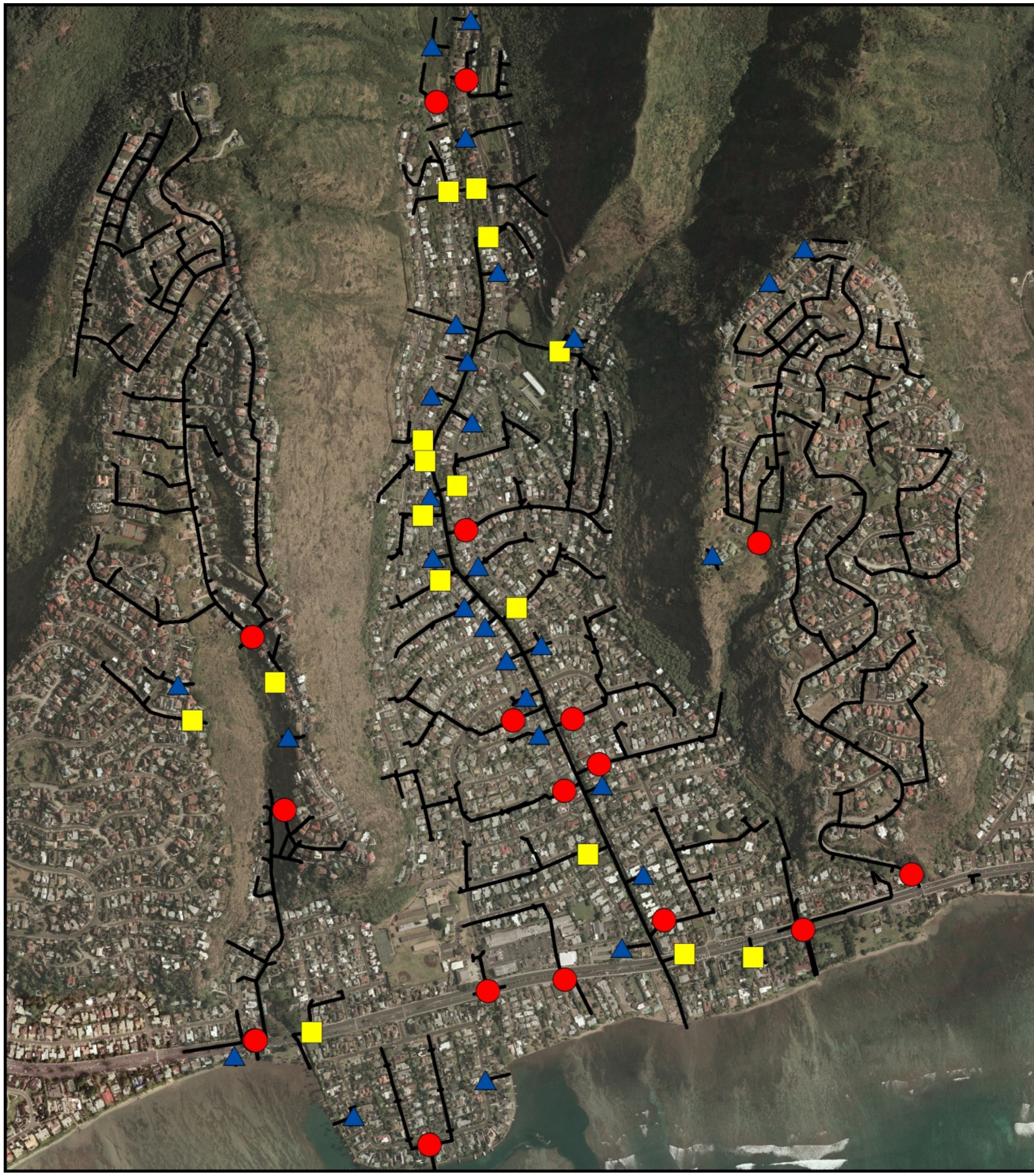

Figure 9

Urban Management Unit Baffle Boxe Locations

Legend

Retrofit Priority

- High
- Moderate
- Low
- MS4 Conduit

N

0 0.1 0.2 0.3 0.4

Miles

Wailupe Watershed Based Plan

Source: SRGII

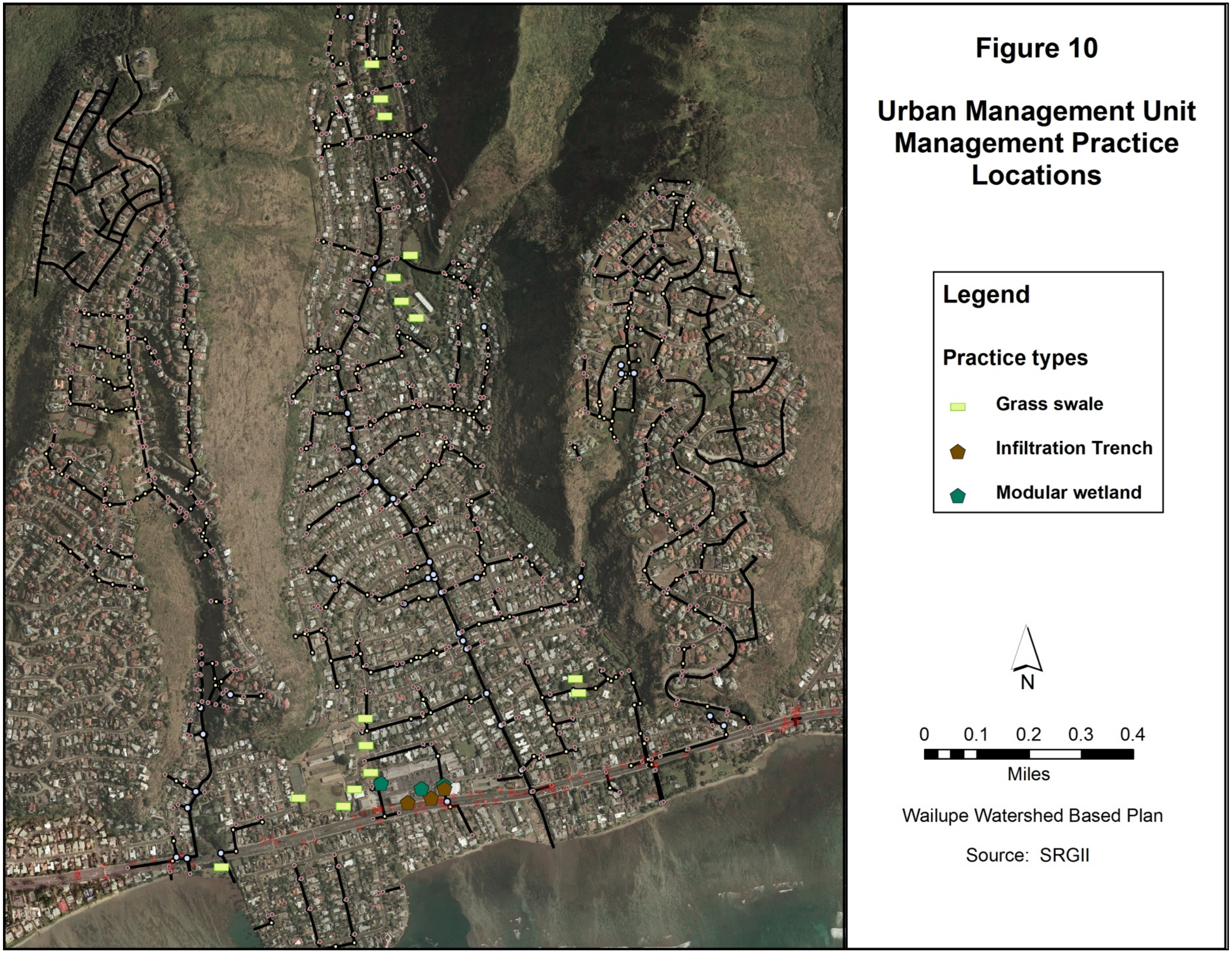

Figure 10
Urban Management Unit Management Practice Locations
Legend
Practice types
Grass swale
Infiltration Trench
Modular wetland
N
0 0.1 0.2 0.3 0.4
Miles
Wailupe Watershed Based Plan
Source: SRGII

Appendix B: Management Practices: Glossary and Design Features

This appendix provides detailed information about pollution control structures and management practices recommended in this report, including a glossary of terms and drawings, images, and product specifications.

Contents

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Glossary

The following glossary terms relating to management practices are adopted from multiple sources, including but not limited to (USEPA 1993; Field, Tafuri et al. 2004; USEPA 2005; USEPA 2007)

BANK STABILIZATION	Methods of securing the structural integrity of earthen stream channel banks with structural supports to prevent bank slumping and undercutting of riparian trees, and overall erosion prevention. To maintain the ecological integrity of the system, recommended techniques include the use of willow stakes, imbricated riprap, or brush bundles.
BANKFULL EVENT (ALSO BANKFULL DISCHARGE)	A flow condition in which streamflow completely fills the steam channel up to the top of the bank. In undisturbed watersheds, the discharge condition occurs on average every 1.5 to 2 years and controls the shape and form of natural channels.
BASEFLOW	The portion of stream flow that is not due to storm runoff, and is supported by groundwater seepage into a channel.
BIOFILTRATION	The use of natural materials and vegetation to trap and remove pollutants from storm water. Grass swales and constructed wetlands can both be used for biofiltration.
BIOLOGICAL MONITORING	Periodic surveys of aquatic biota as an indicator of the general health of a waterbody. Biological monitoring surveys can span the trophic spectrum, from macro-invertebrates to fish species.
CATCH BASIN	Catch Basins collect the rainwater and Urban runoff from the street and serve as the neighborhood entry point in the MS4 system leading into the ocean.
CATCHMENT AREA	See CONTRIBUTING WATERSHED AREA. Also known as drainage catchment area.
CFS	Cubic feet per second. A measure of volumetric flow rate. One CFS is about 449 gallons per minute.
CHANNEL	A natural or artificial waterway that periodically or continuously contains moving water. It has a definite bed and banks that confine the water.
CHANNEL EROSION	The widening, deepening, and headward cutting of small channels and waterways, due to erosion caused by moderate to larger floods.
CONCENTRATION	The density or amount of a pollutant, or other constituent, in solution. This is commonly measured as the average density of pollutants and expressed as milligrams/liter (mg/l).
CONTRIBUTING WATERSHED AREA	Portion of the watershed contributing its runoff to the site or management practice in question.
CONVEYANCE SYSTEM	The drainage facilities, both natural and human-made, which collect, contain, and provide for the flow of surface water and urban runoff from the highest points on the land down to receiving water. The natural elements of the conveyance system include swales and small drainage courses, streams, rivers, lakes, and wetlands. The human-made elements of the conveyance system include gutters, ditches, pipes, channels, and most retention/detention facilities.
DEBRIS	Any material, organic or inorganic, floating or submerged, moved by a flowing stream.
DESIGN STORM	A rainfall event of specified size and return frequency (e.g., a storm that occurs only once every 2 years) that is used to calculate the runoff volume and peak discharge rate to a management practice.
DETENTION	The temporary storage of storm water runoff in a structural device to reduce the peak discharge rates and to provide settling of pollutants.
DETENTION POND	A constructed pond or vault that temporarily stores storm water runoff and releases it at controlled rates.
DETENTION TIME	Time required for detention of storm water runoff in a storm water quality facility (also see "Detention").
DISCHARGE	Outflow; the flow of a stream, canal, or aquifer. One may also speak of the discharge of a canal or stream into a lake, river, or ocean. (Hydraulics) Rate of flow, specifically fluid flow; a volume of fluid passing a point per unit of time, commonly expressed as cubic feet per second, cubic meters per second, gallons per minute, gallons per day, or millions of gallons per day.

DISSOLVED OXYGEN (DO)	Oxygen which is present (dissolved) in water and available for use by fish and other aquatic animals. If the amount of dissolved oxygen in the water is too low, aquatic animals will suffocate.
DIVERSION	A channel, embankment, or other man-made structure constructed to divert water from one area to another
DRAINAGE BASIN	A geographic and hydrologic subunit of a watershed
DRY POND CONVERSION	A modification made to an existing dry storm water management pond to increase pollutant removal efficiencies. For example, the modification may involve a decrease in orifice size to create extended detention times, or the alteration of the riser to create a permanent pool and/or shallow marsh system.
DRY-WEATHER FLOW	Flow occurring during the dry season (generally considered to be May through September) which may be associated with reservoir releases or releases of water from industrial or residential activities.
ECOSYSTEM	The interacting system of a biological community and its nonliving environmental surroundings.
EFFECTIVE IMPERVIOUS AREA (EIA)	The portion of total impervious cover that is directly connected to the storm drain network (MS4). These surfaces usually include street surfaces and paved driveways and sidewalks connected to or immediately adjacent to them, parking lots, and rooftops that are hydraulically connected to the drainage network (eg. downspouts).
EFFLUENT CONCENTRATION	The average concentration of a pollutant or other constituent in storm water runoff flowing out of the management practice.
EMBANKMENT	A bank (of earth or riprap) used to keep back water.
EMERGENT PLANT	An aquatic plant that is rooted in the sediment but whose leaves are at or above the water surface. Such wetland plants provide habitat for wildlife and waterfowl in addition to removing storm water pollutants.
END OF PIPE CONTROL	Water quality control technologies suited for the control of existing urban storm water at the point of storm sewer discharge to a stream. Due to typical space constraints, these technologies are usually designed to provide water quality control rather than quantity control.
ENERGY DISSIPATION	The loss of kinetic energy of moving water due to internal turbulence, boundary friction, change in flow direction, contraction, or expansion.
EROSION	The wearing away of the land surface by wind or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road building, or timber cutting.
EXTENDED DETENTION (ED)	A storm water design feature that provides for the gradual release of a volume of water (0.25 - 1.0 inches per impervious acre) over a 12 to 48 hour interval time to increase settling of urban pollutants, and protect channel from frequent flooding.
EXTENDED DETENTION (ED) POND	A conventional ED pond temporarily detains a portion of storm water runoff for up to twenty-four hours after a storm using a fixed orifice. Such extended detention allows urban pollutants to settle out. The ED ponds are normally dry between storm events and do not have any permanent standing water. An enhanced ED pond is designed to prevent clogging and resuspension. It provides greater flexibility in achieving target detention times. It may be equipped with plunge pools near the inlet, a micropool at the outlet, and utilize an adjustable reverse-sloped pipe at the ED control device.
EXTENDED DETENTION ZONE	A pondscaping zone that extends from the normal pool to the maximum water surface elevation during extended detention events. Plants within this zone must be able to withstand temporary inundation from 5 to 30 times per year.
FLOODPLAIN	Any lowland that borders a stream and is inundated periodically by its waters.
FOREBAY	An extra storage space provided near an inlet of a management practice to trap incoming sediments before they accumulate in a pond management practice.
FRINGE MARSH CREATION	Planting of emergent aquatic vegetation along the perimeter of open water to enhance pollutant uptake, increase forage and cover for wildlife and aquatic species, and improve the appearance of a pond.

GEOTEXTILE FABRIC	Textile of relatively small mesh or pore size that is used to (a) wallow water to pass through while keeping sediment out (permeable), or (b) prevent both runoff and sediment from passing through (impermeable). Also known as filter fabric.
GRADING	The cutting and/or filling of the land surface to a desired slope or elevation.
GRASSED SWALE	An earthen conveyance system in which the filtering action of grass and soil infiltration are utilized to remove pollutants from urban storm water. An enhanced grass swale, or biofilter, utilizes checkdams and wide depressions to increase runoff storage and promote greater settling of pollutants.
GRAVEL	Sediment particles larger than sand and ranging from 2 to 64 mm (0.25 to 3 inches) in diameter.
GRAVITATIONAL SETTLING	The tendency of particulate matter to drop out of storm water runoff as it flows downstream when runoff velocities are moderate and/or slopes are not too steep.
GROUNDWATER TABLE	The level below which the soil is saturated, that is, the pore spaces between the individual soil particles are filled with water. Above the groundwater table and below the ground surface, water in the soil does not fill all pore spaces.
DETENTION VOLUME	The volume of runoff that is held and treated in a management practice structure.
HABITAT	A place where a biological organism lives. The organic and non-organic surroundings that provide life requirements such as food and shelter.
HEAD	Pressure.
HEAVY METALS	Metals of relatively high atomic weight, including but not limited to chromium, copper, lead, mercury, nickel, and zinc. These metals are generally found in minimal quantities in storm water, but can be highly toxic even at trace levels and tend to accumulate in the food chain.
ILLICIT DISCHARGE	All nonurban runoff discharges to urban runoff drainage systems that could cause or contribute to a violation of State water quality, sediment quality, or ground-water quality standards, including but not limited to sanitary sewer connections, industrial process water, interior floor drains, car washing, and greywater systems.
IMPERMEABLE	Properties that prevent the movement of water through the material.
IMPERVIOUS SURFACE	A hard surface area that either prevents or retards the entry of water into the soil mantle as under natural conditions prior to development and/or a hard surface area that causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious surfaces include, but are not limited to, rooftops, walkways, patios, driveways, parking lots, storage areas, concrete or asphalt paving, gravel roads, packed earthen materials, and oiled, macadam, or other surfaces that similarly impede the natural infiltration of urban runoff. Open, uncovered retention/detention facilities shall not be considered as impervious surfaces.
INFILTRATION	The penetration of water through the ground surface into subsurface soil or the penetration of water from the soil into sewer or other pipes through defective joints, connections, or manhole walls. The infiltration rate is expressed in terms of inches/hour. Infiltration rates will be slower when the soil is dense (e.g., clays) and faster when the soil is loosely compacted (e.g., sands). Can also refer to seepage of groundwater into sewer pipes through cracks and joints.
INFLOW	The volume of storm water that enters a management practice.
INFLUENT CONCENTRATION	The average concentration of a pollutant or other constituent in storm water runoff flowing into the management practice.
INLET	(1) A drainage passway. (2) A short, narrow waterway connecting a bay, lagoon, or similar body of water with a large parent body of water. (3) An arm of the sea (or other body of water) that is long compared to its width and may extend a considerable distance inland.
INVASIVE EXOTIC PLANTS	Non-native plants having the capacity to compete and proliferate in introduced environments.
LAND CONVERSION	A change in land use, function, or purpose.

LAND-DISTURBING ACTIVITY	Any activity that results in a change in the existing soil cover (both vegetative and nonvegetative) and/or the existing soil topography. Land-disturbing activities include, but are not limited to, demolition, construction, clearing, grading, filling, and excavation.
LEVEL SPREADER	A device used to spread out storm water runoff uniformly over the ground surface as sheet flow (i.e., not through channels). The purpose of level spreaders is to prevent concentrative, erosive flows from occurring, and to enhance infiltration.
LOAD ALLOCATION (LA)	The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources.
LOADING CAPACITY (LC)	The greatest amount of loading [pollutant] that water can receive without violating water quality standards.
LOCAL GOVERNMENT	Any county, city, or town having its own incorporated government for local affairs.
LOWFLOW CHANNEL	An incised or paved channel from inlet to outlet in a dry basin which is designed to carry low runoff flows and/or baseflow, directly to the outlet without detention.
MASS WASTING	Dislodgement and downslope transport of loose rock and soil material under the direct influence of gravitational body stresses.
MULTIPLE POND SYSTEM	A collective term for a cluster of pond designs that incorporate redundant runoff treatment techniques within a single pond or series of ponds. These pond designs employ a combination of two or more of the following: extended detention, permanent pool, shallow marsh, or infiltration. The wet ED pond is an example of a multiple pond system.
MUNICIPAL SEPARATE STORM SEWER SYSTEMS (MS4)	MS4 is a storm water conveyance system comprised of inlet, pipes and outfalls that is owned or operated by the State or local government entity, is used for collecting and conveying storm water, and is not part of a publicly owned treatment works, as defined in EPA 40 CFR Part III. MS4 systems are
NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES)	A national program under Section 402 of the Clean Water Act for regulation of discharges of pollutants from point sources to waters of the United States. Discharges are illegal unless authorized by an NPDES permit.
NATURAL BUFFER	A low sloping area of maintained grassy or woody vegetation located between a pollutant source and a waterbody. A natural buffer is formed when a designated portion of a developed piece of land is left unaltered from its natural state during development. A natural vegetative buffer differs from a vegetated filter strip in that it is natural and in that they need not be used solely for water quality purposes. To be effective, such areas must be protected against concentrated flow.
NONPOINT SOURCE (NPS) POLLUTION	Pollution that , unlike pollution from industrial and sewage treatment plants, comes from many diffuse sources. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and manmade pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. Loadings of pollutants from NPS enter waterbodies via sheet flow, rather than through a pipe, ditch or other conveyance.
NUTRIENTS	Elements or substances, such as nitrogen or phosphorus, that are necessary for the growth and development of living things (e.g., plants). Large amounts of these substances reaching water bodies can lead to reduced water quality and eutrophication by promoting excessive aquatic algae growth. Some nutrients can be toxic at high concentrations.
OIL/WATER (OR OIL/GRIT) SEPARATOR	A best management practice consisting of a three-stage underground retention system designed to remove heavy particulates and absorbed hydrocarbons. Also known as a WATER QUALITY INLET.
ON-LOT STORAGE	Refers to a series of practices that are designed to contain runoff from individual lots.
ORGANOPHOSPHATE	Pesticide chemical that contains phosphorus; used to control insects. Organophosphates are short-lived, but some can be toxic when first applied.
OTHER REPORTED MEASURES OF PERFORMANCE	These are measures other than effluent concentration. Other reported measures of performance can include percent removal or similar measures.

OUTFALL	The point of discharge for a river, drain, pipe, etc.
OUTFLOW	The volume of storm water that leaves a management practice.
PASSIVE TREATMENT FACILITY	Facilities which use natural materials and vegetation to cleanse storm water and/or reduce storm water flow. Examples include grass swales, constructed wetlands, etc.
PERCENT REMOVAL	For a management practice, the percentage difference between the effluent concentration and the influent concentration for a given pollutant parameter.
PERCENT VOLUME REDUCTION	The percentage of volume reduced between the maximum influent volume and the maximum effluent volume for a given time period.
PERCOLATION	The downward movement of water through the soil.
PERMANENT POOL	A three to ten foot deep pool in a storm water pond system that provides removal of urban pollutants through settling and biological uptake. (Also referred to as a wet pond).
PERMEABILITY	The quality of a soil horizon that enables water or air to move through it.
PERVIOUS SURFACE	Surface area which allows infiltration of water.
PHYSICAL INFILTRATION	The separation of particulates from runoff by grass, leaves and other organic matter on the surface, as the runoff passes across or through the ground.
PHYTOREMEDIATION	Mitigation of environmental problems through the use of natural plant processes and production to contain, degrade, or eliminate contaminant material such as metals, pesticides, solvents, explosives, crude oil and its derivatives, and various other contaminants, from the media that contain them.
POINT SOURCE	Any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural storm water runoff.
POINT SOURCE OF POLLUTION	Discrete conveyances, such as pipes or man made ditches that discharge pollutants into waters of the United States. This includes not only discharges from municipal sewage plants and industrial facilities, but also collected storm drainage from larger urban areas, certain animal feedlots and fish farms, some types of ships, tank trucks, offshore oil platforms, and collected runoff from many construction sites.
POLLUTANT	Dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended (42 U.S.C. 2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water [40 CFR 122.2].
POLLUTION	Pollution is the introduction of contaminants into an environment that causes instability, disorder, harm or discomfort to the ecosystem i.e. physical systems or living organisms. Pollution can take the form of chemical substances or energy, such as noise, heat, or light. Pollutants, the elements of pollution, can be foreign substances or energies, or naturally occurring; when naturally occurring, they are considered contaminants when they exceed natural levels. Pollution is often classified as point source or nonpoint source pollution.
PONDSCAPING	A method of designing the plant structure of a storm water marsh or pond using inundation zones. The proposed marsh or pond system is divided into zones which differ in the level and frequency of inflow. For each zone, plant species are chosen based on their potential to thrive, given the inflow pattern of the zone.
POST-DEVELOPMENT PEAK RUNOFF	Maximum instantaneous rate of flow during a storm, after development is complete.
PRIORITY POLLUTANTS	Those pollutants considered to be of principal importance for control under the CWA based on the NRDC consent decree settlement [(NRDC et al. v. Train, 8 E.R.C. 2120 (D.D.C. 1976), modified 12 E.R.C. 1833 (D.D.C. 1979)]; a list of these pollutants is provided as Appendix A to 40 CFR Part 423
RECEIVING WATER	The "Water of the United States" as defined in 40 CFR 122.2 into which the regulated storm water discharges.

RETENTION POND	Retention ponds, or “wet ponds,” are among the most common stormwater treatment systems used today. They are not to be confused with detention basins or “dry basins,” which hold runoff for a specified period of time, and then release the entire volume of the runoff. Retention ponds retain a resident pool of standing water, which improves water quality treatment between storms. Retention ponds demonstrate a reasonably strong water quality treatment, particularly in comparison to dry pond systems.
RETROFIT	The creation or modification of an urban runoff management system in a previously developed area. This may include wet ponds, infiltration systems, wetland plantings, streambank stabilization, and other management practice techniques for improving water quality and creating aquatic habitat. A retrofit can consist of the construction of a new management practice in a developed area, the enhancement of an older urban runoff management structure, or a combination of improvement and new construction.
RIPARIAN	A relatively narrow strip of land that borders a stream or river, often coincides with the maximum water surface elevation of the one-hundred year storm.
RIPRAP	A combination of large stone, cobbles, and boulders used to line channels, stabilize banks, reduce runoff velocities, or filter out sediment.
ROOT ZONE	The part of the soil that is, or can be, penetrated by plant roots.
RUNOFF CONVEYANCE	Methods for safely conveying storm water to a management practice to minimize disruption of the stream network, and promote infiltration or filtering of the runoff.
RUNOFF PRETREATMENT	Techniques to capture or trap coarse sediments before they enter a management practice to preserve storage volumes or prevent clogging within the management practice. Examples include forebays and micropools for pond management practices, and plunge pools, grass filter strips, and filter fabric for infiltration management practices.
RUNON	Off-site flows which flows onto a site.
SCOUR	Concentrated erosive action of flowing water in streams that removes material from the bed and banks.
SEDIMENT	The product of erosion processes; the solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice.
SEDIMENT FOREBAY	Storm water design feature that employs the use of a small settling basin to settle out incoming sediments before they are delivered to a storm water management practice. Particularly useful in tandem with infiltration devices, wet ponds, or marshes.
SEDIMENTATION	The process of sand and mud settling and building up on the bottom of a creek, river, lake, or wetland.
SEEDBANKS	Refers to the large number and diversity of dormant seeds of plant species that exist within the soil. The seeds may exist within the soil for years before they germinate under the proper moisture, temperature, or light conditions. Within marsh soils, this seedbank helps to maintain above-ground plant diversity and can also be used to rapidly establish marsh plants within a newly constructed storm water marsh.
SEEPAGE	Water escaping through or emerging from the ground along an extensive line or surface as contrasted with a spring, where the water emerges from a localized spot.
SELF-MONITORING	Sampling and analyses performed by a facility to determine compliance with a permit or other regulatory requirements.
SHEET FLOW	Water, usually storm runoff, flowing in a thin layer over the ground surface.
SLOPE	The degree of deviation of a surface from horizontal, measured as a percentage, as a numerical ratio, or in degrees.
SOURCE CONTROL	A pollution control measure which operates by keeping pollutants from entering storm water
STORM DRAIN (OR STORM SEWER SYSTEM)	Above and below ground structures for transporting storm water to streams or outfalls for flood control purposes.
STORM WATER	Storm water runoff, snow melt runoff, and surface runoff and drainage [40 CFR 122.26(b)(13)].

STORM WATER DISCHARGE-RELATED ACTIVITIES	Activities that cause, contribute to, or result in storm water point source pollutant discharges, including excavation, site development, grading, and other surface disturbance activities; and measures to control storm water, including the siting, construction, and operation of management practices to control, reduce, or prevent storm water pollution.
STORM WATER RUNOFF	Excess precipitation that is not retained by vegetation, surface depressions, or infiltration, and thereby collects on the surface and drains into a surface water body.
STORM WATER TREATMENT	Detention, retention, filtering, or infiltration of a given volume of storm water to remove urban pollutants and reduced frequent flooding.
STREAM BUFFER	A variable width strip of vegetated land adjacent to a stream that is preserved from development activity to protect water quality, aquatic, and terrestrial habitats.
SUBSOIL	The bed or stratum of earth lying below the surface soil
SUSPENDED SEDIMENT	The very fine soil particles that remain in suspension in water for a considerable period of time.
SWALE	A natural depression or wide shallow ditch used to temporary store, route, or filter runoff.
TOPOGRAPHY	The relative positions and elevations of the natural or man-made features of an area that describe the configuration of its surface.
TOTAL LOAD REDUCTION	An estimate of the management practice removal efficiency target for reducing the total amount or load of pollutants (sediment, nutrients, oxygen-demanding material, or other chemicals or compounds) in storm water runoff.
TOTAL MAXIMUM DAILY LOAD (TMDL)	A calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources.
TOTAL SUSPENDED SOLIDS (TSS)	A measure of the filterable solids present in a sample, as determined by the method specified in 40 CFR Part 136.
TOXIC POLLUTANT	Pollutants or combinations of pollutants, including disease-causing agents, which after discharge and upon exposure, ingestion, inhalation or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will, on the basis of information available to the Administrator of EPA, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions, (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring. Toxic pollutants also include those pollutants listed by the Administrator under CWA Section 307(a)(1) or any pollutant listed under Section 405(d) which relates to sludge management.
TRASH AND DEBRIS REMOVAL	Mechanical or manual removal of debris, snags, and trash deposits from the streambanks to improve the appearance of the stream.
TREATMENT	The application of engineered systems that use physical, chemical, or biological processes to remove pollutants. Such processes include, but are not limited to, filtration, gravity settling, media adsorption, biodegradation, biological uptake, chemical oxidation and UV radiation.
TREATMENT CONTROL PRATCICE	Any engineered system designed to remove pollutants by simple gravity settling of particulate pollutants, filtration, biological uptake, media adsorption or any other physical, biological, or chemical process.
TURBIDITY	A cloudy condition in water due to suspended silt or organic matter.
URBAN RUNOFF	That portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, underflow, or channels or is piped into a defined surface water channel or a constructed infiltration facility.
VEGETATED BUFFER	Strips of vegetation separating a waterbody from a land use with potential to act as a nonpoint pollution source; vegetated buffers (or simply buffers) are variable in width and can range in function from a vegetated filter strip to a wetland or riparian area.
VELOCITY	The distance that water travels in a given direction in a stream during an interval of time.
VOLUME	The amount of storm water (expressed in liters) that enters or leaves a management practice.

WASTELOAD ALLOCATION (WLA)	The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution
WATERS OF THE UNITED STATES	All waters which are currently used, or were used in the past, or may be susceptible to use in interstate or foreign commerce, including all waters which are subject to the ebb and flow of the tide, all interstate waters and wetlands, tributaries of these waters, and the territorial seas
WATER QUALITY CRITERIA	Comprised of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal.
WATER QUALITY INLET	See OIL/WATER SEPARATOR.
WATER QUALITY STANDARDS	Includes three major components: designated uses, water quality criteria, and antidegradation provisions.
WATERSHED	The land area that drains into a receiving waterbody.
WEEPHOLE	A small opening or pipe left in a revetment or bulkhead to allow groundwater drainage.
WET POND	A conventional wet pond has a permanent pool of water for treating incoming storm water runoff. In enhanced wet pond designs, a forebay is installed to trap incoming sediments where they can be easily removed; a fringe marsh is also established around the perimeter of the pond.
WETLANDS	Areas that are inundated or saturated by surface or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions; wetlands generally include swamps, marshes, bogs, and similar areas.
WET-WEATHER FLOW	Water derived primarily from rain, melting snow or irrigation during the wet season (generally considered to be October through April) that flows over the surface of the ground.
WETLAND PLANT UPTAKE	Marsh plant species rely on nutrients (i.e., phosphorous and nitrogen) as a food source; thus, they may intercept and remove nutrients from either surface or subsurface flow.

Management Practice Descriptions

Management practices are structural controls or non-structural procedures used to control pollutants. Management practices depicted include both those identified as part of the *Pollution Control Strategies Report*, as well as general management practices for reference. They are described for illustration purposes only. To provide effective control of runoff and pollution, management practices must be correctly designed, installed, and maintained. Management practices can be installed along existing stormwater conveyance systems to treat pollution. They can also be installed or implemented at the source areas of pollution.

Baffle Box. The Nutrient Separating Baffle Box is a unique hydrodynamic separator. Effective at capturing sediments, TSS, and hydrocarbons; this system is specially designed to capture trash and debris, organics, and gross solids in a raised screening basket which allows these pollutants to be stored in a dry state (http://www.biocleanenvironmental.com/product/ns_baffle_box).

Bio Sorb. Hydrocarbon Absorbent Bio Sorb is an absorbent polymer ideal for removing large quantities of hydrocarbons, including: oils and grease, Total Petroleum Hydrocarbons, and polynuclear aromatic hydrocarbons. The physical properties of the media prevent leaching of absorbed hydrocarbons; incredibly this media can absorb up to three times its weight in oils and grease.

Coir logs are rolled materials made from natural fibers of coconut and other degradable materials. The logs range in diameter from 6-18 inches and length from 6-12 feet. The logs are permeable, allowing surface water to pass at a reduced rate while trapping sediments and other detritus. They are placed on slopes to reduce the slope length and slow the overland flow velocity.. They can be installed in shallow excavation trenches around the base of stock piles containing fill and along excavated runoff ditches. Vegetation such as small woody shrubs and grasses can be planted in, and at the interface of the logs at their upslope side. The logs act like sponges and are expected to aid in plant establishment by trapping sediments, retaining water, and providing a microclimate (increase R.H.). They will also provide immediate erosion control. The logs are installed by excavating shallow trenches, placing the logs in direct contact with exposed substrate, and anchoring logs with wood stakes. The depth of the excavated housing trench is a function of the insitu conditions and will vary.

Detention and Retention Practices detain runoff to attenuate peak discharge rate to protect downstream channel erosion and bank failure and developments from flooding. Both can be designed to capture bedload and fine suspended sediments. These systems can be designed as a multi-parameter approach to ecological sustainability of receiving systems.

> **Dry Extended Detention (ED) Ponds** A conventional ED pond temporarily stores a portion of storm water runoff for a specified period of time (usually 24-48 hours) which allows sediment particles and associated pollutants to settle out. The ED ponds are normally dry between storm events and do not have any permanent standing water. An enhanced ED pond is designed to prevent clogging and resuspension. It provides greater flexibility in achieving target detention times. It may be equipped with plunge pools near the inlet, a micropool at the outlet, and utilize an adjustable reverse-sloped pipe at the ED control device. Water is discharged through a hydrologic outlet structure to a downstream conveyance system. Dry ED ponds are among the most widely applicable storm management practice.

Retention Ponds use permanent pools, extended detention basin, or shallow marsh to remove pollutants. Retention ponds can include a wet pond; micropool extended detention ponds; multiple pond systems. These ponds serve the same function as an ED pond and often contain a fringe wetland installed around the perimeter of the pond for the purpose to increase habitat and pollutant removal values.

Energy dissipaters are used to prevent erosion at the outlet of a channel or conduit by reducing the velocity of flow and dissipating the energy.

Erosion mats are materials constructed of either synthetic or natural fibers. They are used to cover bare ground to reduce rainfall impacts and overland flow. Depending on the type of materials and the density of the openings, they can be used to cover areas that have been seeded or planted as part of erosion control design. Natural fiber mats are biodegradable and provide protection during the interim period between seeding or planting and establishment of vegetative ground cover. Many manufacturers claim that the by-products of the biodegrading process do not contain any substances that adversely affect aquatic flora or fauna. The key to using erosion mats is to anchor them properly to the ground surface to prevent overland flow between the mats and the ground.

Geosynthetics are a broad class of materials designed primarily for use in engineered earth applications. These materials are used in locations where biodegradation could be a problem and in situations requiring inherent strength and durability of the material. Most geosynthetic materials used in erosion control applications are made of plastic, nylon, or other synthetic materials and may contain other chemical components added to create certain physical characteristics. Geosynthetic materials are divided into several different subcategories:

Geomembranes are probably the largest categories of geosynthetics. According to the Geosynthetic Research Institute (GRI), geomembranes are “impervious thin sheets of rubber or plastic material used primarily for linings and covers of liquid- or solid-storage facilities.” GRI notes that although “nothing is strictly impermeable,” when compared with competing materials such as natural or amended clay–substances with an impermeability of 10-7 cubic meters per second (m^3/s), geomembranes offer a much smaller diffusion permeability of 10-11 to 10-13 m^3/s and are considered relatively impermeable.

Geotextiles are the second largest category of geosynthetic products. Classified as textiles because of their fabric-like consistency, geotextiles consist of synthetic fibers, which are highly resistant to degradation when in contact with soil or water. Both woven and nonwoven geotextiles are manufactured. They are porous to water flow both across and through the sheet, although the density of the weave or matting determines the porosity through the fabric. Geotextiles can be used to line road sub-grades and runoff ditches to prevent vegetation from growing up through the surfaces.

Geogrids, unlike geotextiles, contain relatively large open spaces. Geogrids are used primarily for reinforcement, such as for soil reinforcement in the construction of retaining walls. This segment of the industry is rapidly growing, with at least 25 different applications already identified.

Other geosynthetic categories include geonets or geospacers, designed to move water through a drainage area, and geosynthetic clay liners, impervious products consisting of clay sandwiched between layers of geotextile or geomembrane. These geosynthetic materials are often used at landfill sites to prevent fluid infiltration into adjacent soils.

Geotextile fabric liner is a synthetic geotextile mat that can be used to line excavated runoff ditches. The material mesh size allows to water pass, but will prevent vegetation from growing up through the matting and reducing flow capacity. It is u.v. stabilized and can be covered with a layer of large gravel/rubble. Material is installed by rolling out over the excavated ditch, tamping down, and securing using anchor pins. The material selected for this application is designed to be used in waterways and will withstand the expected shear stresses.

Geotextile erosion control material is made from polymers and is u.v stabilized. This material is used to cover steep exposed slopes, or slopes where vegetation is expected to be sparse. The material aids in reducing surface erosion by providing a permanent ground cover that will protect soil surface from rain drop displacement, increase surface shear stress resistance, and thus reduce kinetic energy along ground surface. The material is applied by anchoring into an excavated trench at the top of the slope and rolling the fabric down slope and anchoring it to the ground using soil staples. The slope to be treated will be prepped prior to application to insure that the fabric is in direct contact with the ground surface. This material has mesh size that allows grasses and other herbaceous plants to grow up through the mat without tearing the fabric.

Grassed swales are shallow grass-covered hydraulic conveyance channels that help to slow runoff and facilitate infiltration. The suitability of grassed swales depends on land use, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the grassed swale system. In general, grassed swales can be used to manage runoff from drainage areas that are less than 4 hectares (10 acres) in size, with slopes no greater than 5 percent. Use of natural, low-lying areas is encouraged and natural drainage courses should be preserved and utilized.

Green roofs consist of an impermeable roof membrane overlaid with a lightweight planting mix with a high infiltration rate and vegetated with plants tolerant of heat, drought, and periodic inundations. In addition to reducing runoff volume and frequency and improving runoff water quality, a green roof can reduce the effects of atmospheric pollution, reduce energy costs, and create an attractive environment. They have reduced replacement and maintenance costs and longer life cycles compared to traditional roofs.

Infiltration Trenches are trenches that have been back-filled with stone. These trenches collect runoff during a storm event and release it into the soil by infiltration. Infiltration trenches may be used in conjunction with another storm water management device, such as a grassed swale, to provide both water quality control and peak flow attenuation. Runoff that contains high levels of sediments or hydrocarbons (i.e. oil and grease) that may clog the trench is often pretreated with other devices such as grit chambers, water quality inlets, sediment traps, swales, and vegetated filter strips.

Native grasses can be be contained in hydromulch mixture and applied to targeted areas. The grasses should be selected based on the species' ability to propagate in the site's physiographic conditions, to provide surface cover of soils, increase tensional strength of soils and not require maintenance past the grow in period. A hydro-seed unit will be used to hydraulically disperse grass seed. The mixture will include a geo-binding agent to aid in mixture stickiness, soil amendments, mulch, and grass (seed and/or stolons).

Permanent seeding is used to establish vegetative grass cover that will prevent soil detachment by raindrop impact, reduce sheet and rill erosion, and stabilize slopes and channels. Permanent seeding can be used in conjunction with erosion control blankets and mats to provide both temporary and permanent erosion control. Perennial grasses, when used with turf reinforcement mats, provide the fibrous root network that anchors the channel linings. These treatments can greatly increase the maximum permissible velocities and are very useful in stabilizing channels and grass-lined channels.

Porous (Permeable) pavement is an alternative to asphalt or concrete surfaces that allows storm water to drain through the porous surface to a stone reservoir underneath. The reservoir temporarily stores surface runoff before infiltrating it into the subsoil. The appearance of the alternative surface is often similar to asphalt or concrete, but it is manufactured without fine materials and instead incorporates void spaces that allow for storage and infiltration. Underdrains may also be used below the stone reservoir if soil conditions are not conducive to complete infiltration of runoff.

Rain barrels and cisterns harvest rainwater for reuse. Rain barrels are placed outside a building at roof downspouts to store rooftop runoff for later reuse in lawn and garden watering. Cisterns store rainwater in significantly larger volumes in manufactured tanks or underground storage areas. Rainwater collected in cisterns may also be used in non-potable water applications such as toilet flushing. Both cisterns and rain barrels can be implemented without the use of pumping devices by relying on gravity flow instead. Rain barrels and cisterns are low-cost water conservation devices that reduce runoff volume and, for very small storm events, delay and reduce the peak runoff flow rates. Both rain barrels and cisterns can provide a source of chemically untreated “soft water” for gardens and compost, free of most sediment and dissolved salts.

Vegetative filter strip. A vegetated section of land designed to accept runoff as overload sheet flow from upstream development. It may adopt any natural vegetated form, from grass meadow to small forest. The dense vegetative cover facilitates pollutant removal. A filter strip cannot treat high velocity flows and is generally recommended for use in agriculture and low density development. A vegetated filter strip differs from a natural buffer in that the strip is not natural; rather, it is designed and constructed specifically for the purpose of pollutant removal. A filter strip can also be an enhanced natural buffer, however, whereby the removal capability of the natural buffer is improved the rough engineering and maintenance activities such as land grading or the installation of a level spreader. A filter strip differs from a grassed swale in that a swale is a concave vegetated conveyance system, whereas a filter strip has a fairly level surface.

Design Considerations

The proper selection and successful design of structural practices for storm water quality enhancement is the first priority of storm water management. The cost effectiveness of each control has to be considered and measured against the actual environmental benefits realized. Design objectives can be stated as in terms of technology (i.e. by specifying a particular control device) or in terms of quantitative effect (i.e. by specifying a required degree of control or a maximum allowable effect). The addition of water quality considerations in the design of management practices has created a shift from capturing peak flows during flood events to a continuous long-term rainfall-runoff design volume approach and the pollutant loads associated with these volumes. To treat the bulk of the pollutant loads from storm water runoff, a treatment volume that is designed to capture the initial component of the storm water runoff is essential.

The general design for implementing many management practices will need to take into consideration proper site suitability, drainage area, land availability, construction material selection, and maintenance requirements. Specific features will need to be considered for each management practice, some of which are listed in Table 1. This table presents general key considerations for each management practice. Each structure will require an engineering design prior to installation to insure the design is feasible for the site conditions. Feasibility of designs requires detailed analysis through an engineering process that takes into consideration all physical aspects of implementation, such as hydrology and geography.

Table 1. Design Considerations for Recommended Management Practices

Management Practice	Sizing Considerations	Design Considerations
Baffle box	• Sizing of unit function of design hydrology and sediment sizes of influent.	• Located within 15 ft. of paved surface to allow access for maintenance
Coir logs	• Site specific	• Securing method • Regevetation • Types of plant • Anchoring device selection • Additional stabilization and protection works (other than coir logs)
Curb inlet baskets	• Sediment volume	• Hooded outlet • Filtering variety • Maintenance frequency
Extended detention basin	• Drainage area • Slope • Soils/Topography • Groundwater	• For both water quality and storm water attenuation • Pretreatment/Treatment • Filter fine terrigenous sediment • Conveyance • Maintenance Reduction • Landscaping
Good housekeeping practices	N/A	N/A
Grass swale	• Drainage area • Slope • Soils/Topography • Groundwater	• A parabolic or trapezoidal cross-section with side slopes no steeper than 1:3 • Most effective when used in conjunction with other practices, such as wet ponds, infiltration strips, wetlands, etc. • Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion

Management Practice	Sizing Considerations	Design Considerations
Green roof – Green grid	• Site specific • Maximum weight load	• Types of plants • Maintenance requirements • Disability access • Liability Issues • Architectural accents
Infiltration trench	• Drainage area • Slope • Soils/Topography • Groundwater	• Native soils are excavated and replaced with an improved soil mixture column • Can be used in extremely narrow spaces • Conveyance • Maintenance Reduction • Landscaping
Invasive species control	• Site specific	• Types of plants • Time scale • Equipment needed • Maintenance requirements
Modular wetland	• Drainage area	• Type of plants • First flush • Conveyance • Maintenance Reduction • Landscaping
Natural/Native vegetation	• Site specific	• Types of plants • Maintenance
Porous pavement	• Used in a wide variety of land use settings • Overflow parking areas or other areas such as fire lanes with low traffic loads • Load bearing • Slope/Topography	• Native soils on the site should be conducive to infiltration, with an infiltration rate at least 0.3 inches/hour • Not to be used in areas with a slope > 15% • Seasonal high water table should be at least 3 feet below grade
Rain barrels	• Roof • Water demand • Rainfall Pattern • Capacity • Overflow Device	• Modify downspout to barrel inflow site • Screened inflow design • Outflow hose/barrel connection • Keep hose above barrel rim
Retention pond	• Drainage area • Slope • Soils/Topography • Groundwater	• Pretreatment/Treatment • Filter fine terrigenous sediment • Conveyance • Maintenance Reduction • Landscaping
Subsurface storage	• Drainage area • Groundwater level • Available land	• Many types of material including galvanized metal, reinforced concrete or synthetic compounds or any pre-manufactured containers adaptable to ground contact • Conveyance
Turf reinforcement mats	• Site specific	• Site preparation • Anchoring device selection • Soil type • Maintenance

Design Features

1. Baffle Box
2. Coir Log
3. Curb Inlet Basket
4. Extended-Detention Pond
5. Grass Swale
6. Green Roof – Green Grid
7. Infiltration Trench
8. Modular Wetland
9. Rain Barrel
10. Retention Pond
11. Subsurface Storage
12. Turf Reinforcement Mats

Design Feature 1. Baffle Box

The Nutrient Separating Baffle Box is a multi chambered concrete box separated with baffles used to settle out pollutants. Chambers can be fitted with absorbent membranes to trap floating pollutants, e.g. hydrocarbons. Effective at removing sediments, TSS, and hydrocarbons; this system is specially designed to capture trash and debris, organics, and gross solids in a raised screening basket which allows these pollutants to be stored in a dry state.

http://www.biocleanenvironmental.com/product/ns_baffle_box

BIO CLEAN
ENVIRONMENTAL SERVICES, INC.

Nutrient Separating Baffle Box

A Superior Stormwater Treatment System Separated from the Rest.

The Nutrient Separating Baffle Box (NSBB) is a widely accepted and desired stormwater solution chosen by civil engineers, municipalities and developers nationwide because of its superior characteristics. The NSBB is easy to install and maintain and is the only systems with a two stage maintenance option, which minimizes maintenance costs.

Hundreds of Nutrient Separating Baffle Boxes have been installed nation wide, from Florida to California because of its superior and proven design. The NSBB efficiently removes TSS, hydrocarbons, nutrients, metals and debris/organics from stormwater runoff. The patented filtration screen system captures and stores trash and organics in a dry state, which prevents nutrient leaching and bacterial build up.

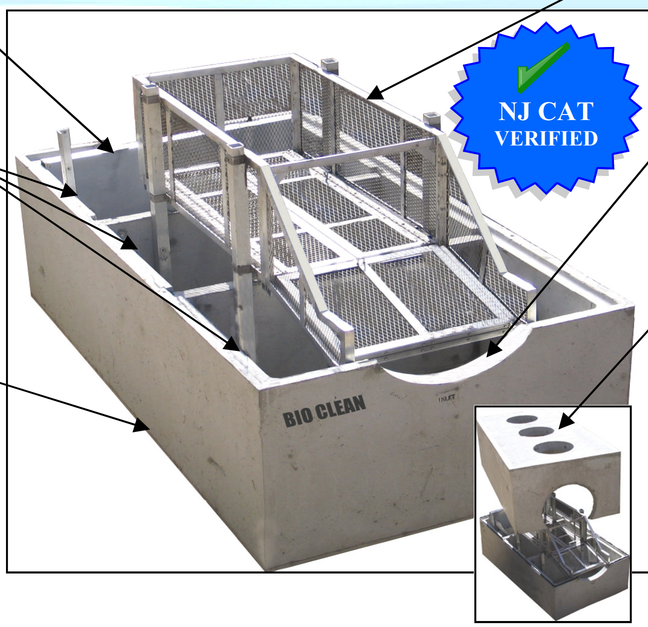
System Characteristics

Traps Oil & Grease
The skimmer and hydrocarbon booms captures all forms of hydrocarbons.

High TSS Removal
The three chambered design maximizes capture of large and fine TSS.

89.8% TSS Removal
Pandit - 1996
86.3% TSS Removal
Harvey's Lake - 2004
93.3% TSS Removal
Dillard - 2006

Low Installation Cost
Bottom of structure less than 4 feet from invert of pipe.



Separates Nutrients & Trash
The patented filtration screen system captures and stores trash and organics in a dry state which prevents nutrient

Low Head Loss
Allows for easy retrofit and inline installation. Eliminates the need for expensive diversion structures.

Easy Maintenance
Unobstructed Manhole Access

POLLUTANT	REMOVAL EFFICIENCY
Trash & Debris	99%[1]
TSS	76.9%[2] to 93.3%[3]
Fine TSS (d_{50} 63 μm)	67.3%[4]
Metals	Up to 57%[5]
Total Nitrogen	38% to 63%[5]
Total Phosphorus	18% to 70%[2,5]

1. Rockledge Baffle Box Independent Field Report. Applied Environmental Technology. 2007.
2. Brevard County (Micco & Indialantic). St. Johns River Water Management District. 1994.
3. Field Test for Suntree Nutrient Separating Baffle Box. Dillard & Associates. 2005.
4. New Jersey Corporation for Advanced Technology. 2008.
5. Atlantic Beach Field Report. Blue Water Environmental. 2004.

Setting a New Standard for Hydrodynamic Separators.

The Nutrient Separating Baffle Box is designed to do more than most systems. This system is effective at removing not only TSS, but also fine TSS and gross solids making it, overall, a more effective treatment system compared to traditional swirl type separators. This system has been proven to provide the following benefits:

System Benefits

- **Can Treat 100% of the Flow.**
  Offline Configuration is Not Required.
- **Inexpensive Maintenance.**
  Patented screen system allows gross solids to be removed without vacuuming out the water.
- **Minimal Head Loss.**
  Hydraulically efficient design generates less head loss than diversion structures.
- **Custom Designs Available.**
  Can be modified to meet your needs.
- **Easy to Install.**
  Delivered in a top & bottom half to minimize weight. Shallow profile minimizes installation costs.
- **5 Year Warranty.**
  Made of precast concrete, fiberglass, aluminum & stainless steel. No cheap plastics!

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P O Box 869, Oceanside, CA 92049
(760) 433-7640 • Fax (760) 433-3176
www.biocleanenvironmental.net

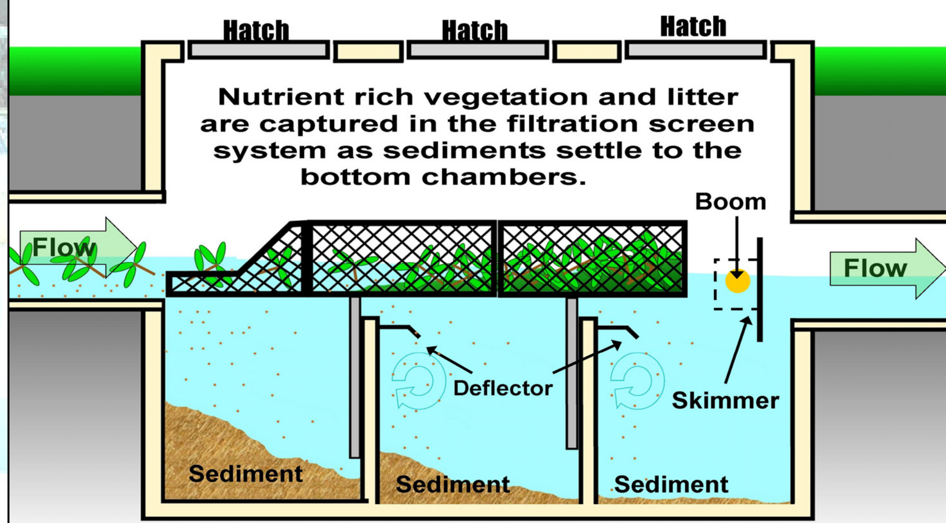
"The Stormwater Standard"

Functional Description

Captures:

- Trash & Debris D
- Oxygen Demanding Substances/Organic Compounds D
- Hydrocarbons, Oils & Grease
- TSS (including fines)
- Nutrients (particulates)
- Heavy Metals (particulates)

"Pollutants with this symbol D are stored in a dry state".



The Filtration Screen System is Patented

During Storm Event

Why Dry State Storage? D

Storing Trash, Debris, Organics, and Oxygen Demanding Substances in a Dry State Prevents:

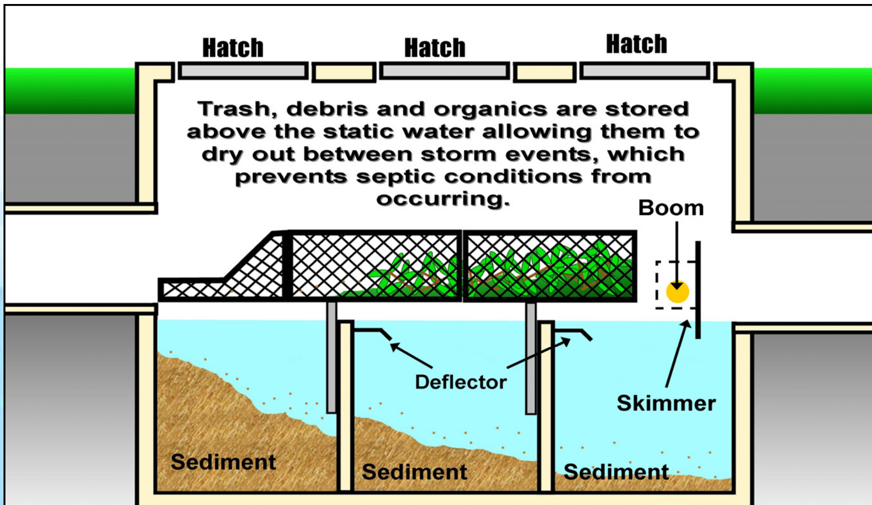
- **Prevent Nutrient Leaching**
- **Eliminate Septic Conditions**
- **Minimize Bacteria Growth**
- **Eliminate Bad Odors**

Nutrient Separating Baffle Box

Standing Water is Clear & No Bacteria Growth Visible.

Other Systems

Standing Water is Not Clear & Bacteria Growth Visible.



After Storm Event

Operation:

Skimmer & Boom

Collects hydrocarbons & controls flow velocity which improves removal efficiency.

Deflectors

Prevents re-suspension of captured pollutants at higher flows by directing water currents above sediment chambers.

Filtration Screen System

Collects and stores trash, debris, organics, and oxygen demanding substances in a dry state above the standing water. As mentioned above this has many performance benefits along with simplifying maintenance.

Multiple Sediment Chambers

Maximizes TSS removal and eliminates scouring during extreme flow rates.

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Design Feature 2. Coir Log

SedimentSTOP™ BIODEGRADABLE Filtration System

The SedimentSTOP™ (Patent Pending) shall be a machine-produced 100% biodegradable sediment filtration system.

The SedimentSTOP™ shall be composed of 70% agricultural straw and 30% coconut fiber matrix evenly distributed over the entire area of the bottom netting. The SedimentSTOP™ shall consist of a bottom netting and a 2 ft. (0.61 m) top netting that covers the matrix material on the "splash apron" of the SedimentSTOP™ system. The netting shall be constructed from 100% biodegradable woven natural organic fiber netting. The netting shall consist of machine directional strands formed from two intertwined yarns with cross directional strands interwoven through the twisted machine strands (commonly referred to as a Leno weave) to form an approximate 0.50 x 1.00 inch (1.27 x 2.54 cm) mesh. The blanket shall be sewn together on 1.50 inch (3.81 cm) centers (50 stitches per roll width) with biodegradable thread.

Each SedimentSTOP™ shall yield a structure 50 lineal feet (15.2 m) in length, with an approximate finished diameter of 9 inches (0.23 m). The diameter of the finished structure may be increased to meet individual project specifications by spreading loose straw, pine needles, wood chips, grass cuttings, etc. across the width of the SedimentSTOP™ before rolling edge to edge.

The SedimentSTOP™ shall be manufactured by North American Green, or equivalent. The SedimentSTOP™ shall have the following properties:

Material Content

Matrix	70% Straw Fiber 1.225 lbs/yd^2 (0.665 kg/m^2) 30% Coconut Fiber 0.525 lbs/yd^2 (0.285 kg/m^2)
Netting	Bottom side, Leno woven 100% biodegradable natural organic fiber (9.30 lbs/1,000 ft^2 [4.50 kg/100 m^2] approximate weight) Top side, 2 ft. (0.61 m) strip covering the "splash apron" of the SedimentSTOP™, Leno woven 100% biodegradable natural organic fiber (9.30 lbs/1,000 ft^2 [4.50 kg/100 m^2] approximate weight)
Thread	Biodegradable

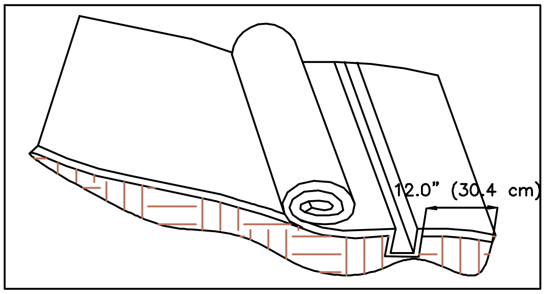
Physical Specifications

	English	Metric
Width	6.67 ft	2.03 m
Length	50.00 ft	15.24 m
Weight	65.00 lbs ± 10%	29.50 kg ± 10%
Stitch Spacing	1.50 inches	3.81 cm

Finished Structure Diameter - Approximately 9.00 in (0.23 m)

Effective 1/1/2002

SEDIMENTSTOP INSTALLATION



4

NORTH AMERICAN GREEN

4a

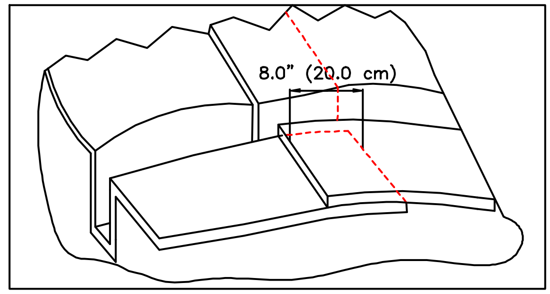
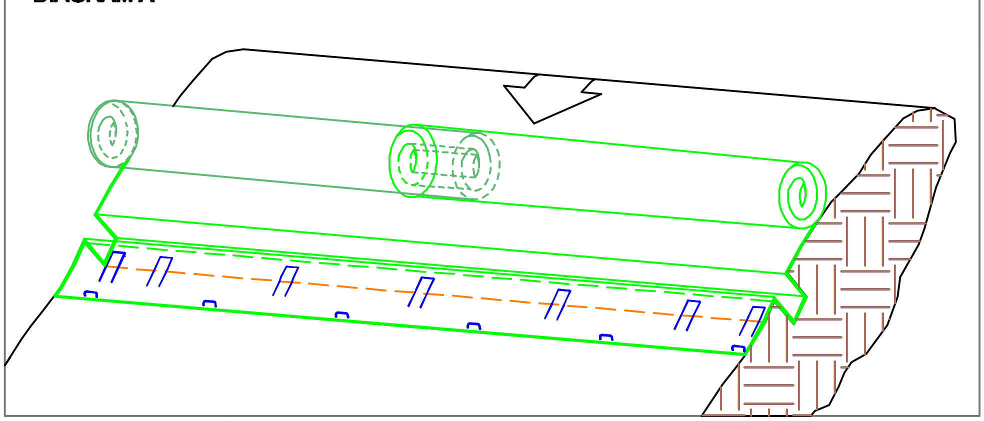


DIAGRAM A



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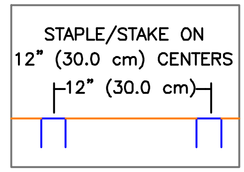

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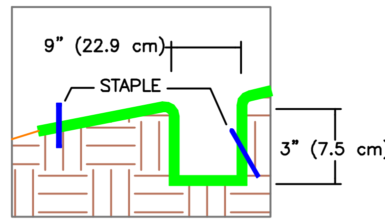
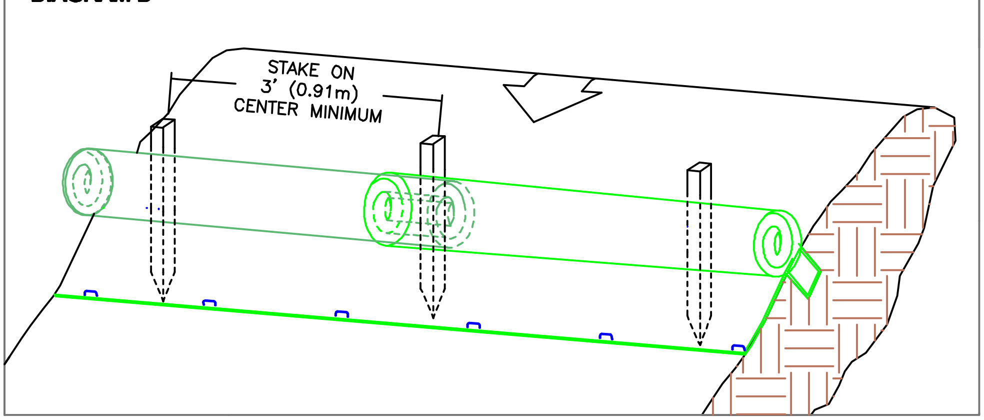


DIAGRAM B



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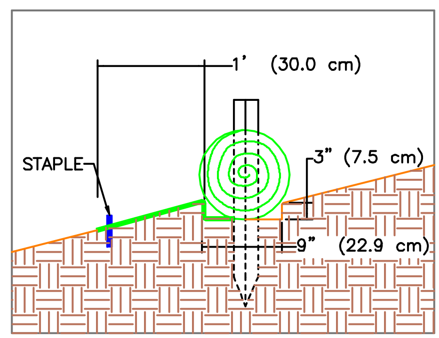


1. BEGIN AT THE LOCATION WHERE THE SEDIMENTSTOP (Patent Pending) IS TO BE INSTALLED BY EXCAVATING A 3" (7.5 CM) DEEP X 9" (22.9 CM) WIDE TRENCH ALONG THE CONTOUR OF THE SLOPE. EXCAVATED SOIL SHOULD BE PLACED UP-SLOPE FROM THE ANCHOR TRENCH.

2. UNROLL THE SEDIMENTSTOP SO THE SECTION WITH THE 2' WIDE TOP NETTING IS THE DOWN SLOPE END (SPLASH APRON). THE SPLASH APRON OF THE SEDIMENTSTOP SHOULD COVER THE ANCHOR TRENCH ENSURING THAT APPROXIMATELY 12" (30 CM) IS EXTENDED BEYOND THE LOWER EDGE OF THE ANCHOR TRENCH. NOTE: SEEDING MUST BE CONDUCTED PRIOR TO INSTALLATION OF THE SEDIMENTSTOP.

3. SECURE THE SEDIMENTSTOP IN THE ANCHOR TRENCH BY PLACING A ROW OF STAPLES/STAKES ON 12" (30 CM) CENTERS ACROSS THE ENTIRE LENGTH OF THE SEDIMENTSTOP. A SECOND ROW OF STAPLES/STAKES MUST BE PLACED ACROSS THE ENTIRE LOWER EDGE OF THE SEDIMENTSTOP SPLASH APRON ON APPROXIMATELY 12" (30 CM) CENTERS, STAGGERED WITH THE FIRST ROW OF STAPLES/STAKES.

4. BEGIN ROLLING THE SEDIMENTSTOP FROM ITS UPPER EDGE (UP-SLOPE EDGE) INTO A CONSISTENT ROLL DIAMETER UNTIL THE ROLL IS LOCATED IN THE ANCHOR TRENCH. IF A LARGER DIAMETER STRUCUTRE IS DESIRED, PLACE ADDITIONAL ORGANIC MATERIAL (I.E. STRAW, LEAVES, PINE NEEDLES OR LAWN CLIPPINGS) ACROSS THE ENTIRE WIDTH OF THE SEDIMENTSTOP PRIOR TO ROLLING. SEE DIAGRAM 4a FOR SEAMING OF ADJACENT SEDIMENTSTOP ROLLS.

5. STOP ROLLING THE SEDIMENTSTOP WHEN THE ROLL IS LOCATED IN THE ANCHOR TRENCH.

6. SECURE THE SEDIMENTSTOP STRUCTURE TO THE SLOPE SURFACE BY DRIVING APPROXIMATELY 18" - 24" (45-60 CM) STAKES THROUGH THE CENTER OF THE ROLL EVERY 3' (0.9 M) ON CENTER. IF TWO SEDIMENTSTOP STRUCTURES ARE SEAMED TOGETHER ENSURE A STAKE IS DRIVEN THROUGH THE SEAM. THE FINAL STRUTURE'S DIAMETER WILL DICTATE STAKE LENGTH. LEAVE A SUFFICIENT AMOUNT OF STAKE EXPOSED ABOVE THE SEDIMENTSTOP TO ENSURE THE STRUCUTRE IS NOT COMPRESSED. BOTH LONGITUDINAL ENDS SHOULD BE ANGLED UP SLOPE.

7. BACKFILL AND COMPACT SOIL INTO THE UP-SLOPE PORTION OF THE ANCHOR TRENCH. SMOOTH AND LEVEL ANY SOIL REMAINING ABOVE THE SEDIMENTSTOP NOT USED TO FILL THE ANCHOR TRENCH. PLACE SEED ALONG UP-SLOPE PORTION OF SEDIMENTSTOP IF REQUIRED.

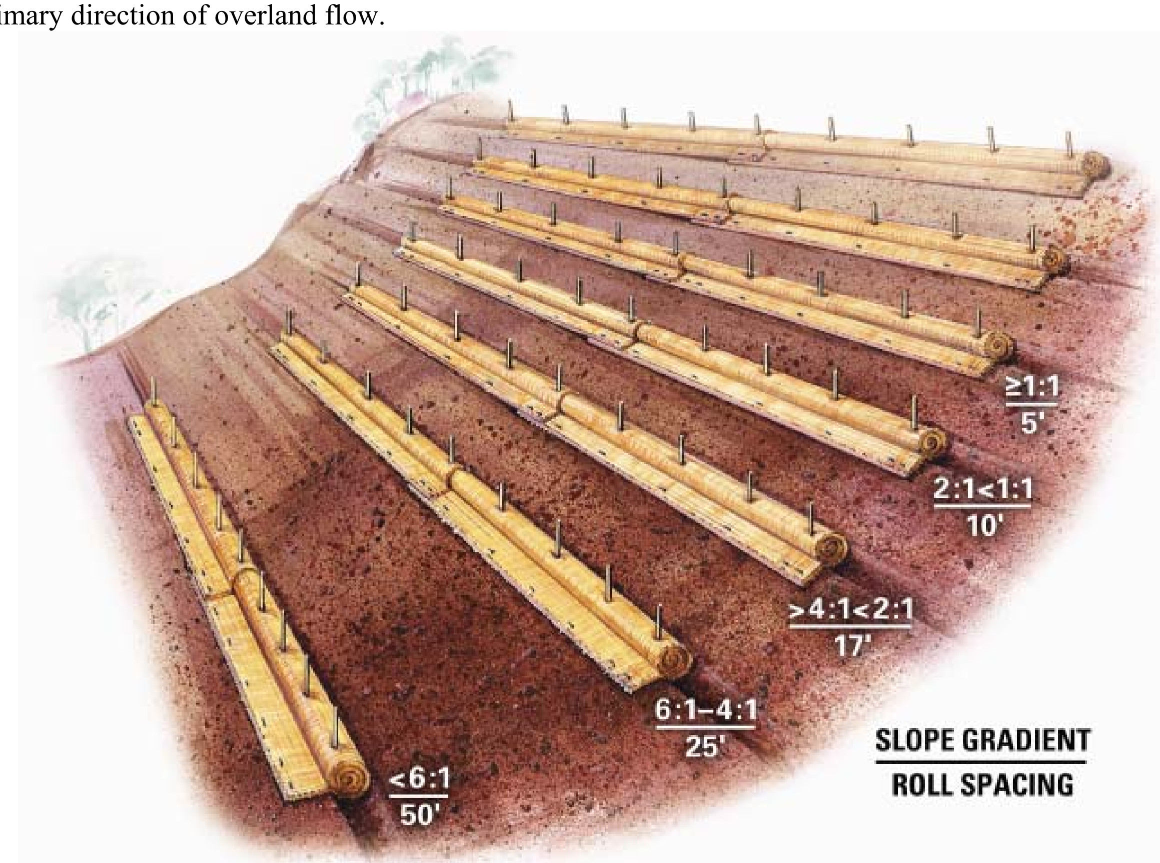
14649 HIGHWAY 41 NORTH, EVANSVILLE, INDIANA 47725
USA 1-800-772-2040 CANADA 1-800-448-2040
www.nagreen.com

SedimentSTOP™ BIODEGRADABLE Filtration System

APPLICATION GUIDELINES

North American Green SedimentSTOP™ is a 100% biodegradable best management practice (BMP) that offers an effective and economical alternative to silt fence, straw bales, and wattles for sediment control and storm water runoff. The SedimentSTOP's combination of straw/coconut fibers and leno woven jute netting has been proven in university and field research to afford exceptional sediment control by slowing and filtering runoff and trapping sediment. The research showed that properly installed, the SedimentSTOP structure reduced initial sediment migration by up to 98% compared to unprotected control plots.

The following guidelines are provided to assist in design, installation, and structure spacing. These guidelines may require modification due to variation in soil type, rainfall intensity or duration, and amount of runoff affecting the application site. SedimentSTOP should be installed perpendicular to the primary direction of overland flow.



To maximize sediment containment with the SedimentSTOP place the initial structure at the top/crest of the slope if significant runoff is expected from above. If no runoff from above is expected, the initial SedimentSTOP can be installed at the appropriate distance downhill from the top/crest of the slope. The final structure should be installed at or just beyond the bottom/toe of the slope.

The SedimentSTOP is a temporary sediment control device and is not intended to replace erosion control blankets or turf reinforcement mats. If vegetation is desired for permanent erosion control, North American Green recommends that rolled erosion control products be used to provide effective immediate erosion control until vegetation is established. The SedimentSTOP may be used in conjunction with blankets and mats as supplemental sediment and runoff control for these applications. Like all sediment control devices, the effectiveness of SedimentSTOP is dependent on storage capacity.

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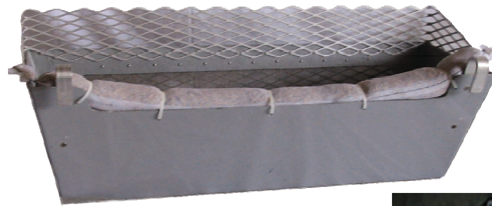
800-772-2040 • FAX 812-867-0247 • www.nagreen.com

Design Feature 3. Curb Inlet Basket

The Curb Inlet Basket is the only filter available with the patented ‘Easy Maintenance Shelf System’, positioning the basket directly under the manhole for easy maintenance. This shelf has been tested and continues to be used in Hawai‘i with positive results and feedback.

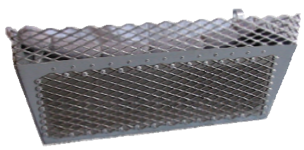
Curb Inlet Basket

w/ Easy Maintenance Shelf System



Extreme Durability—
Constructed from:

- Heavy Duty UV Protected Marine Grade Fiberglass
- High Grade Stainless Steel Hardware and Screens



"Highest Rated Catch Basin Insert"

(The Efficiency of Storm Drain Filters in Removing Pollutants from Urban Road Runoff Report, University of Hawaii, Dept of Oceanography, Honolulu, Hawaii, 2005).

5 Year Unlimited Warranty on Construction

Ask Our Competition if They Have a Warranty Like This. Then Give us a Call.

The Easiest Filter to Clean and Install

- **Maintenance and Cleaning Crews Throughout Southern California Appreciate the User Friendly Design of Our Filters.**

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Case Study of Curb Inlet Filters

Prepared for The City and County of Honolulu, Hawaii

AbTech System Servicing Box-Score

	Poor 1	2	Fair 3	4	Excellent 5
Ease of Attachment/Reattachment to Drain					√
Ease of Handling and Entry Through Manhole			√		
Ease of Cleaning and Filter-Media Replacement			√		
Prevention of Debris Loss During Removal From Drain			√		
Overall Maintenance Turn-Around Time				√	

Total Score = 18

KriStar System Servicing Box-Score

	Poor 1	2	Fair 3	4	Excellent 5
Ease of Attachment/Reattachment to Drain			√		
Ease of Handling and Entry Through Manhole					√
Ease of Cleaning and Filter-Media Replacement		√			
Prevention of Debris Loss During Removal From Drain			√		
Overall Maintenance Turn-Around Time		√			

Total Score = 15

Hydrocompliance Servicing Box-Score

	Poor 1	2	Fair 3	4	Excellent 5
Ease of Attachment/Reattachment to Drain	√				
Ease of Handling and Entry Through Manhole	√				
Ease of Cleaning and Filter-Media Replacement				√	
Prevention of Debris Loss During Removal From Drain		√			
Overall Maintenance Turn-Around Time	√				

Total Score = 9

BioClean System Servicing Box-Score

	Poor 1	2	Fair 3	4	Excellent 5
Ease of Attachment/Reattachment to Drain				√	
Ease of Handling and Entry Through Manhole					√
Ease of Cleaning and Filter-Media Replacement				√	
Prevention of Debris Loss During Removal From Drain				√	
Overall Maintenance Turn-Around Time					√

Total Score = 22 **Highest Score**

Performance matrix for field tested DII systems

Parameter	AbTech	Hydrocompliance	KriStar	Bioclean
Initial device cost (10 ft drain inlet)	10	5	15	20
Initial installation requirements	10	2.5	7.5	5
Flow capacity	5	10	2.5	7.5
Turbidity during short term test	5	10	7.5	2.5
Short term RDS retention	10	5	7.5	2.5
Short term organics retention	10	2.5	7.5	5
Long term RDS retention	2.5	10	7.5	5
Long term PAH retention (mg)	5	10	7.5	5
Long term O/G retained (mg)	10	5	2.5	7.5
Long term overall rubbish retention	5	5	10	10
Suitability for Vector Control	5	2.5	7.5	10
Unit durability	7.5	2.5	7.5	10
Media replacement Costs	5	10	15	20
Suitability for Type B basin	2.5	2.5	7.5	10
Servicing Requirements	18	9	15	22
TOTAL SCORE	110.5	91.5	127.5	142

Performance of DII is ranked from one to four, with increasing scores assigned to increasing performance of the device. Ranks for each category are scaled to 10 except initial costs and media replacement costs which are scaled to 20. Servicing requirements are based on a score of 25 as determined in Appendix A. Maximum total possible score is 185.

Highest Score

Table 17: DII Servicing Time Table

Site	DII System	Required Servicing Time (hours)
15	Hydrocompliance	1.75 105 Minutes
17	KriStar	1.0 60 Minutes
18	AbTech	0.5 30 Minutes
19	Bioclean	0.25 15 Minutes

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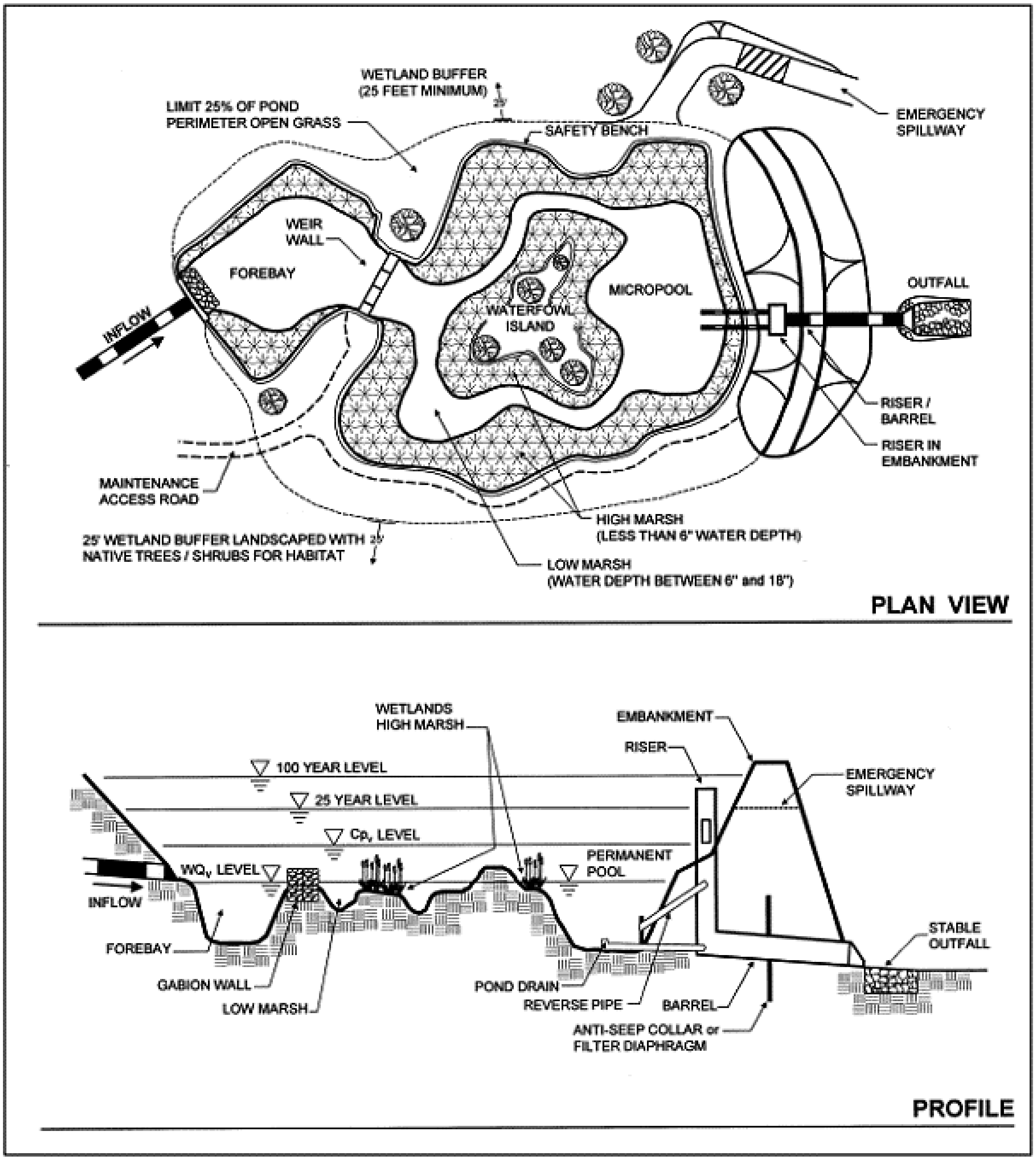
Honolulu, Hawaii 96814

See Full Report at:
http://www.biocleanenvironmental.net/stormdrain/products/reports/reports.htm

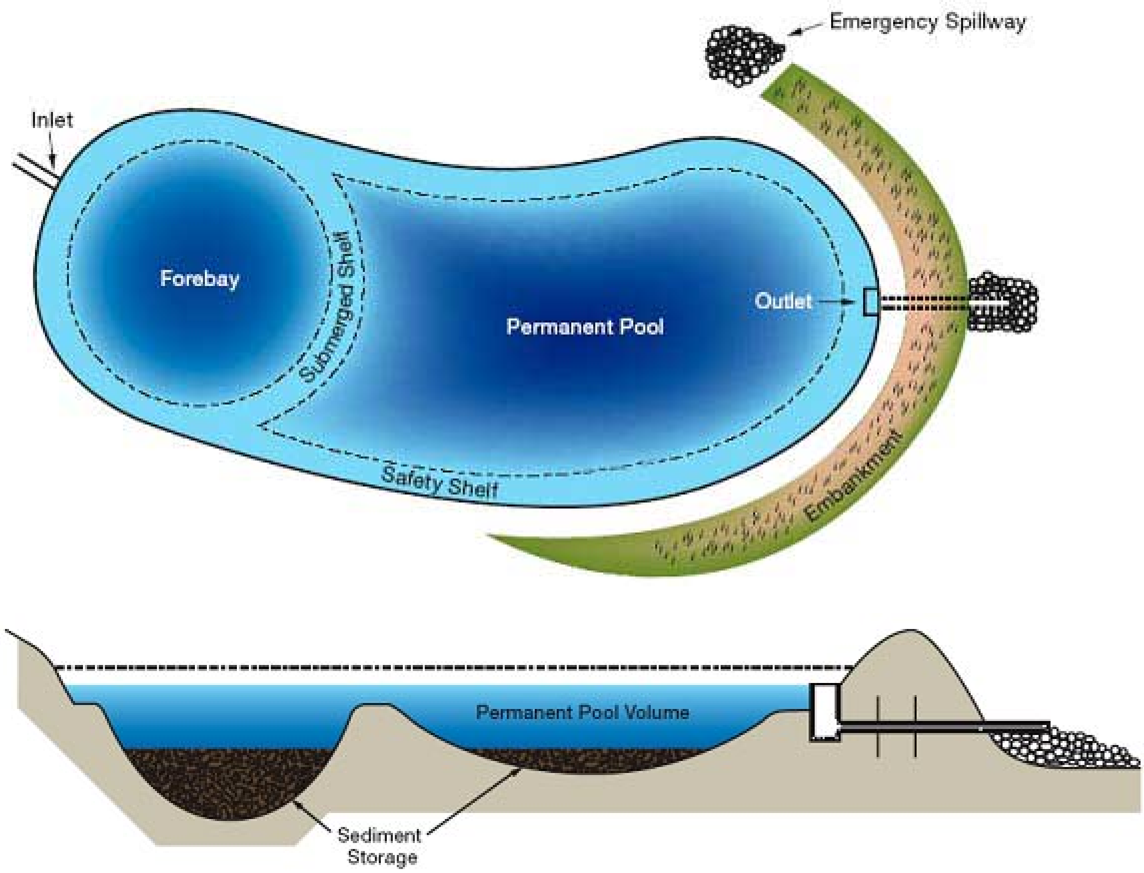
Design Feature 4. Extended-Detention Pond[1]

Schematic of a Dry Extended-Detention Pond (MDE 2000)



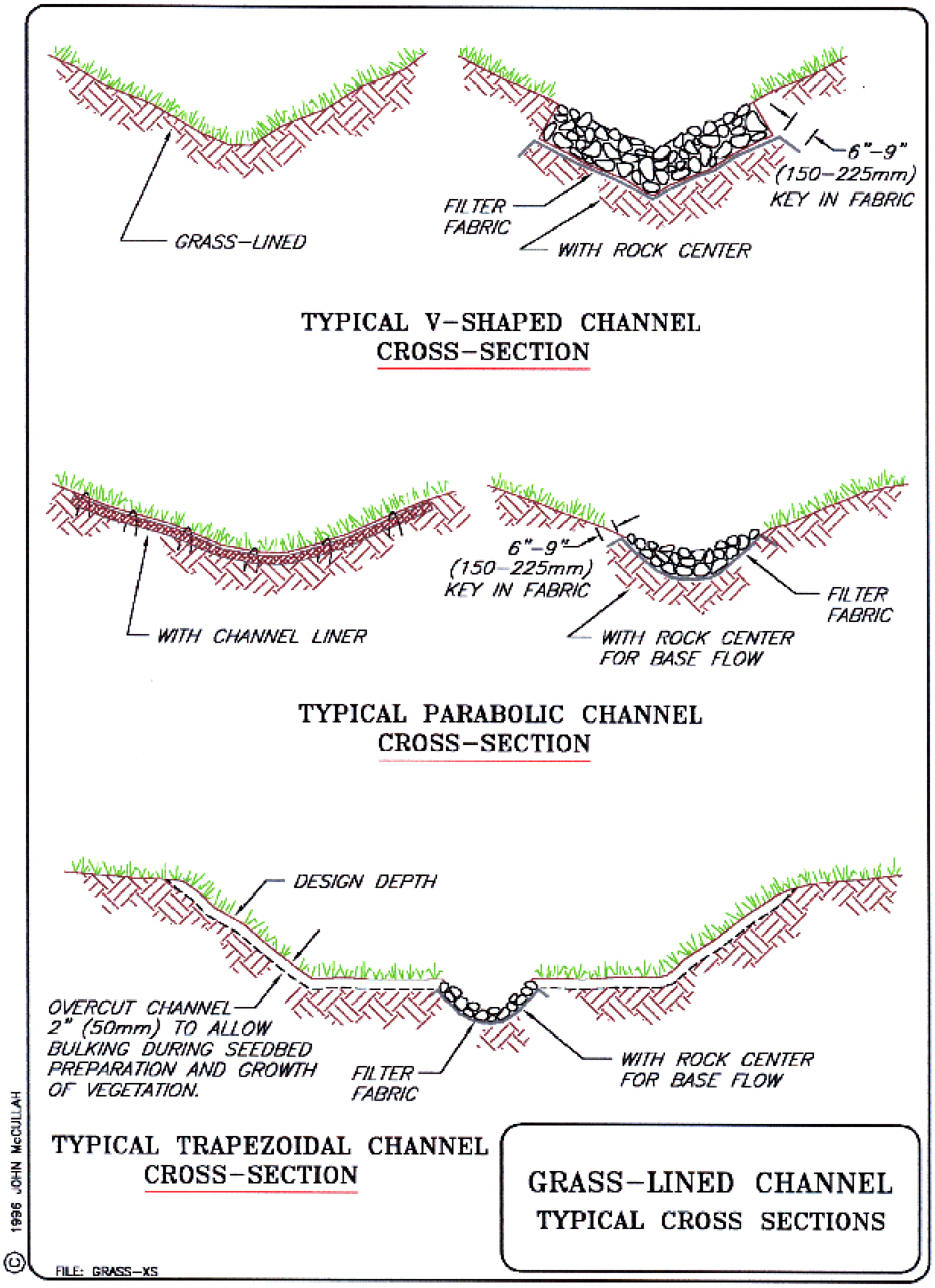
[1] Image depicts general design.

Example Detention Pond Design (Liebl 2006)



Design Feature 5. Grass Swale

Figure used with permission of Salix Applied Earthcare.



Design Feature 6. Green Roof – Green Grid

GREENGRID®
The Natural Choice for Your Roof

The PREMIER Green Roof System

The GreenGrid® Green Roof System offers distinct advantages over more complex systems with its simplicity in design, pre-planted modules, and movable modular features.

WESTON SOLUTIONS®

www.greengridroofs.com

Introducing the GreenGrid® Modular Green Roof System

Simplicity in design and flexibility are the hallmarks of the GreenGrid® System. The system was designed by engineering, roofing, and horticultural experts to produce an efficient, integrated green roof product. GreenGrid® offers a modular design that arrives at your site pre-planted and ready for installation. The modules contain 100% recycled plastics, and the components can be hoisted to the roof via elevator, forklift, or crane, and quickly installed in accordance with the design. The modules can be placed directly on the roof membrane or on any other surface with adequate structural capacity.

GreenGrid® Green Roof System modules are lightweight compared to many other green roof systems. The Ultra-Extensive (2.5-inch depth) modules weigh approximately 11-13 pounds per square foot (wet). The Extensive (4-inch depth) modules weigh approximately 18-22 pounds per square foot (wet). Both Ultra-Extensive and Extensive modules support highly drought-resistant ground covers that can thrive in a non-irrigated (climate dependent), rooftop environment in the project location. The Intensive (8-inch depth) modules—supporting a large variety of variety of grasses, perennials, and/or groundcovers that can thrive in an irrigated or non-irrigated, rooftop environment in the project location—weigh approximately 35 pounds per square foot (wet) and up, depending on plant selection and growth media. They can be easily arranged or rearranged to suit the needs and desires of the client. Most important, roof maintenance and repair is simple—modules can just be moved should roof repair/maintenance be required, then put back in place.

About Green Roofs

Green roofs are not a new phenomenon. Due to their excellent insulation and stormwater retention properties, these roofs have been a standard construction practice in many countries for years. Since the 1970s, green roofs increasingly have become part of the landscape in Europe, where there are over 100 million square feet of planted roofs today. Due to the complexity of some of these systems, green roofs have been somewhat slow to catch on in North America. These "European" systems are constructed in layers, starting with a waterproof membrane and drainage layer, then insulation, root barriers, soil layers, and a wind erosion blanket are put in place. The landscape is then installed, which can take considerable time to mature.

The GreenGrid® System offers distinct advantages over these complex systems with its straight-forward design, pre-planted modules, and movable modular features.

System Options

Ultra-Extensive Modules

The 2.5-inch Ultra-Extensive GreenGrid® System is an extremely lightweight green roof system of modules, composed of 2.5 inches of growth media and drought-tolerant vegetation. This functional green roof system is generally designed to require minimal irrigation and maintenance. The 2.5-inch green roof system is appropriate for small applications with limited structural capacity. The approximate weight of a wet 2.5-inch GreenGrid® ultra-extensive green roof system is 11–13 pounds per square foot, which is similar to the weight of gravel ballast placed on many conventional roofs.

Extensive Modules

The 4-inch Extensive GreenGrid® System is a lightweight green roof modular system composed of a 4-inch layer of growth media and highly drought-tolerant vegetation that is composed of ground covers that can thrive in a non-irrigated (climate dependent), rooftop environment in the project location. Like the ultra-extensive modules, this highly functional green roof system is generally designed to require minimal irrigation and maintenance. The approximate weight of a wet 4-inch GreenGrid® extensive green roof system is 18-22 pounds per square foot.

Intensive Modules

The 8-inch Intensive GreenGrid® System is designed for more elaborate roof landscapes. These rooftop gardens are typically designed to be accessible for leisurely enjoyment and therefore must have the proper structural capacity for live loads. The 8-inch depth system allows for a larger selection of plants, including grasses, perennials, natives, and/or groundcovers. The addition of paver pathways, terraces, edge treatments, and other architectural features result in beautiful and dramatic new usable spaces. Depending on the plant selection, drip irrigation systems and maintenance may be necessary, just as they would be for a traditional garden. Although a more refined application, the ecological benefits of Intensive green roofs are wide-ranging due to the utilization of larger and greater plant species diversity. The average weight of a wet 8-inch GreenGrid® intensive green roof system starts around 35 pounds per square foot, and may be higher depending on plant selection and growth media.

The Advantages a GreenGrid® System Brings to Your Building

Easy Roof Maintenance and Repair: Since the GreenGrid® system is modular, roof surfaces are always accessible for maintenance and repair. "No matter the type or age of a roof, eventually it will leak. The question is, when," said Larry Flynn, Senior Editor, *Building Design & Construction*[1]. When the roof requires maintenance or repair, the GreenGrid® modules are simply removed and then put back in place when repair is complete, without disturbing growing media or plants.

Engineered, Integrated System: All components of the GreenGrid® Green Roof System are designed and engineered to work together. This results in installation efficiencies, thereby lowering costs, and assures an integrated design.

Lightweight for Existing/New Roofs: The GreenGrid® system can be installed on any roof in good condition where structural capacity is present. The choice of lightweight modules make a green roof feasible for almost any building, without requiring upgrades to its structural capacity.

Pre-Planted and/or Pre-Grown System: The GreenGrid® modules are planted in advance at the nursery.This means modules arrive at the job site already planted and ready for installation. This feature helps reduce costs associated with labor and helps reduce installation time. Plants can also be grown at the nursery in advance of shipment to the project site.

The table below presents additional GreenGrid® advantages.

GreenGrid® Advantages	GreenGrid® Green Roof System Solution	Traditional (Built-in-Place) Systems
Easy Roof Maintenance & Repair	Modules can easily be moved then put back in place without disturbing growing media or plantings	Layers need to be cut and rolled back until repair location found; plants and layers damaged
Competitive Installed Cost	Competitive installed cost versus leading built-in-place systems	New roof surface plus mat, drainage, root barrier, moisture retention layers often costly
Quick Installation	Delivered pre-planted, ready to set in place; reduced downtime due to inclement weather	Multi-layer, built-in-place, vegetation planted at job site, time-consuming
Pre-planted	Pre-planted at the nursery; speeds installation time and reduces labor costs	Planted on site; increases labor costs
Lightweight for Existing/ New Roofs	Lightweight—installs on any existing roof surface in good condition and with structural capacity	Systems often heavy; roof surface replacement often required despite condition
Easy Rooftop Placement	All modular system components quickly put in place on roof in accordance with design	Components delivered to rooftop by multiple sources can present scheduling difficulties
LEED® Recycling Credits	All GreenGrid® modules contain 100% recycled material, contributing to LEED® recycling credits	Components generally do not contain recycled material
Built-In Water Retention	Module design provides built-in water retention	Water retention layers must be added
Easy System Alteration/Additions	Option of installing green roof in sections offers opportunity for future add-ons	Often difficult and expensive to change/add-on due to edge design requirements
Alliances	Wrap-around or full-system warranties are available as part of a Mule-Hide or Carlisle GreenGrid® Roof	Limited Warranty – Removal and re-installation of plants/vegetation generally not included

[1] *Building Design & Construction*, 1 Sept. 2003, vol. 44, no. 9, p. 66

Reduced Energy Costs: When the outside air temperature reaches 95° F, traditional black rooftop surface temperatures can be as high as 175° F. The heat load of a roof impacts the amount of energy necessary to cool the building to the desired temperature. Due to its insulating properties, GreenGrid® green roofs can significantly reduce the heat load of the roof in warm seasons.

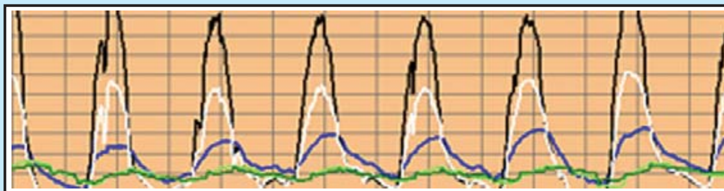
Reduced Urban Heat Island Effect: The urban heat island effect occurs in most of the large cities of the world and has actually been shown to change weather patterns in some. Roads and building rooftops absorb a significant amount of heat during the day, which in turn is radiated back into the atmosphere, causing further warming. GreenGrid® green roofs help insulate and shade buildings. Plus, the plants on green roofs transpire, cooling the atmosphere around them.

Stormwater Management: Green roofs help alleviate stormwater runoff through retention and detention of rainfall and detention of runoff from roofs. This benefit can cut costs associated with required municipal on-site stormwater retention.

Sound Insulation: The growth media, plants, and layers of trapped air in a green roof system serve as excellent sound insulators. Tests have shown that green roofs can reduce the indoor noise pollution from outdoor contributors by as much as 10 decibels per every 3 inches of soil media.

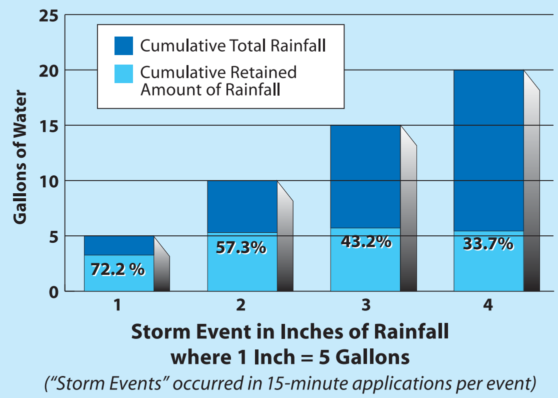
Extended Roof Life: GreenGrid® green roofs can protect roof membranes from ultraviolet radiation, extreme temperature fluctuations, and puncture or other physical damage.

Creation of Added Value and Aesthetics: Green roofs can provide an oasis of green in the urban environment by creating visually pleasing vistas, serene rooftop gardens, and functional gathering areas.

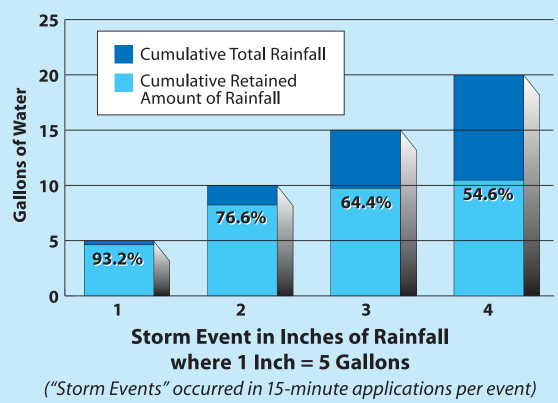


Real-time and Historic GreenGrid® Data Charts Available at GreenGridRoofs.com

Cumulative Water Retention in a 4-Inch GreenGrid® Module During a Simulated 2-Hour Rainstorm



Cumulative Water Retention in an 8-Inch GreenGrid® Module During a Simulated 2-Hour Rainstorm



APPLE COMPUTER STORE - NORTH MICHIGAN AVENUE

Client: Apple Computer, Inc.
Location: 679 N. Michigan Ave., Chicago, IL
GreenGrid® Size: 2,400 Square Feet
Installation Contractor: WESTON
Landscape Design: Douglas Hoerr Landscape Architecture
Rooftop System: Extensive
Status: Completed Summer 2003

AMERICAN RED CROSS OF GREATER CHICAGO - RAUNER CENTER

Client: American Red Cross of Greater Chicago
Location: 2200 W. Harrison St., Chicago, IL
GreenGrid® Size: 2,800 Square Feet
Installation Contractor: WESTON
Landscape Design: Douglas Hoerr Landscape Architecture
Rooftop System: Extensive
Status: Completed Summer 2004

MILWAUKEE HOUSING AUTHORITY - HIGHLAND GARDENS

Client: Milwaukee Housing Authority
Location: 1818 W. Juneau Ave., Milwaukee, WI
GreenGrid® Size: 20,032 Square Feet
Installation Contractor: WESTON
Landscape Design: WESTON
Rooftop System: Extensive
Status: Completed Fall 2004

UWM GREAT LAKES WATER INSTITUTE

Client: University of Wisconsin-Milwaukee – Great Lakes Water Institute
Location: 600 E. Greenfield Ave., Milwaukee, WI
GreenGrid® Size: 6,480 Square Feet
Installation Contractor: WESTON
Landscape Design: WESTON
Rooftop System: Extensive/Intensive
Status: Completed Summer 2003

U.S. EPA REGION 8 HEADQUARTERS

Client: U.S. Environmental Protection Agency
Location: 1595 Wynkoop St., Denver, CO
GreenGrid® Size: 19,396 Square Feet
Installation Contractor: WESTON
Landscape Design: WESTON
Rooftop System: Extensive
Status: Completed Fall 2006

HASTINGS KEITH FEDERAL OFFICE BUILDING

Building Owner: United States General Services Administration
Client: J & J Contractors, Inc.
Location: Hastings Keith Federal Office Building, 56 North 6th St., New Bedford, MA
GreenGrid® Size: 3,400 Square Feet
Installation Contractor: WESTON and J & J Contractors, Inc.
Landscape Design: Oak Point Associates
Rooftop System: Extensive
Status: Completed Spring 2004

KOHL's RETAIL STORE
Client: Kohl's Illinois, Inc.
Location: 2140 N. Elston Ave., Chicago, IL
GreenGrid® Size: 32,500 Square Feet
Installation Contractor: WESTON
Landscape Design: WESTON
Rooftop System: Extensive
Status: Completed Spring 2005

BARBER PARK GREEN BUILDING
Client: Ada County Parks & Recreation
Location: 4049 S. Eckert Rd., Boise, ID
GreenGrid® Size: 3,660 Square Feet
Installation Contractor: WESTON
Landscape Design: WESTON
Rooftop System: Ultra-Extensive
Status: Completed Summer 2005

HOLY REDEEMER CATHOLIC CHURCH
Client: Holy Redeemer Catholic Church
Location: 25 N. Rosa Parks Way, Portland, OR
GreenGrid® Size: 4,464 Square Feet
Installation Contractor: WESTON
Landscape Design: WESTON
Rooftop System: Extensive
Status: Completed Summer 2005

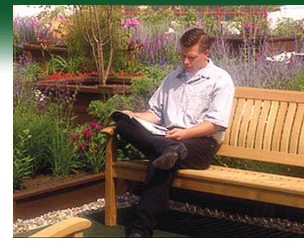
IKEA STORE
Client: IKEA US
Location: 1 Ikea Way, Stoughton, MA
GreenGrid® Size: 21,376 Square Feet
Installation Contractor: WESTON
Landscape Design: WESTON
Rooftop System: Extensive
Status: Completed Summer 2005

CENTER FOR URBAN ECOLOGY
Client: National Parks Service
Location: 4598 MacArthur Blvd., Washington, DC
GreenGrid® Size: 6,500 Square Feet
Installation Contractor: WESTON/Platinum One Contracting
Landscape Design: U.S. Department of the Interior
Rooftop System: Extensive
Status: Completed Summer 2004

SUSTAINABLE SOUTH BRONX
Client: Sustainable South Bronx
Location: 890 Garrison Ave., Bronx, NY
GreenGrid® Size: 1,052 Square Feet
Installation Contractor: WESTON/Corporate Contractors, Inc.
Landscape Design: WESTON
Rooftop System: Intensive/Extensive
Status: Completed Summer 2005

NATTY BOH BREWERY REDEVELOPMENT
Client: Natty Boh Brewery
Location: 3600 O'Donnell St., Baltimore, MD
GreenGrid® Size: 12,000 Square Feet
Installation Contractor: WESTON
Landscape Design: Cho Benn Holback & Associates
Rooftop System: Extensive
Status: Completed Fall 2005

Optional Features



Additional features are available to enhance the benefits and aesthetic appeal of your green roof. Whether your goal is to create a pleasing and enjoyable space, or optimize the beneficial use of your building's roof space, there are many options available to make the most of your GreenGrid® Green Roof System.

Beneficial Enhancements

- Ecoballast®—These modules can be added to augment stormwater retention.
- Drip Irrigation Systems—Some configurations may require the installation of a drip irrigation system, due to climate and/or plant selection.

Ecoballast®

Drip Irrigation System

Aesthetic Enhancements

- Pavers
- Edge Treatment
- Outdoor Furniture and Planter Boxes

Pavers

Edge Treatment

Outdoor Furniture & Planter Boxes

GREENGRID The Natural Choice for Your Roof

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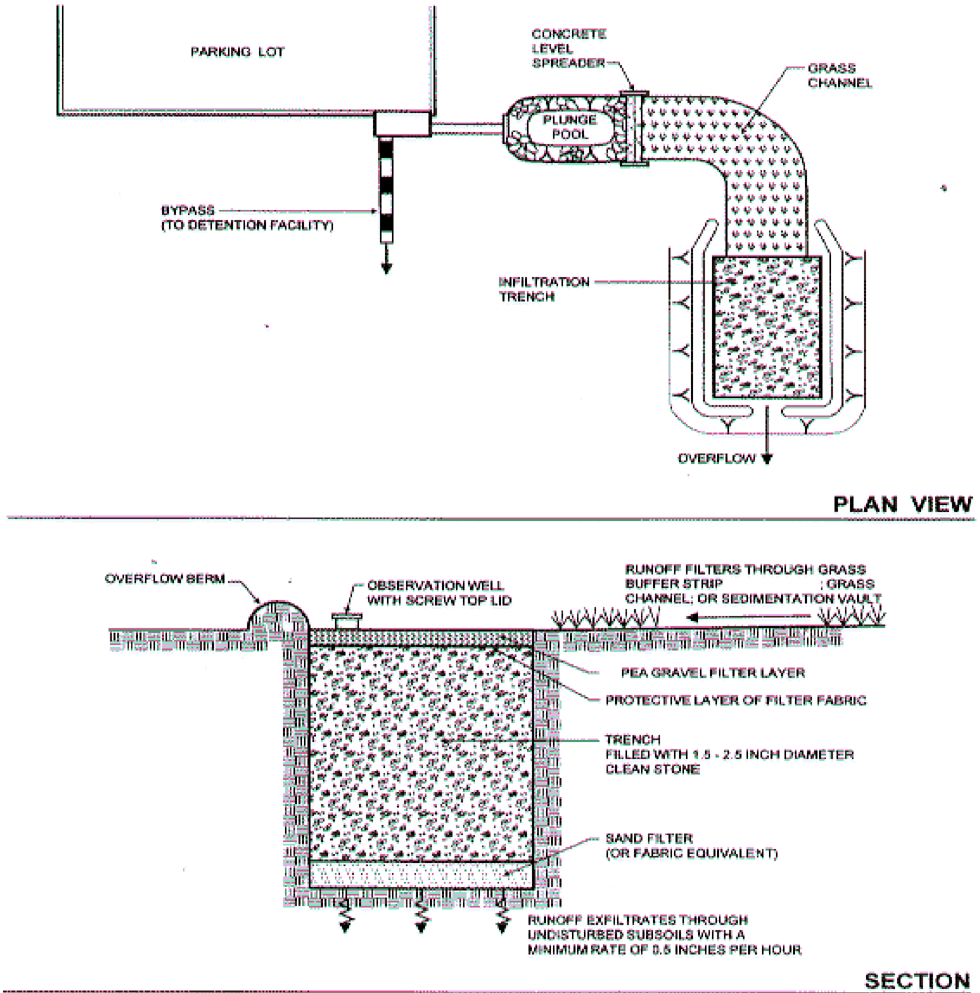
www.greengridroofs.com

Design Feature 7. Infiltration Trench

Figure from The Storm Water Manager's Resource Center's Infiltration Trench fact sheet, http://www.storm watercenter.net/



Design Feature 8. Modular Wetland

INTRODUCING

MWS-LINEAR STORMWATER FILTRATION SYSTEM

NATURE AND TECHNOLOGY WORKING TOGETHER IN PERFECT HARMONY.

The need for a new stormwater treatment system is evident. Federal and state requirements on cities and industry to reduce stormwater runoff increase every year as our population explodes. The EPA is now reporting that stormwater runoff represents the nation s number one water quality problem, and is the reason why nearly half of our rivers and lakes are not even clean enough to support fishing or swimming. ***Nearly half.***

MODULAR WETLANDS™

To combat this catastrophe, we turned to the expert in this field: **Nature.** By developing technology that imitates the processes found in nature, we ve created the most advanced stormwater filtration system available. Years ahead of current EPA requirements, our clients understand that when they invest in our new technology, they are investing in the future. For all of us.

CONFIGURATION 1: GRATE TYPE

CONFIGURATION 2: CURB TYPE

MWS–LINEAR TESTED REMOVAL EFFICIENCIES*

TSS "Sil-Co-Sil 106"	Dissolved Cadmium	Dissolved Copper	Dissolved Lead	Dissolved Zinc	Dissolved Mercury	Bacteria E. Coli
98%	74%	93%	81%	80%	89%	60%

*Laboratory Testing of Quarter Scale Model- Average Removal Efficiencies. Tested at Scaled Flow Rate Equal To 120 GPM For Full Size System.

BioMediaGREEN TESTED REMOVAL EFFICIENCIES*

TSS "Sil-Co-Sil 106"	Total Phosphorus	Dissolved Copper	Dissolved Lead	Dissolved Zinc	TPH	Turbidity
85%	69%	79%	98%	78%	99%	99%

*Laboratory Testing - Average Removal Efficiencies. Tested at Flow Rate of 3 GPM Per Square Foot Media Surface Area & Minimum Head.

CURB & GRATE TYPE FLOW BASED DESIGN

- **Primary Treatment Peak Flow Rate** = 120 GPM or .27 CFS
- **Internal Bypass Peak Flow Rate** = 4.28 CFS "Grate Type"
- **Internal Bypass Peak Flow Rate** = 2.01 CFS "Curb Type"
- **O.D Dimensions** = 22' x 5' x 4.8'
- **Curb Type Minimum Fall Required** = 3.57' "Flow Line to Invert Out"
- **Grate Type Minimum Fall Required** = 4.13' "Top of Grate to Invert Out"
- **Storage Capacity** = 1000 LBS "Settling Chamber Storage"

VAULT TYPE VOLUME BASED DESIGN (Configuration not shown)

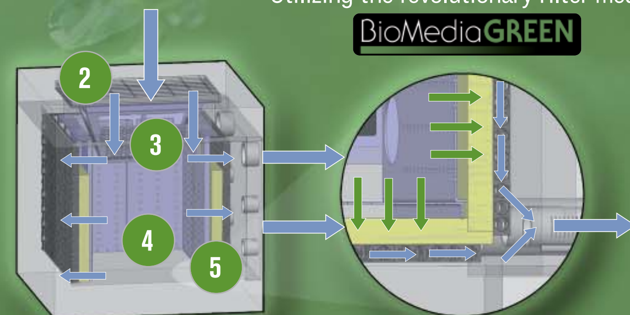
- **Peak Treatment Volume** = 4000 Cubic Feet "10 GPM Discharge Rate & 48 Hour Drain Down Time" "Pre-Storage Required"
- **Install External Bypass Prior To Pre-Storage**
- **O.D Dimensions (at grade)** = 22' x 5' x 4.8'
- **O.D Dimensions (below grade)** = 22' x 5' x 5.6'
- **Vault Type Minimum Fall Required** = 4.13' "Finish Grade to Invert Out"
- **Storage Capacity** = 1000 LBS "Settling Chamber Storage"

SYSTEM OPERATIONS

MWS-LINEAR IS DESIGNED TO MEET THE MOST STRINGENT STORMWATER REGULATIONS.

The system utilizes multi-stage treatment processes including the revolutionary filter media (BioMediaGreen) for primary filtration followed by a 4th generation sub-surface flow wetland for biological remediation .

Utilizing the revolutionary filter media: BioMediaGREEN



THIS SYSTEM PROVIDES THE MOST EFFECTIVE TREATMENT IN THE INDUSTRY.

FEATURES

1. **CATCH BASIN CHAMBER - Capture, Screen, Separate, Filter**
   Directs Incoming Stormwater Through The First Three Stages of Treatment.
2. **GRATE TYPE CATCH BASIN INLET**
   A standard 41" x 24" grate type traffic rated catch basin opening directs stormwater into the system.
3. **CATCH BASIN INSERT FILTER UTILIZING BIO CLEAN ENVIRONMENTAL SERVICES, INC. - CATCH BASIN FILTERS**
   Provides the first stage of treatment by capturing trash & litter, gross solids, and sediment.
4. **SETTLING CHAMBER**
   Provides the second stage of treatment by separating out larger suspended solids.
5. **PERIMETER FILTER UTILIZING BioMediaGREEN SEE TESTED REMOVAL EFFICIENCIES**
   Provides the third stage of treatment by physically and chemically capturing fine TSS, metals, nutrients, and bacteria.
6. **HIGH FLOW INTERNAL BYPASS**
   Flow rates greater than the systems treatment capacity are bypassed directly to the discharge chamber.
7. **WETLAND CHAMBER SUB-SURFACE FLOW - Biological Remediation**
   Provides the final stage of treatment through a combination of physical, chemical, and biological processes.
8. **DISCHARGE CHAMBER - Flow Control, Drain Down, Discharge**
   Controls flow rates with adjustable valves and contains a drain down filter that eliminates any standing water.
9. **MULTI-LEVEL FLOW CONTROL VALVES**
   Two 4" adjustable ball valves allows various flow rates to be set for primary and secondary treatment levels.

FSC
Mixed Sources
Product group from well-managed forests, controlled sources and recycled wood or fiber
Cert no. XXX-XXX-000
www.fsc.org
© 1996 Forest Stewardship Council

MODULAR WETLANDS™

RAINFOREST ALLIANCE CERTIFIED EST 1987

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Design Feature 9. Rain Barrels

United States Environmental Protection Agency

August 2009

What is a Rain Barrel?

Environmental Assessment & Innovation Division
EPA Region 3, Philadelphia, PA

A rain barrel is a system that collects and stores rainwater from your roof that would otherwise be lost to runoff and diverted to storm drains and streams. Usually a rain barrel is composed of a 55 gallon drum, a vinyl hose, PVC couplings, a screen grate to keep debris and insects out, and other off-the-shelf items, a rain barrel is relatively simple and inexpensive to construct and can sit conveniently under any residential gutter down spout.

A rain barrel used to collect rooftop runoff using a gutter / downspout system

What are the advantages of a rain barrel?

Lawn and garden watering make up nearly 40% of total household water use during the summer. A rain barrel collects water and stores it for when you need it most -- during periods of drought -- to water plants, wash your car, or to top a swimming pool. It provides an ample supply of free "soft water" to homeowners, containing no chlorine, lime or calcium making it ideal for gardens, flower pots, and car and window washing.

A rain barrel will save most homeowners about 1,300 gallons of water during the peak summer months. Saving water not only helps protect the environment, it saves you money and energy (decreased demand for treated tap water). Diverting water from storm drains also decreases the impact of runoff to streams. Therefore, a rain barrel is an easy way for you to have a consistent supply of clean, fresh water for outdoor use, FREE.

Where can I buy a ready-made rain barrel?

Ready-made rain barrels can be purchased from a number of companies, including hardware stores and garden supply stores. In addition, local governments sometimes offer them for a reduced price as part of their environmental education programs. Below are just a few sources (this listing does not constitute an endorsement by EPA). All links below exit EPA.

- Ace Hardware has a couple of models, 866-290-5334
- Gaiam produces the Great American Rain Barrel, 877-989-6321
- Plow & Hearth has several rain barrels including a pop-up barrel that folds flat when not needed, 800-494-7544
- Rain Barrel Source offers an extra large system, 866-912-9719
- Spruce Creek Company produces the Spruce Creek Rainsaver, 800-940-0187
- Urban Garden Center sells the Urban Rain Barrel, 866-923-1992

Design Feature 10. Retention Pond

Retention Pond

About Retention Ponds

Retention ponds, or "wet ponds," are among the most common stormwater treatment systems used today. They are not to be confused with detention basins or "dry basins," which hold runoff for a specified period of time, and then release the entire volume of the runoff. Retention ponds retain a resident pool of standing water, which improves water quality treatment between storms. Retention ponds demonstrate a reasonably strong water quality treatment, particularly in comparison to dry pond systems. However, lack of maintenance often leads to pollutant export and a gradual erosion within the system for large flows.

Where to Use It

Acceptance of retention ponds is widespread, and examples of these systems can be found all over the world in any climate, soil, and development setting.

In many areas, retention ponds are the system of choice, a preference likely due to their ease of design, which can be adapted to provide water quality treatment and water quantity control in a variety of settings.

Implementation

While retention ponds are common, their use raises concerns related to human and ecosystem health. Standing water, for example, can be a drowning hazard. They also serve as a habitat for mosquitoes associated with diseases. Ponds that contain excess nutrients can foster eutrophication. In hot weather, retention ponds can superheat already warm parking lot runoff, impacting aquatic habitats and cold water fisheries. Some innovative retention pond outlet designs include the use of gravel subdrains to cool effluent.

The cost to install a retention pond system to treat runoff from one acre of impervious surface was $13,500. This does not include maintenance expenditures, which may involve routine inspection, periodic mowing, and sediment dredging, as needed. For more information about this design, contact the UNHSC.

During the first year of operation, the retention pond at UNHSC was reasonably effective in removing many of the pollutants commonly found in runoff. However, during its second year, researchers observed a reduction in its water quality performance. This indicates that its performance may continue to diminish over time.

Fast Facts

CATEGORY TYPE
Stormwater Pond, Sedimentation

BMP TYPE
Structural, Conventional

DESIGN SOURCE
New York State Stormwater Management Design Manual

BASIC DIMENSIONS
Surface Area: 46 ft X 70 ft (varies)

SPECIFICATIONS
Catchment Area: 1 acre
Peak Flow: 1 cfs
Water Quality Volume: 3,264 cf

TREATMENT FUNCTION
Physical Settling & Biological

INSTALLATION COST PER ACRE TREATED
$13,500

MAINTENANCE
Maintenance Sensitivity: Low
Inspections: Low
Sediment: Low

How the System Works

Design

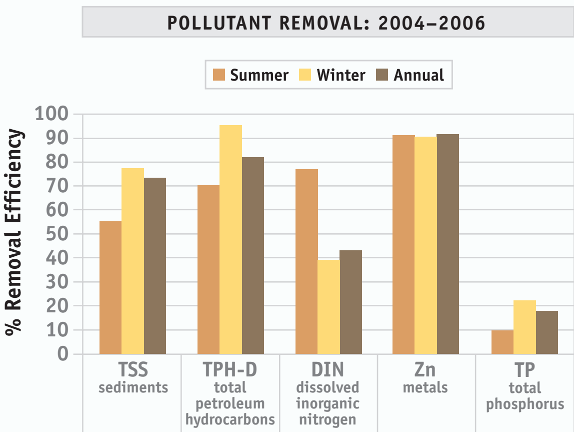
The retention pond tested at the UNHSC is comprised of a sedimentation forebay and a larger basin sized to hold a resident pool of water. It was installed below the water table to maintain a permanent pool of water, and in clay soils, which effectively act as a lining for the system. Side slopes were stabilized with grass, and spillways with stone and geotextile.

Improved designs, not used here, would include stabilization of wetland perimeter with stone and fabric. This perimeter was the location of failure for the pond. In this area, vegetation could not establish and soils were prone to erosion.

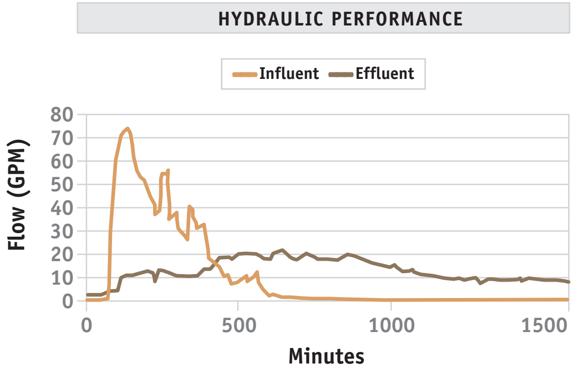
In general, these ponds can be designed either above or below the groundwater table. Ponds are commonly designed for both aesthetic and habitat function.

The system is designed to treat the water quality volume. Typically, channel protection volumes (CP_V) are conveyed through the system within 24 to 48 hours.

During conveyance protection volume (Q_P) rain events, stormwater is conveyed through the system, and bypasses the water quality treatment process.



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124



	Winter	Summer	Annual Average
Average Peak Flow Reduction	84%	79%	81%
Average Lag Time (minutes)	540	321	424

Water Quality Treatment

During the first year of operation, the retention pond was reasonably effective in removing many of the pollutants commonly found in runoff. It consistently met EPA's recommended level of removal for total suspended solids, as well as regional ambient water quality criteria for petroleum products, metals, and nutrients. However, during its second year, researchers observed a 25 percent reduction in its TSS median removal efficiency—from 81 percent down to 71 percent. This indicates that while the pond still effectively treats most contaminants, its performance may continue to diminish. Like the other systems evaluated at UNHSC, it does not provide chloride removal, but can dampen chloride peaks.

The chart at top left reflects the system's performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over a two-year monitoring period, with the data further divided into summer and winter components.

Water Quantity Control

Retention ponds exhibit a tremendous capacity to reduce peak flows, retain channel protection volume, and provide flood protection for up to 48 hours. In the figure at bottom left, the retention pond demonstrates effective peak flow reduction and long lag times, regardless of season. However, in general, these systems do not reduce runoff volume.

Research indicates that the extended duration effluent flows typical of retention ponds negatively impact receiving streams, particularly when post-development runoff subjects streams to erosive flows for long periods. This phenomenon is observed in urban areas, where it leads to channel instability and lost ecological value and function.

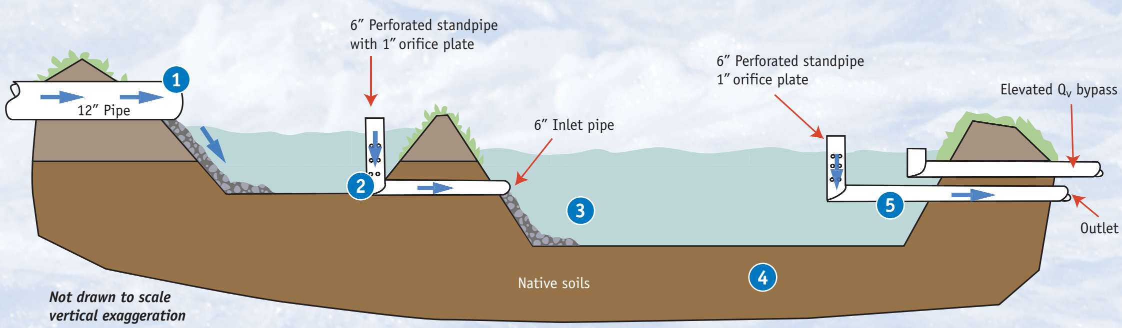
Maintenance

Minimal need for maintenance contributes to the popularity of retention ponds. However, while little maintenance may be required to support their ability to manage peak flow and floods, more frequent attention is critical for effective water quality treatment. Previous research has demonstrated that erosion and re-suspension of benthic sediments in these systems leads to sediment export. Since sedimentation is the main water quality treatment mechanism, inspections are critical to maintaining performance in sites with heavy sediment loads. Dredging for debris and trash is also needed. While not necessary for these systems to function, the establishment of a viable pond ecosystem can enhance treatment, prolong the system's lifespan, and increase aesthetic appeal.

Cold Climate

The system's ability to treat water quality and manage water quantity remained effective during cold winter months. While some variation in both kinds of performance does occur in cold conditions, it does not warrant significant alterations to system design to compensate.

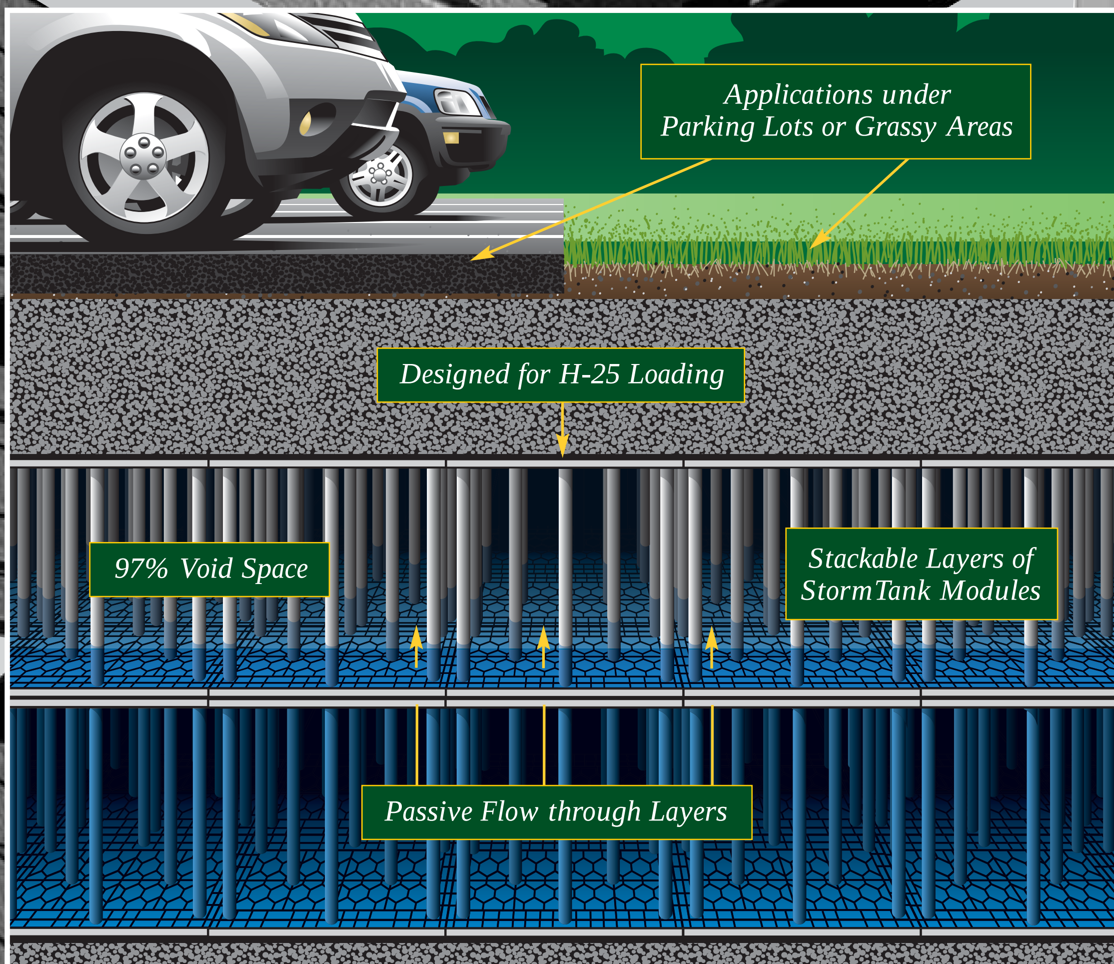
Water Quality Treatment Process



1. **Runoff flows into a forebay that removes large objects and allows larger sediment particles to settle.**
2. **Runoff exits the forebay though a perforated standpipe and flows into the pond. When forebay capacity is reached, the overflow spills across a weir into the retention pond basin.**
3. **Water quality treatment is a function of storage volume and retention time, i.e., larger storage volumes and longer retention times promote better treatment. The removal of TSS, some phosphorus, petroleum hydrocarbons, and metals occurs primarily through sedimentation.**
4. **Several components contribute to biological treatment. Nutrients removal occurs primarily through the activity of macroinvertebrates, microorganisms, and plants. Long-term breakdown of petroleum hydrocarbons is through microbial processes. Metals that accumulate in the sediment may be taken up by the roots of aquatic vegetation.**
5. **The runoff is conveyed by a perforated standpipe modified with a one-inch outlet which regulates flow from the system.**

Design Feature 11. Subsurface Storage

STORMTANK™ STORMWATER STORAGE MODULES

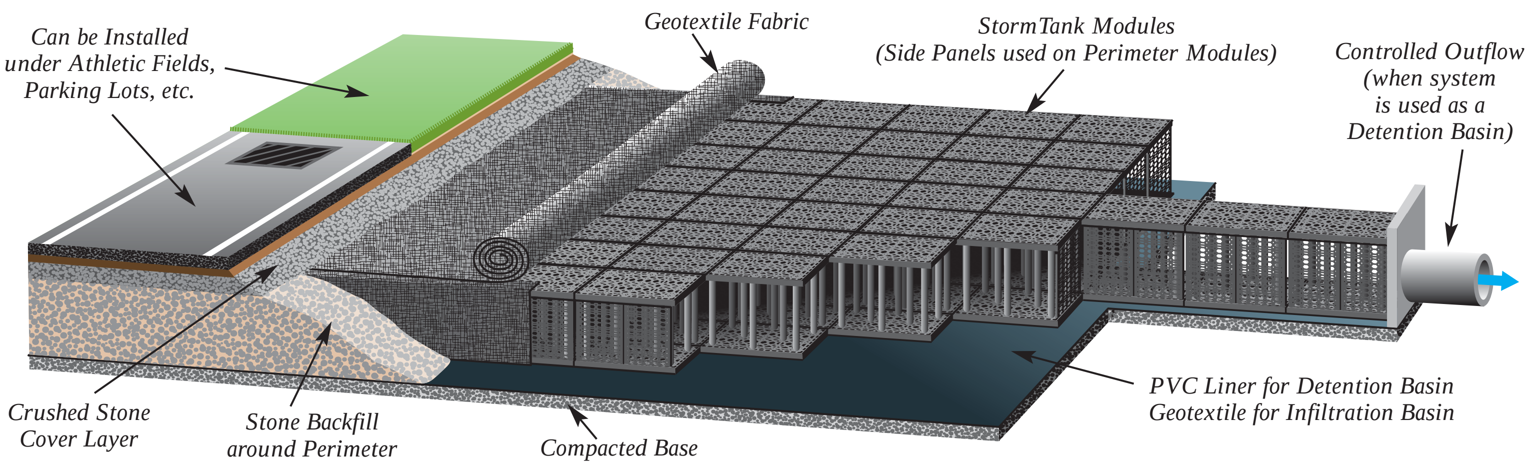


StormTank™

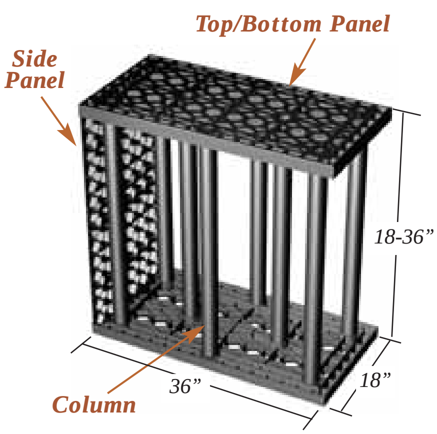
Stormwater Storage Modules are a high-void, strong, affordable alternative to crushed stone, concrete structures, or pipe chambers for sub-surface stormwater detention or infiltration basins.

BRENTWOOD INDUSTRIES

STORMTANK™ STORMWATER STORAGE SYSTEM



Brentwood's StormTank™ Stormwater Storage System is a high-void, strong, affordable alternative to crushed stone, concrete structures, or pipe chambers for sub-surface stormwater detention or infiltration basins.



HIGH VOID, HIGH STRENGTH Our modules offer the largest void space of any underground stormwater storage units currently on the market (97%), and are load-rated for use under parking lots, athletic fields, parks, etc. (Designed to exceed H-25 loading criteria)!

EASY TO INSTALL The entire StormTank Storage System is built on-site from Top / Bottom Panels and Side Panels made of rugged, lightweight polypropylene and 2-3 / 8" diameter PVC columns. Combinations of these three components create all the module configurations needed for a fully-functioning underground system (see example at top). To minimize shipping costs, the StormTank components are delivered unassembled, but on-site assembly is a snap! No special equipment, tools, or bonding agents are needed to assemble or install the modules. All components easily attach with a secure concentric pressure fit.

EASY TO CLEAN The open tops / bottoms and sides of the modules makes flushing and cleaning easy ... a great advantage over storage systems where access is limited.

SAVES SPACE AND MONEY Because of its 97% void space, stackability, and H-25 strength, a StormTank system offers significant space and cost savings when compared to conventional stormwater storage solutions. For example:

• A StormTank installation requires a much smaller footprint than a crushed rock system with the same amount of stormwater storage capacity. And less space used also means less expense for excavation, geotextile, liner, installation, and backfill.

• Because a StormTank system is installed underground, it frees up surface space for uses that would be otherwise unavailable with a typical detention pond.

• StormTank's stackability and variable column height (18"-36") can maximize the use of a site with limited surface area.

The Brentwood AccuPier Support System (above) has been in use for several years and is installed in over 50 biological oxidation towers throughout the U.S. and Canada. Each PVC AccuPier column, fitted with upper and lower base caps, can hold 7000 lbs. and has been compression-tested to 24,000 lbs. All the technology, materials, and experience gained from the AccuPier System have been applied to our new StormTank Modules.

BRENTWOOD INDUSTRIES

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Email wwsales@brentw.com
Website www.BrentwoodProcess.com

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Design Feature 12. Turf Reinforcement Mats

LANDLOK® TURF REINFORCEMENT MATS

Our Landlok® Turf Reinforcement Mats (TRMs) are the industry's most advanced solutions for applications requiring immediate, long-term erosion protection, vegetative reinforcement and water quality enhancement capabilities. Our first generation TRMs are constructed of a dense web of 100% polypropylene fibers positioned between two biaxially oriented nets. When vegetated, they provide twice the erosion protection of vegetation alone.

Now we've taken the same woven technology in our High Performance Turf Reinforcement Mats (HPTRMs) and used it to design the next generation of TRMs. These netless, composite-free three-dimensional second generation TRMs feature a rugged material construction that combines superior tensile strength, flexibility and UV stability. This allows them to deliver better, long-term performance over traditional methods like rock riprap and concrete paving and increased design life over first generation netted, fused, glued or stitch-bonded TRMs. All Landlok TRMs feature our patented X3® fiber technology, which provides 40% greater surface area for trapping and protecting seed and soil.

1ST GENERATION LANDLOK® TRMs FEATURES & BENEFITS

- Provides permanent turf reinforcement to enhance vegetation's natural ability to filter soil particles and prevent soil loss during storm events
- 100% synthetic and UV-stabilized components
- Utilizes X3 fiber technology for up to 40% greater surface area to protect emerging seedlings and sediment retention
- Promotes infiltration which leads to groundwater recharge
- More aesthetically pleasing than conventional methods (i.e. rock riprap and concrete paving)
- Superior product testing and performance
- Easier installation than conventional solutions (no heavy equipment required)

*Design life performance may vary depending upon field conditions and applications.

2ND GENERATION LANDLOK® WOVEN TRMs FEATURES & BENEFITS

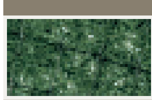
All the features and benefits of first generation Landlok TRMs, plus:

- A unique, patented matrix of pyramids formed with X3 fibers that gridlocks soil in place under high-flow conditions
- 3-D woven material with superior tensile strength for loading and/or survivability requirements
- Greater flexibility to maintain intimate contact with subgrade, resulting in rapid seedling emergence and minimal soil loss
- Completely interconnected yarns that provide superior UV resistance throughout the TRM
- A combination of superior characteristics for long-term performance and a longer design life than first generation Landlok TRMs
- Meets requirement of 5 mm^2 or less mesh size to prevent wildlife entanglement in any sensitive habitats

Outperforms and is more cost-effective than conventional erosion control methods, including:

- **Rock riprap**
- **Concrete paving**
- **Erosion Control Blankets (ECBs)**

LANDLOK® TURF REINFORCEMENT MATS PRODUCT FAMILY TABLE

PRODUCT		DESCRIPTION	FUNCTIONAL LONGEVITY	COLOR	FIBER TYPE	# OF NETS	FHWA FP-03, SECTION 713 COMPLIANCE
	LANDLOK® 450	1ST GENERATION TRM	PERMANENT	TAN OR GREEN	POLYPROPYLENE X3® FIBER TECHNOLOGY	2	TYPE 5A, 5B, 5C
	LANDLOK 1051	1ST GENERATION TRM	PERMANENT	TAN	POLYPROPYLENE X3 FIBER TECHNOLOGY (GEOTEXTILE BACKING)	1	TYPE 5A, 5B, 5C
	LANDLOK 300	2ND GENERATION TRM	PERMANENT	TAN OR GREEN	POLYPROPYLENE X3 FIBER TECHNOLOGY	0 (WOVEN)	TYPE 5A, 5B, 5C

LANDLOK® TURF REINFORCEMENT MATS

APPLICATION SUGGESTIONS FOR LANDLOK® TURF REINFORCEMENT MATS

	APPLICATION	FUNCTIONAL LONGEVITY	PRODUCT STYLE	INSTALLED COST[1]	ANCHOR SUGGESTIONS[5]
SLOPES[2]	UP TO 1H:1V	PERMANENT	LANDLOK® 300	\$10.00 - 15.00/yd^2 \$11.96 - 17.94/m^2	2.5 ANCHORS/yd^2 3 ANCHORS/m^2
SLOPES[2]	UP TO 1.5H:1V UP TO 2H:1V	PERMANENT	LANDLOK 450	\$9.00 - 14.00/yd^2 \$10.77 - 16.75/m^2	2 ANCHORS/yd^2 2.5 ANCHORS/m^2
CHANNELS[3]	SHEAR STRESS UP TO 10 lb/ft^2 (479 N/m^2) VELOCITY UP TO 18 ft/sec (5.5 m/sec)	PERMANENT	LANDLOK 450	\$9.00 - 14.00/yd^2 \$10.77 - 16.75/m^2	2.5 ANCHORS/yd^2 3 ANCHORS/m^2
CHANNELS[3]	SHEAR STRESS UP TO 12 lb/ft^2 (576 N/m^2) VELOCITY UP TO 20 ft/sec (6.1 m/sec)	PERMANENT	LANDLOK 300	\$10.00 - 15.00/yd^2 \$11.96 - 17.94/m^2	2.5 ANCHORS/yd^2 3 ANCHORS/m^2
BANKS[4]	WAVE ACTION < 1 ft (30 cm)	PERMANENT	LANDLOK 1051	\$10.00 - 15.00/yd^2 \$11.96 - 17.94/m^2	2.5 ANCHORS/yd^2 3 ANCHORS/m^2

NOTES: 1. Installed cost estimates range from large to small projects according to material quantity. The estimates include material, seed, labor and equipment. Note that costs vary greatly in different regions of the country. 2. For slopes steeper than 1H:1V, please see our Pyramat® HPTRM product brochure. 3. Values shown are short-term fully vegetated maximums. For channels with a shear stress greater than 12 lb/ft^2 (576 N/m^2) and velocity greater than 20 ft/sec (6.1 m/sec), please see our Pyramat HPTRM product brochure. 4. For wave action greater than 1 ft (30 cm), please see our Pyramat HPTRM product brochure. 5. For anchor size and style, please see our TRM Installation Guidelines.

KEY PHYSICAL PROPERTIES OF LANDLOK® TURF REINFORCEMENT MATS

- Tensile Strength: High-strength and low-strain minimizes seed, root damage and material under heavy loads.
- Flexibility: Greater flexibility allows our TRMs to conform and maintain intimate contact with the prepared grade, increasing the ease of successful installation.
- Seedling Emergence: Landlok TRMs, now with X3® fiber technology, offer 40% more fiber surface area to capture the critical sediment and moisture needed to increase seed germination within the first 21 days.
- UV Resistance: All Landlok TRM components are constructed with the top-tested UV stabilizers, such as carbon black and hindered amine light stabilizers (HALS).

SEVEN STEPS FOR SUCCESSFUL TRM SELECTIONS*

1. SELECT APPLICATIONS
2. DETERMINE FUNCTIONAL LONGEVITY
3. ANTICIPATE CLIMATE (ARID, SEMI-ARID OR TEMPERATE)
4. UNDERSTAND TRADITIONAL SOLUTION
5. PREDICT NON-HYDRAULIC STRESSES (MAINTENANCE STRESSES)
6. KNOW VEGETATION TYPE
7. CALCULATE HYDRAULIC STRESSES

*See Propex Engineering Bulletin or EC-DESIGN® software for more information.

LANDLOK® TURF REINFORCEMENT MAT PROPERTY TABLE[1] ENGLISH & METRIC UNITS

	PROPERTY	TEST METHOD	VALUE[2]	LANDLOK® 450	LANDLOK® 1051	LANDLOK® 300
PHYSICAL	MASS PER UNIT AREA	ASTM D-6566	MARV	10.0 oz/yd^2 340 g/m^2	14 oz/yd^2 475 g/m^2	8.3 oz/yd^2 281 g/m^2
PHYSICAL	THICKNESS	ASTM D-6525	MARV	0.4 in 10.1 mm	0.4 in 10.1 mm	0.3 in 7.6 mm
PHYSICAL	LIGHT PENETRATION	ASTM D-6567	TYPICAL	20%	5%	50%
PHYSICAL	COLOR	VISUAL	–	GREEN, TAN	TAN	GREEN, TAN
MECHANICAL	TENSILE STRENGTH	ASTM D-6818	MARV	400 x 300 lb/ft 5.8 x 4.3 kN/m	300 x 225 lb/ft 4.3 x 3.2 kN/m	2400 x 2000 lb/ft 35.0 x 29.2 kN/m
MECHANICAL	TENSILE ELONGATION	ASTM D-6818	MAXIMUM	50%	85%	50%
MECHANICAL	RESILIENCY	ASTM D-6524	MARV	90%	80%	75%
MECHANICAL	FLEXIBILITY	ASTM D-6575	TYPICAL	0.026 in-lbs 30000 mg-cm	0.022 in-lbs 25000 mg-cm	0.195 in-lbs 225000 mg-cm
ENDURANCE	FUNCTIONAL LONGEVITY	OBSERVED	TYPICAL	PERMANENT	PERMANENT	PERMANENT
DURABILITY	UV RESISTANCE	ASTM D-4355	MINIMUM	80% @ 1000 HOURS	80% @ 1000 HOURS	90% @ 3000 HOURS
PERFORMANCE	SEEDLING EMERGENCE[3]	ECTC DRAFT METHOD #4	TYPICAL	409%	220%	296%
PACKAGING	ROLL WIDTH	MEASURED	TYPICAL	6.5 ft 2.0 m	6.5 ft 2.0 m	8.5 ft 2.6 m
PACKAGING	ROLL LENGTH	MEASURED	TYPICAL	138.5 ft 42.2 m	138.5 ft 42.2 m	106 ft 32.3 m
PACKAGING	ROLL WEIGHT	CALCULATED	TYPICAL	75 lb 34 kg	101 lb 46 kg	51 lb 23 kg
PACKAGING	ROLL AREA	MEASURED	TYPICAL	100 yd^2 84 m^2	100 yd^2 84 m^2	100 yd^2 84 m^2

NOTES: 1. The listed property values are effective 06/2009 and are subject to change without notice. 2. MARV indicates Minimum Average Roll Value calculated as the typical minus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any sample taken during quality assurance testing will exceed the reported value. 3. Calculated as percent increase in average plant biomass with tall fescue grass seed in sand 14 days after seeding versus traditional monofilament TRMs and HPTRMs.

LANDLOK® TURF REINFORCEMENT MAT PERFORMANCE VALUES ENGLISH & METRIC UNITS

MATERIAL	FUNCTIONAL LONGEVITY	SHORT-TERM MAXIMUM SHEAR STRESS AND VELOCITY						MANNING'S "n"		
		VEGETATED[4, 7]		PARTIALLY[5]		UNVEGETATED[6]		0"-6"	6"-12"	12"-24"
LANDLOK® 450	PERMANENT	10 lb/ft^2 479 N/m^2	18 ft/sec 5.5 m/sec	8 lb/ft^2 383 N/m^2	15 ft/sec 4.6 m/sec	5 lb/ft^2 239 N/m^2	12 ft/sec 3.7 m/sec	0.035	0.025	0.021
LANDLOK 1051	PERMANENT	10 lb/ft^2 479 N/m^2	18 ft/sec 5.5 m/sec	n/a	n/a	5 lb/ft^2 239 N/m^2	12 ft/sec 3.7 m/sec	0.036	0.026	0.020
LANDLOK 300	PERMANENT	12 lb/ft^2 576 N/m^2	20 ft/sec 6.1 m/sec	–	–	–	–	0.030	0.028	0.018

NOTES: 4. Maximum permissible shear stress has been obtained through fully vegetated (70% to 100% density) testing programs featuring specific soil types, vegetation classes, flow conditions and failure criteria. These conditions may not be relevant to every project nor are they replicated by other manufacturers. Please contact Propex for further information. 5. Maximum permissible shear stress has been obtained through partially vegetated (30% to 70% density) testing programs featuring specific soil types, vegetation classes, flow conditions and failure criteria. These conditions may not be relevant to every project nor are they replicated by other manufacturers. Please contact Propex for further information. 6. Maximum permissible shear stress has been obtained through unvegetated (0% to 30% density) testing programs featuring specific soil types, vegetation classes, flow conditions and failure criteria. These conditions may not be relevant to every project nor are they replicated by other manufacturers. Please contact Propex for further information. 7. Maximum permissible shear stress achieved after only 14 weeks of vegetative establishment versus the industry standard of two full growing seasons.

For downloadable documents like construction specifications, installation guidelines, case studies and other technical information, please visit our web site at **geotextile.com.** These documents are available in easy-to-use Microsoft® Word format.

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

Implementation Strategy Report

Draft

June 2010

Prepared for:

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1 Introduction

The goal of the *Wailupe Watershed Based Plan* (WBP) is to identify management objectives and pollutant control strategies to reduce the generation and discharge of non point source (NPS) pollutants into the receiving waters of Wailupe Stream and Maunalua Bay based on an assessment of the watershed condition. The *Pollution Control Strategies Report* identifies management units for Wailupe Watershed and associated management practices to achieve this goal. This *Implementation Strategy Report* provides details to facilitate the implementation of the recommended management practices. In particular, this report provides:

- An estimate of the technical and financial resources required to implement the recommended pollution control measures.
- A prioritization for implementing the recommended pollution control measures.
- Identification of the entity/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 to addressing the larger set of pollution control strategies should be considered when determining the reduction potential of each management practice. Each management practice will contribute to the overall success, and in combination, implemented practices will result in cumulative net reductions of pollutant runoff loads from the watershed. Identifying key implementation strategies will ensure that the management measures and practices identified in this WBP are developed and implemented with a solid foundation and oversight aimed ultimately at measureable reductions in pollutant loads.

2 Resources Required for Implementation

A watershed management approach to NPS pollution control requires systematic steps. The implementation of specific management practices is part of this process and follows the identification of pollutant sources, selection of the appropriate practice to reduce the target NPS pollutant, identification of the locations for installation, and acceptance of responsibility by the sponsoring entity. The resources required to implement a management practice are a function of the complexity of the design, the site conditions for its installation, and the regulatory and land owner requirements and ordinances. The management practices identified in this report vary in complexity and the resources to implement them range from minor to significant.

2.1 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[1], 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. 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 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 on O‘ahu and Hawai‘i, it will be important that the design and construction manger articulate to contracting crews the objectives and installation nuances, and provide detailed guidance to facilitate correct and expeditious installations.

2.2 Financial Resources

Financial resources required to implement the management practices can vary considerably. Comparing cost between the more complex baffle box and a simple grass swale finds that relatively the baffle box cost is high versus low for the grass swale. In many instances the cost for implementing one practice is relatively high when compared to the net benefit it can provide. Similar to production costs that function by economies of scale, the cost to implement per unit management practice goes down as the number of units installed goes up. The total implementation cost increases as more units are installed, but not linearly. As the number of units installed increases, the net benefit in terms of NPS pollutant reduced increases as a power function.

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

Cost and equations to generate cost estimates to implement selected management practices are shown in Table 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

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

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 proper 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 were not recommended.

Funding for implementation of management practices can come from a range of sources including Federal, State, local and private sources. 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 1. Costs Associated with Recommended Management Practices

Implementation Cost					
Management Practice	**Calculated Cost[2]**	**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, Tafuri 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 2001)
Good housekeeping practices	N/A	Low	Moderate	High	(LA-SMD 2000)
Grass swale	$0.25 - $0.50/$ft^2$	Moderate	Moderate	Low	(Barr 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 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	$22/sq meter	Moderate	Low	Low	Vendor quote

[2] Includes installation cost unless noted otherwise.

3 Implementation Priority

Sites that are generating the most NPS pollutants and locations that are logistically favorable were given the highest implementation priority for management practices. For most of the recommended treatment practices, benefits are manifested immediately or upon the first rainfall event that generates overland flow. The priority pollutant of concern identified in the Maunalua Bay Strategic Conservation Strategic Plan is land based pollutants, specifically fine terrigenous sediment running off into Maunalua Bay (Mālama Maunalua 2006). As described in the *Pollution Control Strategies Report*, sediments are primarily generated from the upper watershed, adjacent slopes, and stream corridor management units. 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.

The long-term solution to reducing the amount of land based pollutants reaching Maunalua Bay is to prevent generation or reduce generation to background levels. In most cases this is not feasible, especially in the near future. Reducing sediment generation to background levels would require considerable cost and multiple years. 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 would result in immediate benefits were assigned high priority for implementation. Although there may be a lag time for prevention controls, such as restoring vegetation, to result in significant reduction of NPS pollutants, they are recommended with a lower implementation priority.

Implementation priority considered sediment "hotspots" locations as priority for treatment. An effort was made to identify installation locations along pathways that sediment are routed into the stream and ocean. Since sediment is generated across diffuse and numerous locations, it is most efficient to treat when 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 along the pollution train.

Management practices for implementation were prioritized within each management unit. Similar to ranking the units for priority, specific areas were evaluated and management practices prioritized. The priority for implementation should not be considered rigid, and if a land owner or entity responsible for a particular parcel has resources to implement a management measure that is lower priority the opportunity should be taken. Any installation of a management measure 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. Table 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 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 the best estimates of where treatments are possible and which treatments will provide the most effective pollutant removal. The prioritization should be used as a guideline, and if there are opportunities to implement a management practice considered lower priority (i.e. available funding, volunteer work), that should be done. In general, reduction in NPS pollution is a function of the extent to which management practices are installed, including how many and the spatial area they cover.

Table 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. 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

Management Practice	Priority
Green roof – Green grid	Low
Infiltration trench	Moderate
Modular wetland	High
Natural/Native vegetation	Low
Porous pavement	Moderate
Rain barrels	Low
Subsurface storage	Moderate
Stream Channel Management Unit[3]	Medium
Coir logs	Moderate
Natural/Native vegetation	Moderate
Turf reinforcement mats	High

4 Responsible Entities

Responsibility for implementing management practices will often fall on landowners of the parcel or site where the practices will be installed. 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. In many locations identified in this report where practices should be installed there are no definitive findings 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.[4]

Recommended management practices can be required under a regulatory program or implemented voluntarily. Table 4 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. Imposing responsibility to implement practices is most effective 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 adherence to the National Pollutant Discharge Elimination System (NPDES) permit program and other permit conditions.

[3] 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.

[4] 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.

4.1 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 and its subsequent amendments, water quality controls were required for certain types of storm water runoff. Point sources are most often controlled using regulatory approaches. Amendments to the Clean Water Act (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 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.

Hawai‘i Department of Health (DOH) administers and approves NPDES permits in the State of Hawai‘i. CCH and HIDOT, through the SWMP, are legally bound to implement the terms of the NPDES permit. In Wailupe Watershed both CCH and HIDOT hold NPDES permits approved by DOH. The CCH permit (No. HI S000002) covers most of the land within the urbanized section of the watershed and specifically addresses water discharge from CCH’s MS4 into State waters. The HIDOT permit (No. S000001) authorizes storm water discharge from the Highways Division MS4 into State waters. Both permits mandate that discharge 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 preventative measures, there are no provisions that require 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.

4.2 Managing NPS Pollution

4.2.1 Federal and State Programs

The Federal Water Pollution Control Act [i.e. Clean Water Act (CWA)] 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 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 Hawai‘i's 303(d) list, and therefore any point discharge into the streams or the bay directly are required to comply with State of Hawai‘i 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 Hawai‘i, 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 by the Hawai‘i Department of Business, Economic Development and Tourism (DBEDT), Office of Planning. 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

[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.

components required under Section 6217, the State developed *Hawai'i'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 *Hawai'i's Implementation Plan for Polluted Runoff Control* (2000).

4.2.2 Voluntary Initiatives

Parallel to Federal and State programs, and often supported by available funding, voluntary initiatives are an important mechanism for both preventative 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 are an integral part of a comprehensive solution to reduce NPS pollution.

Table 4. Agencies with Responsibilities Related to 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 Hawai‘i 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.

4.3 Implementing Management Practices

An important component of an implementation strategy is identification of the entities responsible for implementing the range of management practices. Often, overall implementation of a WBP is accomplished through the joint efforts of private and public entities. 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. Table 5 identifies the primary entities responsible for implementing the recommended management practices in Wailupe Watershed.

Table 5. Entities Responsible for Implementing and Maintaining Management Practices

Management Practice	Responsible Entities
Baffle box	– CCH – HIDOT
Coir logs	– CCH
Curb inlet baskets	– CCH – HIDOT – Commercial
Extended detention basin	– CCH – Private
Good housekeeping practices	– Community groups – Residents/Volunteers
Grass swale	– CCH – Private – Commercial
Green roof – green grid	– Commercial/business owners
Infiltration trench	– CCH – Private – Commercial
Invasive species control	– Various
Modular wetland	– Private
Natural/native vegetation	– DLNR – Volunteers
Porous pavement	– CCH – Private – Commercial
Rain barrels	– Residents/Volunteers
Retention pond	– CCH
Subsurface storage	– Private
Turf reinforcement mats	– USACE

5 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 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.

5.1 Program Implementation

Factors such as funding availability, participation of responsible entities, and pollutant load reduction efficacy will influence feasibility of management measure implementation and the implementation timeline. Milestones for Wailupe Watershed implementation can be assigned to management measures as a means to support scheduling and track tasks (see Table 6). EPA gives three examples of times scales:

- Short-term (1 to 2 years)
- Mid-term (3 to 5 years)
- Long-term (5 to 10 years or longer)

Table 6. 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

With selected practices, and given available funds and time-scales accounted for, an implementation strategy can be developed. EPA suggests outlining subtasks and the level of effort for each milestone to establish a baseline for time estimates. It is also necessary to collectively discuss milestones and identify those that are feasible and identify the responsible parties (USEPA 2008). Table 7 identifies some of the required subtasks 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.

Table 7. Management Practice Subtasks

Management Practice	Subtasks
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

5.2 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. Monitoring efforts to evaluate whether management practices are reducing NPS pollutants are included in the *Evaluation and Monitoring Plan*. An example indicator for measuring pollutant reductions by the management practices is the presence of sediments captured by the installed structures. It will be difficult to quantify specific pollution reduction targets for Wailupe Watershed since there is limited information on baseline conditions. The *Evaluation and Monitoring Plan* addresses both the current lack of available information and the need for ongoing monitoring to both 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 6). 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.

6 Adaptive Management

Adaptive management can be used to address recommendations should the load reductions and load targets not be achieved. 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. 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. Adaptive management builds upon prior results, both positive and negative, and allows managers to continually reassess and incorporate new knowledge into their 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 experimental 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 the 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. 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 what is impacting Maunalua Bay becomes available, priorities pollutants of concern may shift, and management practices would need to be adjusted. The WBP is a living document that will benefit from regular review and updating, to remain current and to support effective management. The *Evaluation and Monitoring Plan* illustrates how adaptive management will be used.

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

Evaluation and Monitoring Plan

Draft

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1 Introduction

The goal of the *Wailupe Watershed Based Plan* is to characterize and assess the condition of the watershed and to identify management objectives and pollutant control strategies to reduce generation and discharge of non-point source (NPS) pollutants into the receiving waters of Wailupe Stream and Maunalua Bay. A watershed characterization is presented in the *Watershed Characterization Report*, while management practices to address priority problems are presented in the *Pollution Control Strategies Report*. The objective of this *Evaluation and Monitoring Plan* is to provide guidance for monitoring and evaluating the effectiveness of the recommended management practices in reducing NPS pollutants once they are installed. This document presents guidelines and methodologies that will provide both qualitative and quantitative assessments that can be used to determine effectiveness of the practices and adaptively apply the findings to other watersheds.

2 Types of Monitoring

Monitoring is a process that provides feed back 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. Measureable 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 a practice installation location 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 Table 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 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 meet the intention of the *Evaluation and Monitoring Plan* requirements and will provide the necessary information to determine if NPS pollutant reduction is occurring and to help refine future selection of practices for other watersheds.

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).

2.2 Baseline Monitoring

Baseline and effectiveness monitoring are temporally linked by pre- and post-implementation of a practice. Baseline monitoring is the initial collection of data and information, and transitions to effectiveness monitoring following installation of a practice or beginning of an activity. Baseline monitoring documents existing conditions of 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, stormwater 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.[1] 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 are developing new ones that can utilize the existing data. Pooling individual studies assists in identifying trends in environmental conditions and comparing implemented management practice effectiveness.

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.

2.3 Effectiveness Monitoring

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 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).

[1] 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.

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.

2.3.2 Sampling Locations

Effectiveness monitoring is primarily conducted at the location where the pollutant control management practice is installed. This 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 and Table 3 are focused on monitoring effectiveness at the installation locations of the management practices.

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 and protocols should minimize opportunities for subjective analysis during the monitoring activities. When utilizing volunteers to conduct monitoring sufficient subject matter background should be provided to minimize bias and subjectivity during monitoring.

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 computation of the amount of sediment that was removed from storm water that entered the baffle box, and would equate to a reduction of sediment 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. This scheme 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, but rather presented as specific examples of rigorous numeric methods that could be conducted by the entity installing the various management practices, or others.

- 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 practices 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.

3 Monitoring Logistics

3.1 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. Water bodies 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.

3.2 Monitoring Program Administration

The City and County of Honolulu (CCH) and the Hawai'i 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 monitoring requirements or WLAs for Wailupe Stream or the nine other streams that drain into Maunalua Bay.

Focus 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 (found in 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 listed 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.

3.3 Monitoring and Data Collection Responsibility

3.3.1 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. 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 recently installed two rain gages in Wailupe Watershed along the headwater ridgeline on top of the pali and Wiliwilinui ridge above Aina Haina neighborhood.

3.3.2 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 has been an important 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 be used to provide baseline data and provide numeric criteria to evaluate the expected changes of water quality following implementation of some or all of the management practices recommended in the *Pollution Control Strategies Report* of this WBP. 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. Their relationships and collaborations with various government agencies and private and public partners makes them uniquely qualified 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 5.3).

4 Monitoring in Wailupe Watershed

4.1 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 6.3). Information on implementation should be conveyed to DOH, 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)

4.2 Monitoring of Environmental Conditions in Wailupe Watershed

4.2.1 Baseline Data for Wailupe Watershed

Previous sections of the Wailupe WBP compiled existing data and identified data gaps 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 *Inventory of Existing Data and Determination of Data Gaps Report* and *Watershed Characterization Report*). 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 *Pollution Control Strategies Report*). 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 2. Sampling of 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 sites across the four management units will provide data and information that can be used to implement 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.

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 though acquisition of 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 *Watershed Characterization Report* and *Pollution Control Strategies Report*).

Table 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 Aina 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.

Table 2. cont.

Monitoring Location	Monitoring Objective	Method
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

4.3 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 6.3).

Table 3 summarizes information on effectiveness monitoring parameters for management practices in Wailupe Watershed. The protocols were developed based on the assumption that members of the Mālama Maunalua volunteer program 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 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

4.3.1 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.

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. These samples should only be collected by persons with the proper training (see Section 5.4.2).

Frequency: Biennially or prior to vault cleanout.

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 of it.

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

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.

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 stormwater 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.

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

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

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 attenuated 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

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

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 and/or other entities exploring invasive species management programs and assessments.

Frequency: N/A

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 attenuate runoff and reduce pollutant loads.

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

Protocol: During runoff events a sample of water entering and exiting the wetland should be collected. Samples should be analyzed to determine the concentration of target pollutants and the percent reduction of each. The structure should be evaluated to determine that over flow is not occurring and the system is functioning per its design. Plants growing in the wetland should be inspected to evaluate vigor and growth.

Frequency: Quarterly, for four separate rain events

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: Vegetation surveys can be conducted for small plots in which each plant is counted at periodic intervals in order to get a value of percent survival. Vegetation transects should be established for large plots.

Frequency: Annually

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

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

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 reservoir.

Frequency: Annually for one rain event

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

4.3.2 Restrictions on Sediment Sampling

Stormwater 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, Tafuri 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 is currently no data to confirm or deny 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.

5 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.

5.1 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) 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

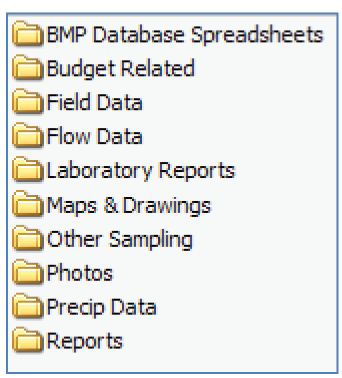
3. Assessment/Oversight
   - Assessment and response action
   - Reports to management

4. Data Validity and Usability
   - Data review, validation, and verification requirements
   - Validation and verification methods
   - Reconciliation and user requirements

5.2 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 (see Figure 1), 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.

Figure 1. Example File Directory for Management Practice Monitoring
(GeoSyntec and ASCE 2002)



5.3 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.[2] 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 a valuable tool for the 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.

5.4 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).

5.5 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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[2] 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.

6 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.

6.1 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.

6.2 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.

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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), Dept 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 Oahu, 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.