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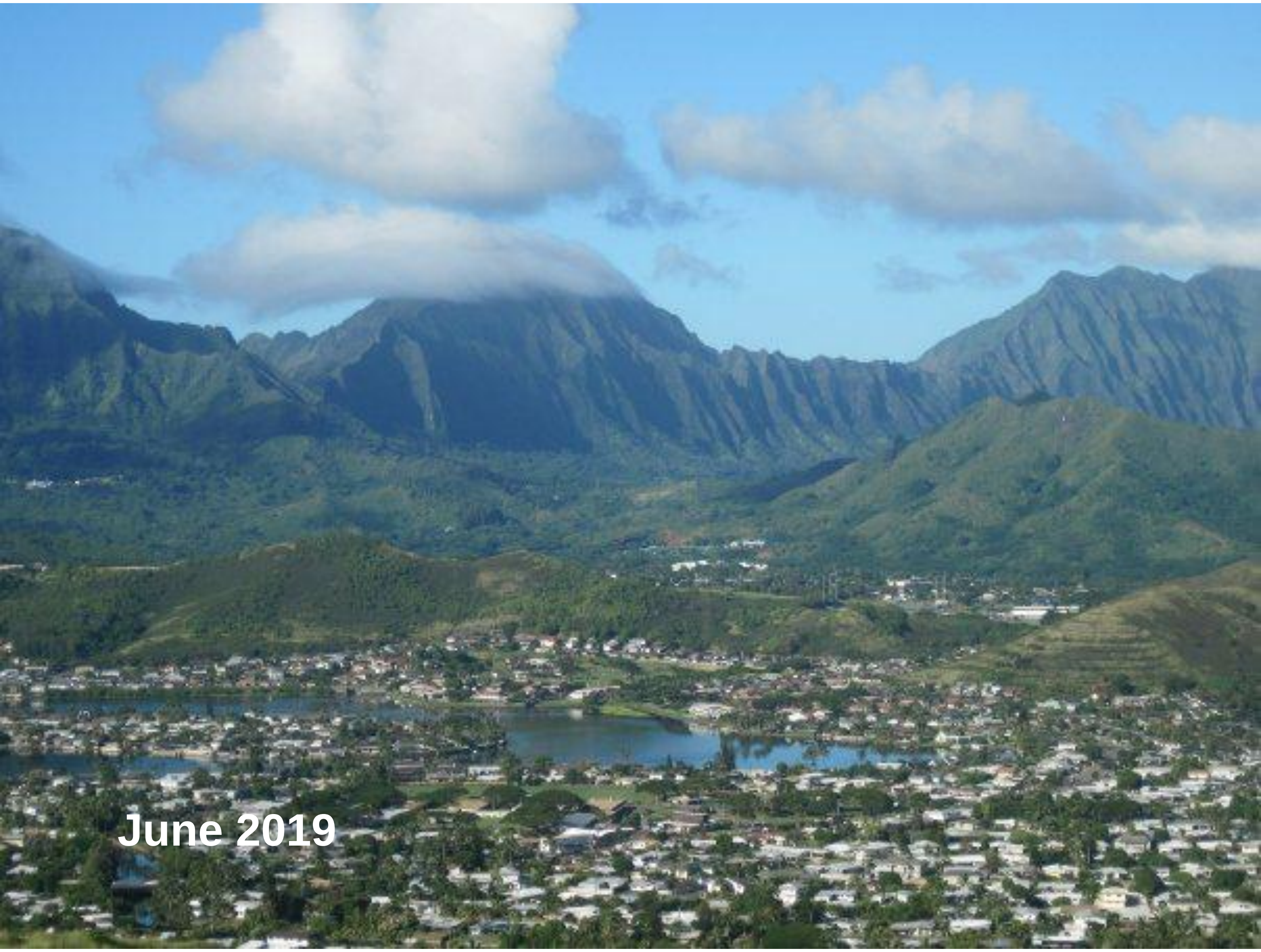
Hydrologic and Water Quality Model Development for the Ka‘elepulu Pond Watershed



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List of Acronyms

%	percent
ac-ft	acre-foot
BASINS	Better Assessment Science Integrating Point and Non-point Sources
BMP	best management practice
CCAP	Coastal Change Analysis Program
CCH	City and County of Honolulu
EPA	Environmental Protection Agency, United States
ET	evapotranspiration
FTable	Function Table
GIS	geographic information system
HDOT	Department of Transportation, State of Hawaii
HSPF	Hydrologic Simulation Program – FORTRAN
ID	identification
IMPLND	impervious land (Imperland)
in	inch
INFILT	infiltration rate
lb	pound
LZSN	lower zone soil moisture storage
mg/L	milligram per liter
NO	nitric oxide
NO_2	nitrite
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
PERLND	pervious land (Perland)
PEVT	potential evapotranspiration
POTFS	scour potency factor
POTFW	washoff potency factor
RCHRES	reach reservoir
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
U.S.	United States
USGS	United States Geological Survey
UZSN	upper zone soil moisture storage
WQ	water quality

EXECUTIVE SUMMARY

The Hydrologic Simulation Program – FORTRAN (HSPF) watershed modeling platform was used to provide a quantitative assessment of the volume of pollutants entering the pond from the watershed. The modeling approach divided the Kaʻelepulu Pond watershed into multiple land use types based on the data provided by the City and County of Honolulu (CCH).

The HSPF was calibrated to recorded flow data and sampled water quality (WQ) data throughout the watershed. The recorded and sampled data locations where intended to isolate individual land uses so that calibration.

The calibration occurred in three steps:

1. *Hydrology:* This step focused on the HSPF model's ability to reasonably simulate the rainfall-runoff processes that occur for each of the land uses and subbasin.
2. *Sediment:* In HSPF sediment transport is based on the available storage of surface material and the energy required by storm runoff to mobilize it. To calibrate sediment, it is required that a calibrated hydrology be accomplished first.
3. *Nutrients:* The WQ parameters associated with nutrients was modeled based on relationships between total suspended solids (TSS) and stormwater runoff volumes. So the calibration of nutrients requires an HSPF model that is calibrated for both flows and TSS.

Based on the calibration of the HSPF to the sampled data the average annual loading of flow and material to the Kaʻelepulu Pond is shown in Table ES-1.

Table ES-1. Flow and Pollutant Loading to Kaʻelepulu Pond

	Flows (ac-ft)	TSS (tons)	Nitrate (lbs)	Ammonia (lbs)	Phosphorus (lbs)
Average Annual Input to Pond	3,254	358	6,573	548	4,449

ac-ft acre-foot
lb pound

To address the improvement of WQ on Kaʻelepulu Pond, multiple best management practices (BMPs) were suggested.

- Modification and Repair of the Existing Kapaa Silt Basin
- Creation of Constructed Wetlands
- Placement of Hydrodynamic Separators
- Incorporating Green Infrastructure into Existing Land Use

Each of the suggested BMPS are intended to take advantage of specific opportunities within the watershed based on land uses and locations. Table ES-2 provides a summary of the potential unit cost and WQ improvement for each of the suggested BMPs.

Table ES-2. Potential WQ Benefits and Costs

BMP	Estimated Project Cost	TSS Removal per Year (lbs)
Kapaa Silt Basin	$2,076,400	31,500
Green Infrastructure	$5,632,300	170,700
Hydrodynamic Separators	$1,378,800	143,000
Constructed Wetlands	$761,600	29,100

This report focused using hydrologic and WQ modeling to estimate the annual loading of material entering Kaʻelepulu Pond that impacts its WQ. The suggested BMPs resulting from this effort are intended to be implemented in conjunction with CCH-led efforts focusing on community involvement and education as recommended in the accompanying report, Kaʻelepulu Watershed Water Quality Analysis Planning Study (AECOM 2018). Using both constructed BMPs and source control approaches, will provide a pathway for the improvement of WQ in the Kaʻelepulu Pond.

1 INTRODUCTION

1.1 Purpose

The general purpose of the Storm Drainage BMPs in the Vicinity of Ka‘elepulu Pond project is to address the growing concerns with the deteriorating WQ and sediment build-up at Ka‘elepulu Pond. To accomplish this goal, seven tasks are identified for the project including: Planning and Scheduling, Preliminary Studies, Planning Phase, Ka‘elepulu Watershed Water Quality Analysis Planning Study; Ka‘elepulu Watershed Planning Model; Pre-Design Phase; and Design Phase. This report details the development and results of the watershed planning model.

1.2 Background

Through the initial planning phase, a *Storm Water Best Management Practices Plan* (AECOM 2008) was prepared to evaluate the discharges from the four major outlets into Ka‘elepulu Pond. The plan analyzed the contributing drainage areas for each outlet, possible sources of pollutants and potential structural and non-structural improvements that could be implemented to improve conditions at the pond. Various proposed improvements were selected to be designed and built as pilot projects intended to help evaluate their effectiveness. Non-structural projects included stream embankment stabilization utilizing anchored erosion matting and hydro-mulching and stream bed protection involving the installation of a concrete articulating block revetment mat. Structural improvement projects include the installation of curb inlet retractable screens that would help prevent gross pollutants from entering the structure and curb inlet baskets installed within the catch basins that would serve to collect debris and filter pollutants prior to their discharge into the pond.

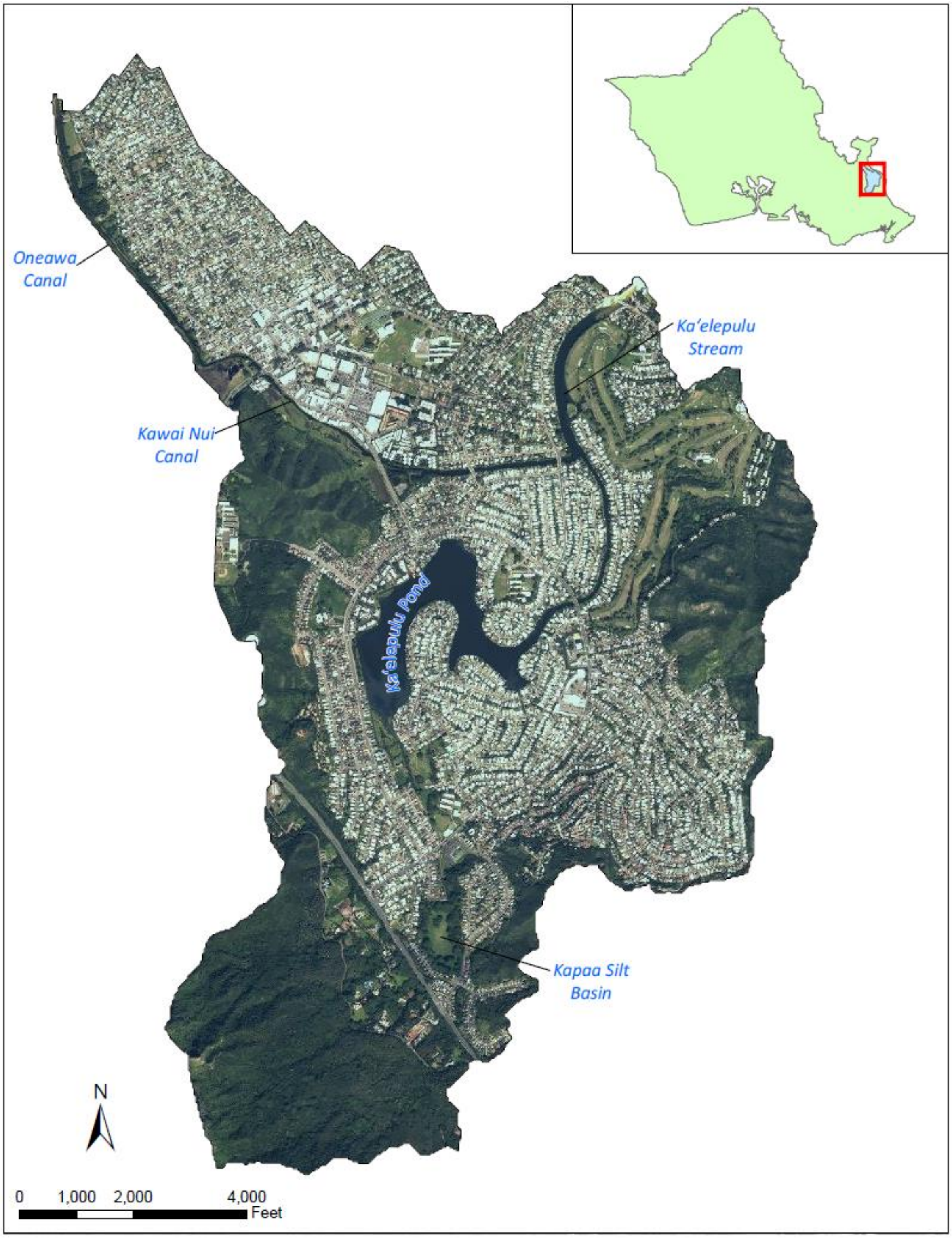
However it became evident that the contributing watershed and potential sources of pollutants extended well beyond the limits of the CCH and that their drainage system served merely as the conduit for these external discharges. To fully address the issues at Ka‘elepulu Pond it would require the support and resources in partnership with their neighboring agencies, watershed groups, and residents of the watershed. The Water Quality Analysis Planning Study and Planning Model were tasked to analyze and evaluate the entire Ka‘elepulu Pond watershed and propose viable BMPs that could be implemented by landowners that would further contribute to the improvement of WQ at the pond.

1.3 Ka‘elepulu Pond Watershed

The approximately 3,000 acres Ka‘elepulu Pond watershed is located on the windward coast of Oahu (Figure 1-1). The current pond configuration was constructed as part of the Enchanted Lake residential subdivision in the 1960s. Prior to development the pond was considered an open waterbody and wetland with water sources provided by the adjacent slopes of the Koolau Mountains. Flood control efforts have diverted flows from Kawai Nui Channel that used to provide fresh water the Ka‘elepulu Pond and Stream.

The area tributary to the pond is a mix land uses including residential, commercial, and natural areas. The areas closest to the pond are mostly residential with many of the upper slopes currently consisting of natural areas. The Ka‘elepulu Stream runs along the western boundary of the developed areas of Kailua. As with the Ka‘elepulu Pond the majority of the tributary area is residential.

Figure 1-1. Kaʻelepulu Pond HSPF Study Area



2 WATER QUALITY

2.1 State of Hawaii Criteria

The State of Hawaii Department of Health, Clean Water Branch lists the entire Kaʻelepulu Stream network, including the pond as both a stream and an estuary (DOH 2014). The 2014 report lists the WQ issues associated with stream and marine (estuary) water listings as:

- *Stream Waters:* Kaʻelepulu Stream, entire network for Total Nitrogen (TN), Nitrate+Nitrite, Total Phosphorus (TP), and Turbidity.
- *Marine Waters:* Kaʻelepulu Stream - Kailua Beach. Listed for TN, Turbidity, TP, Enterococci, Chlorophyll A.

The State's Water Quality Standards are contained in Hawaii Administrative Rule Chapter 11-15 and also presented as Water Quality Standards. For the Kaʻelepulu Pond watershed study, the State's standards are provide in Table 2-1. The State does not have a total suspended solids standard for estuaries.

Table 2-1. State Water Quality Standards for Kaʻelepulu Stream and Pond (Estuary)

Parameter	Units	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value more than 2% of the time
TN	mg/L	0.2	0.35	0.5
Ammonia Nitrogen	mg/L	0.006	0.01	0.02
Nitrate+Nitrite Nitrogen	mg/L	0.008	0.025	0.035
Total Phosphorous	mg/L	0.025	0.05	0.075
Chlorophyll A	mg/L	0.002	0.005	0.01
Turbidity	NTU	1.5	3	5
TSS 1	mg/L	202 103	50 30	80 55

[a] Standards are for streams
[b] Wet Season criteria
[c] Dry Season criteria
% percent
mg/L milligram per liter
NTU nephelometric turbidity unit

Additionally the Kaʻelepulu Pond and stream are listed by the State as Class 2 waters. The objective of class 2 waters is to protect their use for recreation purposes, the support of propagation of aquatic life, agricultural and industrial water supplies, shipping and navigation. These waters shall not act as receiving water for any discharge which has not received the best degree of treatment or control compatible with the criteria set for this class.

Part C of the National Pollutant Discharge Elimination System Permit for the CCH is titled Receiving Water Limitations, Inspections, and Corrective Actions. Under this section of the permit it is stated that the stormwater discharge shall comply with the basic WQ criteria which states:

> All waters shall be free of substances attributable to domestic, industrial, or other controlled sources of pollutants, including:
>
> - Materials that will settle to form objectionable sludge or bottom deposits.

- Substance in amounts sufficient to produce taste in the water or detectable off flavor in the flesh of fish, or in amount sufficient to produce objectionable color, turbidity or other conditions in receiving waters.
- Substance or conditions or combinations thereof in concentration which produce undesirable aquatic life.
- Soil particles resulting from erosion on land involved win earthwork, such as the construction of public works; highways; subdivision; recreational, commercial, or industrial developments; or the cultivation and management of agriculture.

2.2 Water Quality Sampling In Kaʻelepulu Pond Watershed

WQ sampling was conducted within the study area to provide documented conditions related to pollutant concentrations generated from the multiple land uses found in the Kaʻelepulu study area. Six WQ samplers were set up throughout the Kaʻelepulu Pond study area (Figure 2-1). Along with collecting WQ samples, the samplers also recorded flows at each location. The selection of the placement for each sampler was based on isolating a particular land use. A limitation on isolating a particular land was based on finding a secure location for the equipment. A short description of the each of the sampling location is provided. More detailed information can be found in the Monitoring Locations Photo Log and Channel Characteristics report (Cardno TEC 2014).

- *Hamakua:* The sampling location is near the intersection of Hekili Street and Hamakua Drive in Kailua. The sampling basin is approximately 10-acres of commercial land use and roadway. The area includes the parking lot for the Kailua Foodland and Big City Diner.
- *Hele:* The sampler is located on the Hele channel immediately downstream of Keolu Drive. The sampling basin is approximately 275-acres. The majority of the basin is residential land use with commercial uses in the lower area along Keolu Drive and natural areas along the hills.
- *Keolu:* The sampler is located on the Keolu Channel near Akumu Street. The sampling basin is approximately 525 acres. The basin contains multiple land uses with the majority being made up of residential and conservation (forested) lands. Also included are agriculture and the Kalanianaole Highway. Flows at this location are directly impacted by the Keolu regional detention basin.
- *Akipola:* The sampler is located in the concrete channel near the intersection of Keolu drive and Akiohala Street. The sampling basin is approximately 125 acres of low density residential area along with some natural vegetation on steeper slopes.
- *Koapa:* The sampler is located in a concrete channel near Akaakoa Street, immediately upstream of the Keolu regional detention basin. The approximately 125-acres basin is mostly forested but also include low density residential, agriculture and the Kalanianaole Highway.
- *Aleka:* The sampler is located on an unnamed stream along the Old Kalanianaole Highway near Aleka Place. The entire sampling area is forested conservation lands. Flows generated in this watershed are conveyed to the Kaopa sampling location.

Sampling results for five storm events collected for the Kaʻelepulu project are shown in Table 2-1. The sampling results values shown in the table will be used to calibrate the WQ parameter results within the HSPF modeling effort. The calibrated model will then be used to estimate annual sediment and pollutant loads in the Kaʻelepulu Stream

Figure 2-1. Water Quality Sampling Locations

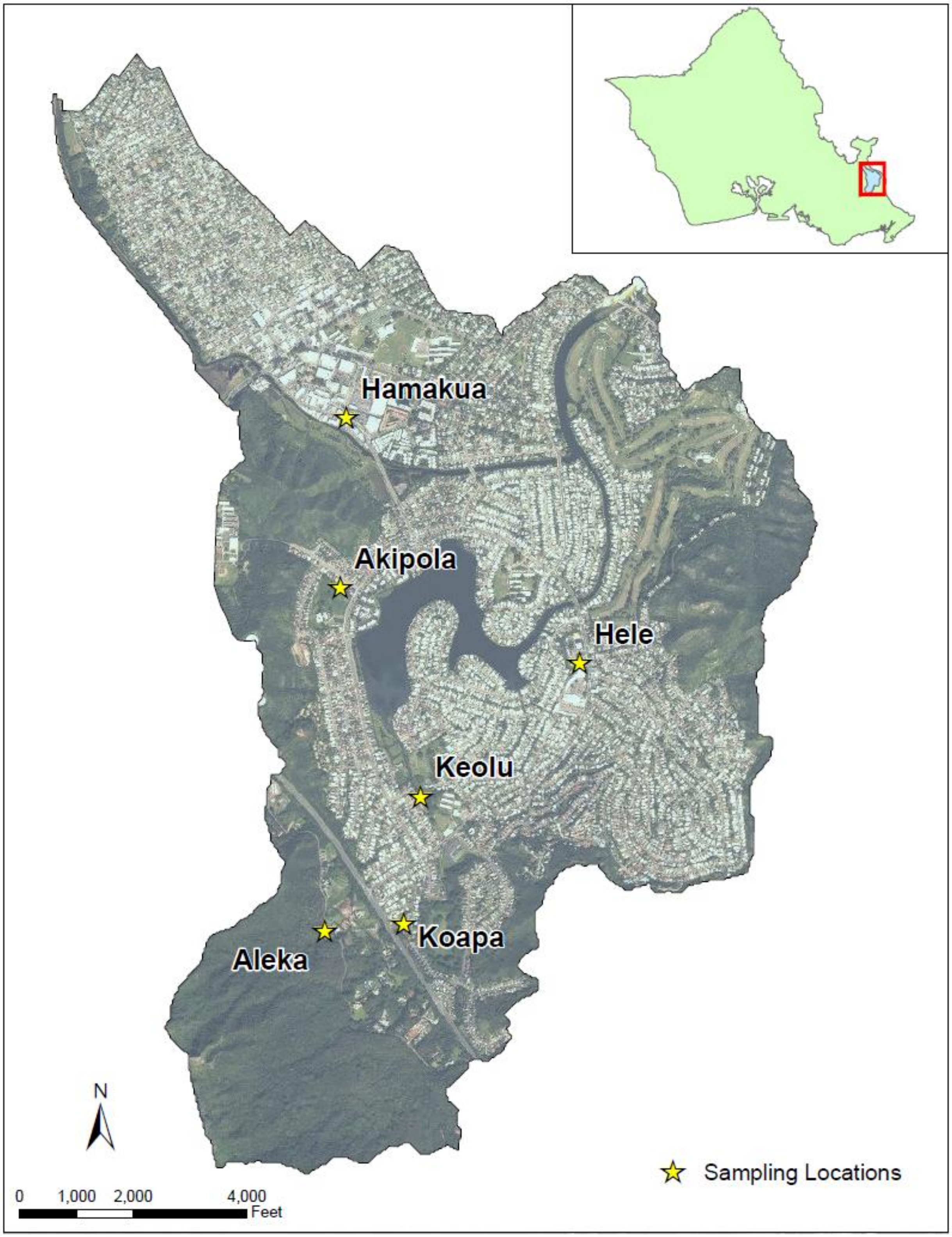


Table 2-2. WQ Sampling Analysis Results

Sample Date	Hamakua	Hele	Keolu	Akipola	Kaopa	Aleka
Total Suspended Solids, mg/L						
7/20/2014	20.5	94.5	56.5	388	348	456
8/8/2014	28	75	30	ND	43	ND
10/18/2014						
1/3/2015	15	62	35	45.5	19	
2/3/2015 1	8	101	47.3	5	28	
Ammonia Nitrogen, mg/L						
7/20/2014	0.129	0.105	0.07	0.075	0.069	0.069
8/8/2014	ND	ND	ND	ND	ND	ND
10/18/2014						
1/3/2015	0.137	0.186	0.088	0.044	0.029	
2/3/2015	0.216	0.161	0.057	0.065	0.14	
Nitrate+Nitrite as Nitrogen, mg/L						
7/20/2014	0.068	1.88	0.38	3.46	0.973	0.966
8/8/2014	ND	0.427	0.19	ND	1.12	ND
10/18/2014						
1/3/2015	ND	0.359	0.217	1.91	0.21	
2/3/2015	ND	0.379	0.385	0.194	0.414	
Total Phosphorous, mg/L						
7/20/2014	0.182	0.492	0.271	0.617	0.478	0.727
8/8/2014	0.133	1.24	0.166	ND	0.288	ND
10/18/2014						
1/3/2015	0.138	0.436	0.429	0.402	0.157	
2/3/2015	0.136	0.463	0.239	0.183	0.285	

Notes:
Values are max.
The Keolu values are based on maximum composite sample.
ND non-detect

2.3 Description of Water Quality Constituents

Each of the sampled WQ constituents are described below. The descriptions also include potential sources of the pollutants

2.3.1 Total Suspended Solids (TSS)

Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. Within the Kaʻelepulu Pond watershed TSS contributions likely come from two sources:

- *Soil Erosion:* Soil erosion is caused by disturbance of a land surface. Soil erosion can be caused by Building and Road Construction, Forest Fires, Logging, and Mining. The eroded soil particles can be carried by stormwater to surface water. This will increase the TSS of the water body.

- *Urban Runoff:* During storm events, soil particles and debris from streets and industrial, commercial, and residential areas can be washed into streams. Because of the large amount of pavement in urban areas, infiltration is decreased, velocity increases, and natural sediment settling areas have been removed. Sediment is carried through storm drains directly to creeks and rivers.

Solids contribute to WQ, habitat and aesthetic problems in urban waterways through:

- Elevated levels of solids increase turbidity.
- Reduced the penetration of light at depth within the water column, and limit the growth of desirable aquatic plants, destroy habitat for fish and bottom-dwelling organisms.
- Solids also provide a medium for the accumulation, transport and storage of other pollutants including nutrients and metals.

2.3.2 Ammonia Nitrogen

Ammonia, another inorganic form of nitrogen, is the least stable form of nitrogen in water. Ammonia is easily transformed to nitrate in waters that contain oxygen and can be transformed to nitrogen gas in waters that are low in oxygen. Ammonia is found in water in two forms - the ammonium ion, and dissolved, un-ionized (no electrical charge) ammonia gas. Total ammonia is the sum of ammonium and unionized ammonia. The dominant form depends on the pH and temperature of the water.

2.3.3 Nitrate+Nitrite as Nitrogen

Nitrate is highly soluble (dissolves easily) in water and is stable over a wide range of environmental conditions. It is easily transported in streams and groundwater. Nitrates feed plankton (microscopic plants and animals that live in water), aquatic plants, and algae, which are then eaten by fish. Nitrite (NO_2) is relatively short-lived in water because it is quickly converted to nitrate by bacteria.

Within the Kaʻelepulu Pond watershed the likely contributing sources of ammonia, nitrate, and nitrite are listed below:

- *Wastewater and Septic System Effluent:* Human waste is significant contributor of nitrogen to water. Ammonia, nitrite, and nitrate are decomposition products from urea and protein, which are in human waste. Ammonia is an ingredient in many household cleaning products and is sometimes used to remove carbonate from hard water. Therefore, these nitrogen species go down the drains in our houses and businesses, and can enter streams from wastewater treatment plant effluent, illegal sanitary sewer connections, exfiltration from old sanitary sewer lines, and poorly functioning septic systems.
- *Fertilizer Runoff:* Fertilizer is a major influence on nitrogen concentrations in the environment. Commercial nitrogen fertilizers are applied either as ammonia or nitrate, but ammonia is rapidly converted to nitrate in the soil. Animal manure is also used as a nitrogen fertilizer in some areas. Organic nitrogen and urea in the manure are converted to ammonia and, ultimately, to nitrate in the soil. Nitrate that is not used by plants washes from farmlands and residential and commercial lawns into storm drains and nearby streams, or seeps into groundwater.
- *Animal Waste:* A significant amount of nitrogen is released in the wastes produced by animals. This can be a serious problem in waters near cattle feedlots, hog farms, dairies, and barnyards. Ducks and geese contribute a heavy load of nitrogen if they are present in large numbers. Excretions of aquatic organisms are very rich in ammonia, a decay product of animal proteins, but the amount of nitrogen they add to waters is usually small. Through the process of nitrification, ammonia is oxidized to nitrite and then to nitrate in water.
- *Fossil Fuels:* The burning of fossil fuels such as gasoline and coal in cars, trucks, and power plants produces many by-products. Coal and petroleum generally contain about 1 percent nitrogen. Part of the nitrogen is converted to the gas nitric oxide (NO) during the burning of the fuel. Nitric oxide is converted by sunlight and photochemical processes in air to nitrogen oxide gases (NO and NO_2, which

are commonly referred together as NOx), which are a major component of smog. Nitrogen oxide gases are a major contributor to acid rain.

2.3.4 Total Nitrogen

TN is the sum of total Kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite. This WQ parameter was not directly sampled or modeled as part of this project but is included here as TN is a common presented value in literature. TN is comprised of three forms of nitrogen that are commonly measured in water bodies: ammonia, nitrates and nitrites. The Kaelepulu Pond sampling collected information on the inorganic components of TN, Ammonia and Nitrate+Nitrite.

$$\text{Inorganic} = \text{Ammonia} + \text{Nitrate} + \text{Nitrite}$$

$$\text{TN} = \text{Inorganic N} + \text{Organic N}$$

2.3.5 Total Phosphorous

TP is a measure of all the forms of phosphorus, dissolved or particulate. The TP in stormwater runoff is typically composed of 50 percent particulate-bound and 50 percent dissolved phosphorus. Soluble reactive phosphorus is a measure of orthophosphate, the filterable (soluble, inorganic) fraction of phosphorus, the form directly taken up by plant cells. Typical sources of TP within the Kaʻelepulu Pond watershed are:

- *Wastewater and Septic System Effluent:* Domestic and industrial sewage are very important sources of phosphorus to surface water. Organic phosphates are formed primarily by biological processes. They are contributed to sewage by body waste and food residues. Phosphorus is essential in metabolism so is always present in animal waste. Orthophosphates and polyphosphates can be contributed by detergents, as discussed below.
- *Detergents:* Orthophosphates and certain polyphosphates are major constituents of many commercial cleaning preparations. In the 1950s and 1960s, sodium phosphate was used often as a "builder" in households detergent to increase cleaning power. The extensive use of detergents led to major eutrophication problems, and in the 1960s efforts were made by governments, detergent manufacturers, and consumers to reduce the use of phosphates in detergents. As a result, phosphorus concentrations in many streams and lakes decreased. This was due to limits on the phosphate content of detergent, and also additional treatment used in waste water treatment plants to remove phosphorus. Many states have a ban on phosphates in detergents.
- *Fertilizers:* Fertilizers generally contain phosphorus in the form of orthophosphate. Phosphate is not very mobile in soil; it tends to remain attached to solid particles rather than dissolving in water. However, if too much fertilizer is applied, the phosphates are carried into surface waters with storm runoff and also with melting snow. Soil erosion of fertilized fields and lawns can also carry a considerable amount of particulate phosphate to streams.
- *Animal Waste:* Phosphorus is essential in metabolism, so is present in animal waste. Therefore, phosphate runoff can be an issue in waters near cattle feedlots, hog farms, dairies, and barnyards.
- *Development/Paved Surfaces:* Development can cause soil erosion, which will release phosphorus. If swamps and wetlands are drained for development, phosphorus that was buried can be exposed. During the building phase, and after everything has stabilized, phosphorus concentrations in stormwater can increase because natural filters such as trees, shrubs, and puddles have been eliminated.

3 HYDROLOGIC DATA INPUTS

3.1 Data Needs for HSPF Modeling

Hydrologic model development required the estimation of parameters significant to the hydrologic process, including infiltration to the soil, water storage both on the surface and in the soil, and losses within the system from groundwater recharge, diversions, and evapotranspiration (ET). Geographic information system (GIS) data developed during previous watershed work and publicly available data from the United States (U.S.) Geological Survey (USGS) and Natural Resources Conservation Service (NRCS) were used to develop model parameters and delineate the basin. This section describes how the data for the key hydrologic parameters were developed.

The HSPF model was used for the Ka'elepulu Pond watershed hydrologic modeling. HSPF is designed to simulate hydrology and WQ in natural and man-made water systems using existing meteorological and hydrologic data. Although data requirements are extensive, HSPF is thought to be the most accurate and appropriate management tool presently available for the continuous simulation of hydrology and WQ in watersheds (EPA 2001). The HSPF model is able to address complex hydrologic conditions while providing flexibility in the model development.

3.2 Land Cover/Land Use Data

The land cover and land use data provides a description of the surface conditions throughout the watershed. These data provide for designating land classifications required for the hydrologic modeling. From the CCH, multiple GIS data sets were incorporated into the development of the land use data including:

- *Building Footprints:* This data set is composed of the individual roofs for most structures on Oahu. In the Ka'elepulu study are, it appears that generally all the roofs for residential land uses were represented. A few of commercial buildings required new delineations likely due to recent development in the Kailua commercial area. Each of the roofs were classified based on zoning or type of facility so that roofs associated with residences can be differentiated from school or commercial building roofs.
- *Tax Parcels:* The tax parcel data was used to develop a GIS coverage to represent paved roads. Following the creation of the data set, the Kalanianaole Highway was reclassified as 'highway' to allow for differentiating stormwater flows and sources between CCH jurisdiction and State of Hawaii Department of Transportation (HDOT) jurisdiction.
- *Parking Lots:* Using aerial photography parking lots associated with commercial areas, schools, multiple family, and churches.
- *Coastal Change Analysis Program (CCAP):* National Oceanic and Atmospheric Administration produces this land cover dataset for the coastal regions of the United States. The data is typically updated on a 5-year schedule, with the most recent data reflecting 2011 conditions. The dataset uses the same land use categories as the National Land Cover Dataset. The CCAP data included a designated impervious land use based on roads, roofs and parking areas. The CCAP impervious areas were compared to aerials of the study area. It was found that the CCAP over estimated impervious areas in the more densely developed areas. As GIS coverages were already available or developed for the roads and roofs, the CCAP data was not used in area zoned as residential by the City of County.

Based on the classifications available within the data sets Table 3-1 lists the resulting pervious and impervious land use classes that were developed for the Ka'elepulu watershed model.

Table 3-1. Designated Land Use within the Ka‘elepulu Pond Watershed

Pervious Land Classes	Impervious Land Classes
Bare Land	Highway
Cultivated Land	Street
Evergreen Forest	Parking Lot
Developed Open Space	Open Water
Emergent Wetland	General Impervious (CCAP)
Forested Wetland	Roof – Single Family
Scrub/Shrub Wetland	Roof - Multi-Family
R-10 Residential	Roof - Commercial
R-7.5 Residential	Roof - Schools
R-5 Residential	Roof - Church
Scrub/Shrub	Roof – Misc. Structures: Rec Center, HDOT, Golf Club House
Unconsolidated Shore	

Figure 3-1 illustrates the delineation of the land use data sets within the study area. As shown in the figure, the delineations of impervious area are not well defined and are not assigned to a particular land use. The original data was edited to provide a more detail description of impervious surfaces based on whether it is associated with streets, parking, or roofs. Figure 3-2 illustrates the “clean” version of the land use, land cover data. For areas outside of the developed areas the CCAP data was used without editing. Figure 3-3 shows the resulting GIS data coverage for the study area. Table 3-2 provides the number of acres associated with each of the land use classifications.

Table 3-2. Distribution of Land Uses for Ka‘elepulu Pond Watershed

Pervious	Area (acres)	Impervious	Area (acres)
Bare Land	7.1	Highway	16.1
Cultivated/Grassland	22.6	Street	288.3
Evergreen Forest	565.9	Parking Lot	68.1
Developed Open Space	158.0	Open Water	125.1
Emergent Wetland	26.9	General Impervious (CCAP)	75.7
Forested Wetland	7.2	Roof – Single Family	434.5
Scrub/Shrub Wetland	4.5	Roof - Multi-Family	16.1
R-10 Residential	90.7	Roof - Commercial	23.1
R-7.5 Residential	141.8	Roof - Schools	12.2
R-5 Residential	625.4	Roof - Church	1.8
Scrub/Shrub	304.0	Roof – Misc. Structures: Rec Center, HDOT, Golf Club House	3.8
Unconsolidated Shore	1.6		
Total Pervious	**1955.7**	**Total Impervious**	**1064.8**

Figure 3-1. Preliminary Land Use Coverage for the Ka'elepulu Pond Watershed

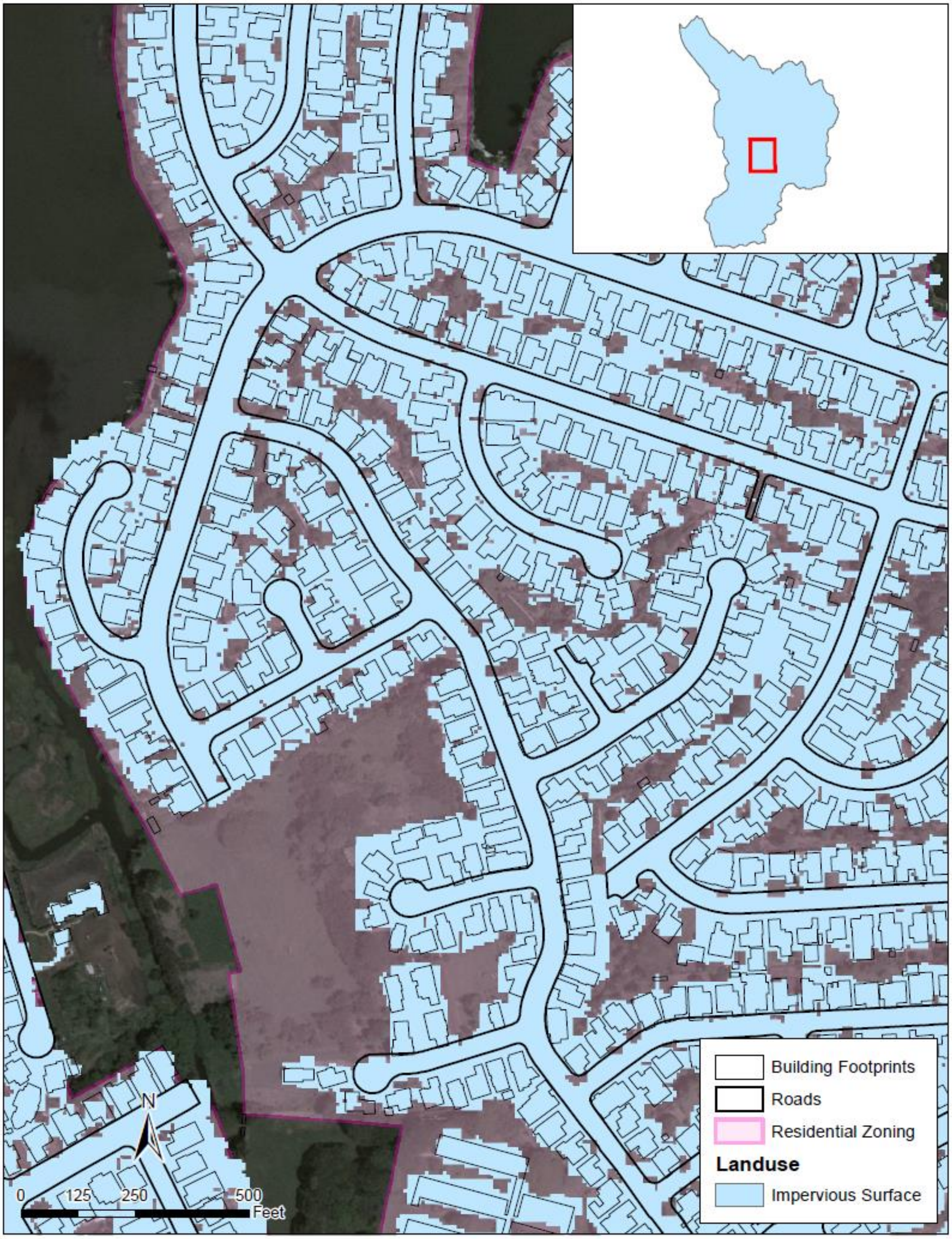
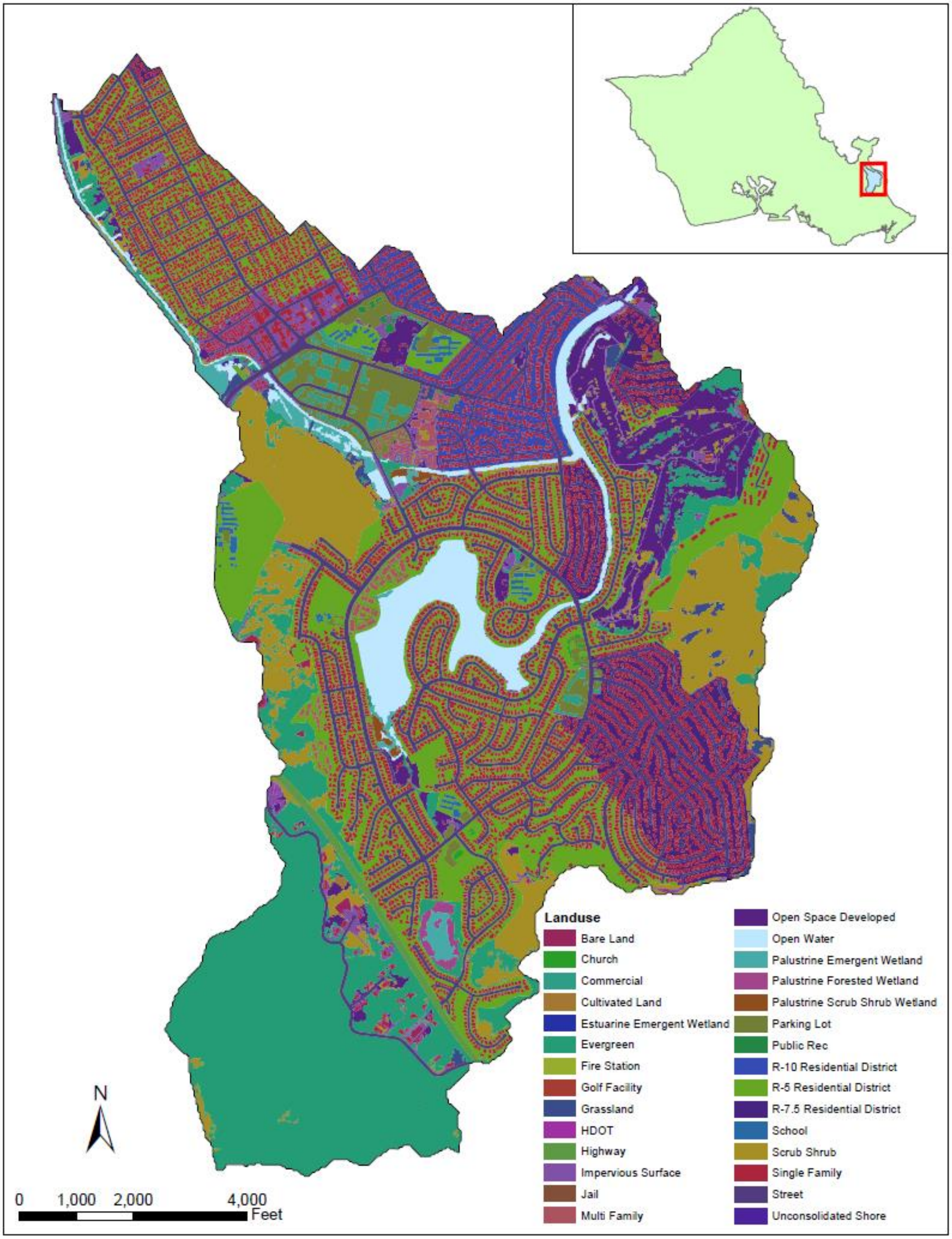


Figure 3-2. Revised CCAP Coverage for Kaʻelepulu Pond Watershed

Figure 3-3. Revised CCAP Coverage for Kaʻelepulu Pond Watershed



3.3 Soil Data

The Kaʻelepulu Pond watershed HSPF modeling efforts used soil data obtained from the NRCS Soil Data Mart (NRCS 2010). Exports from the Soil Data Mart are delivered in what is referred to as Soil Survey Geographic format. Figure 3-4 illustrates the distribution of soils in the Kaʻelepulu Pond watershed study area.

For the HSPF hydrologic model development, the soil data from the GIS coverage provide estimates of physical properties that influence the interaction of rainfall and runoff. These parameters include permeability rate, soil layer (horizon) depth, moisture storage capacity of the soil. The permeability rate was used to set the initial infiltration rate (INFILT), while soil depth and moisture storage capacity were used to estimate the initial soil moisture storages (upper zone soil moisture storage [UZSN], lower zone soil moisture storage [LZSN]). For the purposes of the Kaʻelepulu Pond watershed modeling, INFILTs and moisture storage were classified as low, medium, or high. Soil slope classifications were differentiated into low, mild, steep, and extreme. The table in Appendix 1 lists the soils within the study area along with the initial hydrologic parameters from the soil data set.

3.4 Meteorological Data

The HSPF is a continuous simulation hydrologic model that has the capacity to produce a time series of hydrologic parameters such as surface flow, soil moisture, pollutant loading as output over the duration of the simulation. To produce a continuous time series of hydrologic parameters, the HSPF model requires not only precipitation data to add water to the system, but also a dataset that removes some water from the system. For precipitation stored in the soil, moisture is removed from the system as ET between storm events, allowing the watershed to restore the available storage capacity of the soils.

3.4.1 Precipitation

For the Kaʻelepulu Pond watershed study area HSPF model, the hydrologic data used are the recorded rainfall data to supply moisture to the system and potential ET data to remove it. For the Kaʻelepulu HSPF model, the simulation period was set from October 1, 2004, through February 3, 2015. This simulation period allows for a year of hydrologic simulation so that the model can reach an equilibrium for wetting and drying of the soils. The ending date is set to the last sampled storm event.

Due to the orographic effect of the tradewinds and the Koolau Range, the rainfall patterns with the Kaʻelepulu watershed vary greatly. Two 15-minute interval precipitation gages were incorporated in the HSPF in order to represent the precipitation patterns found in the study area. The Kailua Fire Station gage will be applied to the areas below the Kalanianaole Highway and the Maunawili/Makawao (Upper) gage will be used for the upper watershed. Table 3-3 lists precipitation statistics for the two gages.

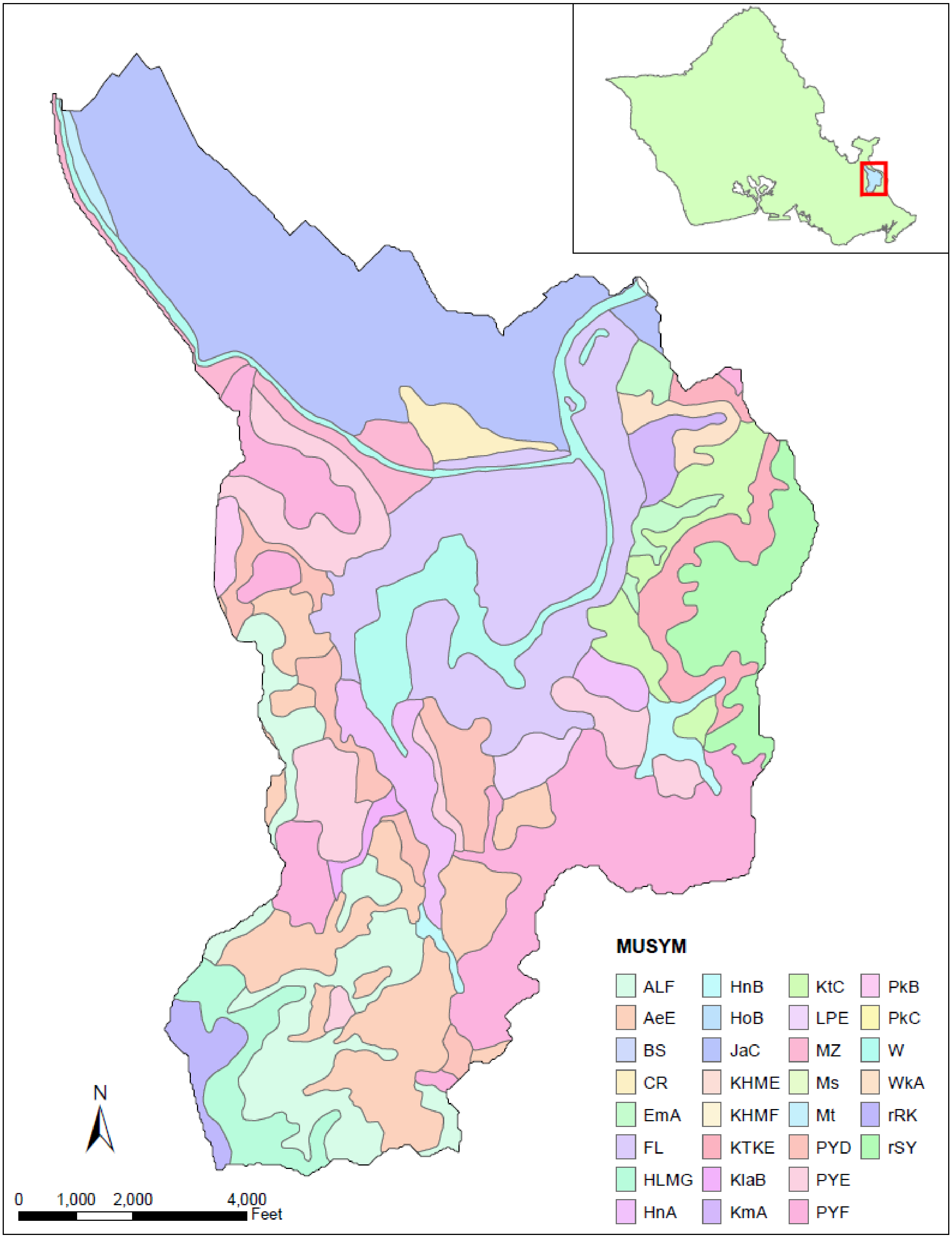
Table 3-3. Precipitation Gages used in the Kaʻelepulu Watershed Study

Precipitation Gage	COOP ID	Maximum (in)	Minimum (in)	Average WY2005-13 (in)
Kailua Fire Station	512683	35.1 - 2011	11.2 – 2007	22.4
Maunawili/Makawao	516222	96.00 - 2006	29.4 - 2013	63.9

Source: National Climate Data Center - http://gis.ncdc.noaa.gov/map/viewer/#app=clim&cfg=cdo&theme=hourly&layers=1.
COOP National Weather Service Cooperative Observer Program
ID identification
in inch

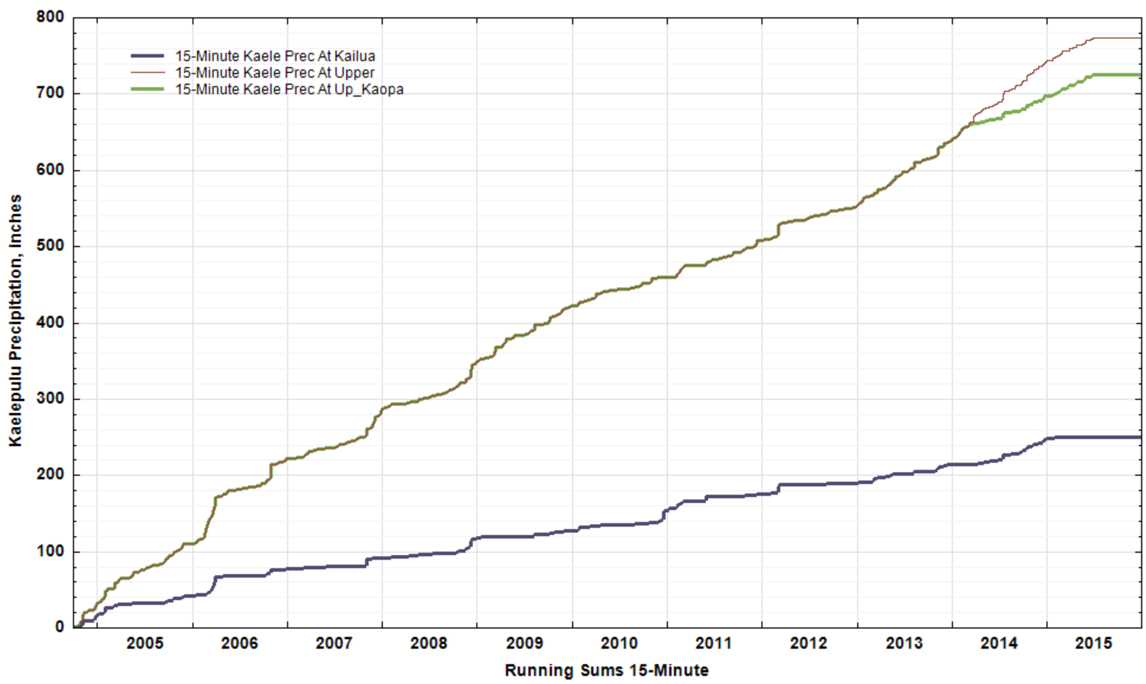
The period of record accessible from the National Climate Data Center at the time of this report for each of the precipitation gages ended in July 2013. In order to extent the precipitation record the National Weather Service (NWS) Hydronet data for the Maunawili/Makawao gage was used. The Kailua Fire Station is not part of the NWS Hydronet, so the time series was supplemented with Olomana Fire Station.

Figure 3-4. NRCS Soil Map for the Kaʻelepulu Pond Watershed



As part of the WQ sampling effort, two precipitation recorders where installed, one at the Kaopa location and one at the Keolu location. The collected rainfall data for these two started in April 2014 and extended to through the last sampling effort, February 3, 2015. For the HSPF model precipitation gages, the Kaopa rainfall data was incorporated in the Upper HSPF time series and the Keolu was used in the Kailua Fire Station. Figure 3-5 shows the running precipitation totals for the precipitation gages used in the Ka‘elepulu Pond HSPF model. The Up_Kaopa gage was used in the modeling but the Upper gage is included to illustrate the difference in rainfall recorded at the Kaopa site and Maunawili/Makawao site.

Figure 3-5. Precipitation Totals for the Ka‘elepulu Study Rain Gages



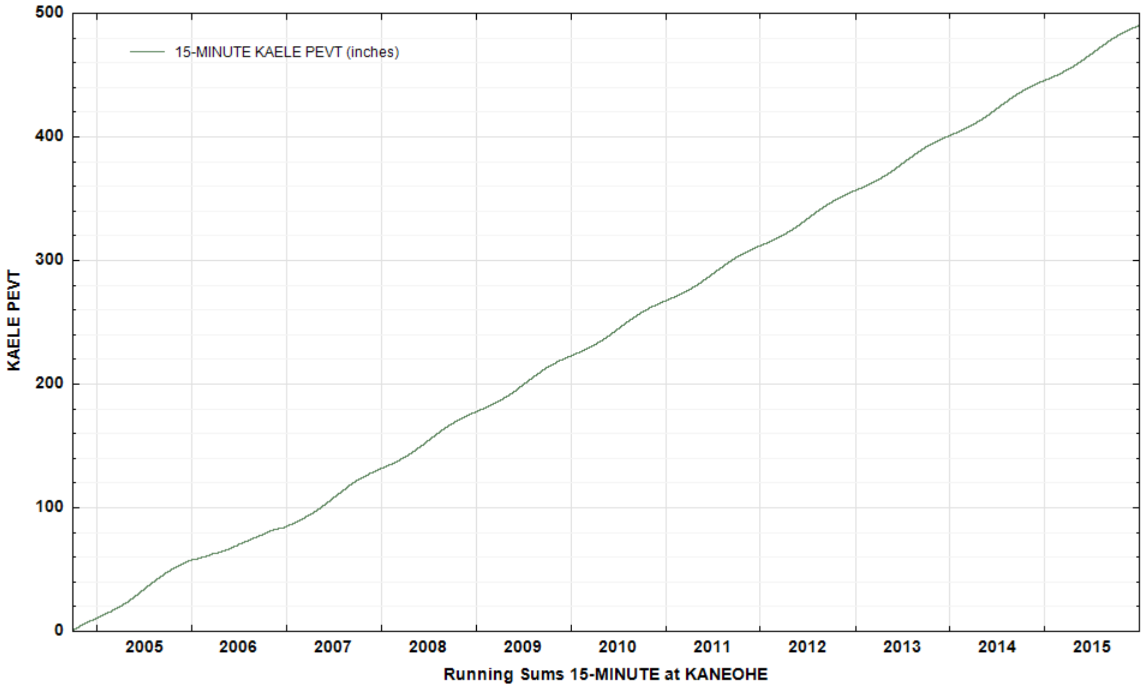
3.4.2 Evapotranspiration Data

ET is the water loss within the hydrologic cycle associated with vegetation uptake and moisture evaporation from soil storage. ET is generally estimated using physical measurements of pan evaporation or calculated using other meteorological relationships based on temperature, wind, and solar radiation. Hourly datasets for measured ET were not available in the Ka‘elepulu study area. Because of the lack of hourly ET datasets within the project area, the U.S. Environmental Protection Agency (EPA) meteorological database developed for use with the Better Assessment Science Integrating Point and Non-point Sources (BASINS) modeling package (which HSPF is part of) was used.

The EPA database includes hourly meteorological data such as, precipitation and temperature for the Kaneohe Bay Marine Corps Air Station (Identification [ID] 911760). The data also included potential ET (PEVT) which is recommended as a more appropriate input parameter for HSPF (EPA 2001). PEVT is the estimated ET that would occur is moisture in the soil was unlimited. The hourly EPA data set had a period of record from 1995-2009. For the Ka‘elepulu HSPF the simulation period is through February 2015 so the PEVT time series needed to be extended.

Using the 14 years of PEVT data, a continuous hourly time series was created using the average time increment values over the entire EPA time series. Figure 3-6 illustrates the resulting running summation of the PEVT time series used in the HSPF modeling effort. The relatively straight line in the figure illustrates the simulated PEVT is relatively consist through the year. On an hourly time scale, the PEVT is highest during the summer months and lowest during the winter months.

Figure 3-6. Running PEVT Totals for Kaneohe Bay Station



4 HSPF MODEL DEVELOPMENT

4.1 Pervious and Impervious Land Uses

Using the datasets described in Section 3, the input parameters for the Kaʻelepulu Pond watershed HSPF model were developed. The HSPF modeling approach was based on using land segments to describe areas of similar hydrologic properties. The land segments describe both pervious areas and impervious areas, commonly referred to in HSPF as Perlands (PERLND) and Imperlands (IMPLND), respectively. Surface runoff, interflow, and groundwater flow are modeled in HSPF with the accumulated flow resulting from rainfall events being conveyed downstream through a watershed using a series of channel reaches. The hydraulic characteristics (stage vs. storage) of each channel reach are generalized into a relationship defined by flow rate, water surface elevation, and storage volume. Table 4-1 lists the relationships between the project datasets and the HSPF model parameters. The soils data describe the ability of the surface to infiltrate precipitation, the volume of infiltrated rain that can be stored in the layers of soils, and the rate at which water is released as base flow.

Table 4-1. Relationship Between Datasets and HSPF Model Parameters

Dataset	HSPF Parameters and How Each Is Used in the Model
Land Use/Land Cover	PERLND/IMPLND designation, distribution of area within the watershed
Soils	Hydrologic Parameters: LZSN, UZSN, INFILT, SLSUR
Precipitation	Input driver for the model resulting in runoff, storage in the model
ET	Removes stored moisture from the system
Stream Flow	Calibration of hydrologic parameters

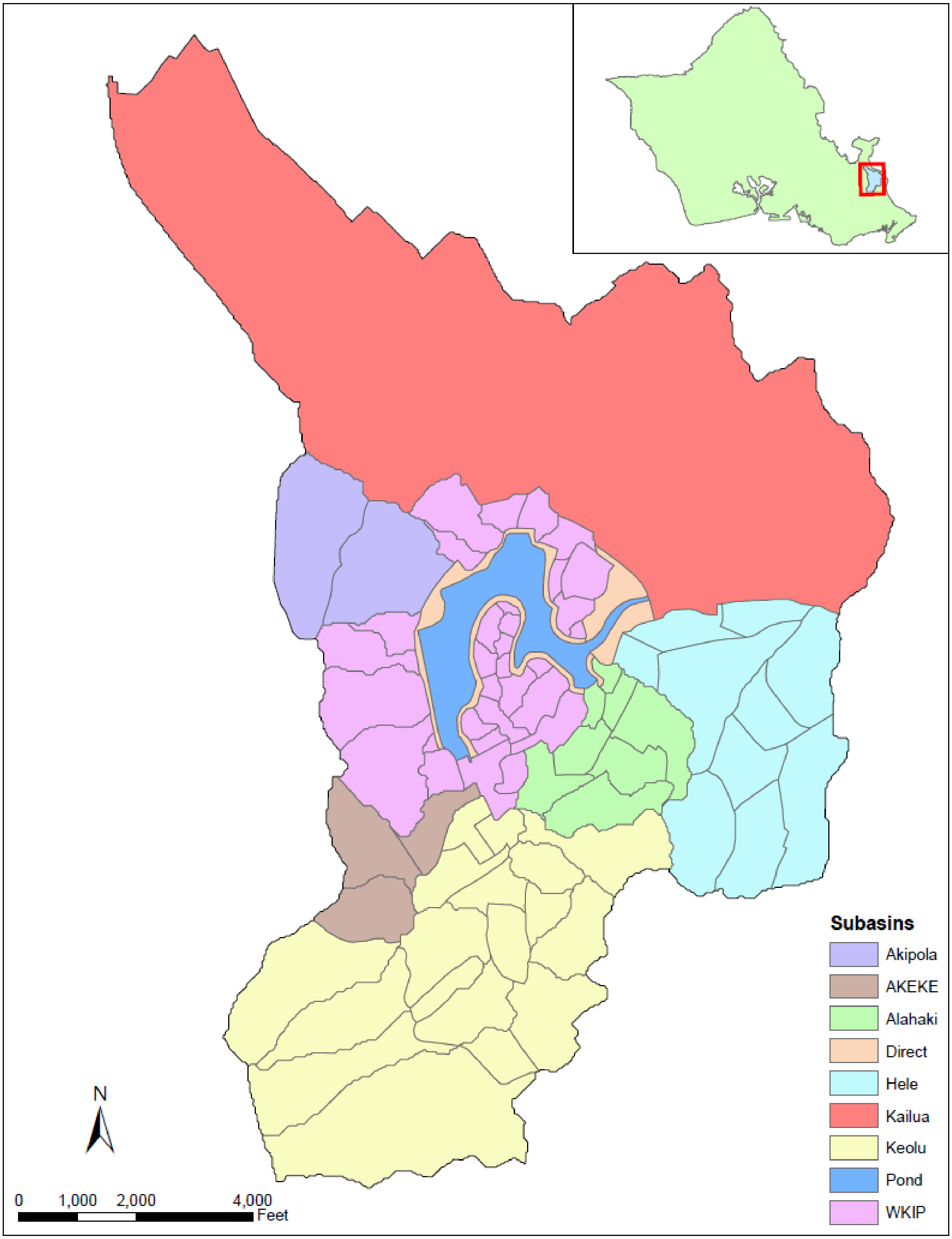
SLSUR slope of land surface

4.2 Subbasin Delineation

The subbasin delineation was conducted using topographic data for the study area based on concentration points, taking into account stormwater conveyance systems and roadways. In general, the location of the concentration points included confluences of tributaries, locations of infrastructure (road crossings), and locations of WQ sampling. Using the concentration points, an automated subbasin delineation process was conducted. The automated delineation process was done using a watershed delineator tool included in the EPA BASINS program. Additional refinements to the subbasin delineation were conducted manually in GIS. These refinements typically were conducted to provide minor boundary edits or sub-divide a larger subbasin.

The 76 subbasins were individually named based on their location with the watershed and discharge point into the pond such as: Hele Channel, Akipola Channel, and Keolu Channel. All the subbasins that discharge directly into the pond were identified based on the outfall ID. The subbasin IDs include two letters based on the subbasin grouping and numbers increasing upstream. If multiple subbasins combine into a single subbasin, the upstream subbasins were assigned a letter starting with A. Figure 4-1 illustrates the major subbasin locations developed for the Kaʻelepulu project along with the drainage area associated with each. The Kailua Basin, which does not directly discharge in to the pond is very flat and delineating subbasins was not easily accomplished. The Kailua area is not directly modeled in HSPF as the exact boundaries of where flows discharge are not known. The flows and loading from this area are based on calibrated loadings directly into Kaʻelepulu Pond.

Figure 4-1. Subbasin Delineation for the Ka‘elepulu Pond Watershed



4.3 Pervious and Impervious Land Area Parameter Development

The designated groups of hydrologic characteristics in the HSPF model are further defined as either pervious or impervious land segments, using modeling parameters termed PERLND and IMPLND, respectively. The definition of a PERLND is entirely dependent on the data available and the modeling needs and goals of the user. For example, pervious and impervious surfaces can be divided into as many or as few types as desired. The Kaʻelepulu Pond modeling effort used land use/land cover, slope, and location within the watershed to define the PERLND and IMPLND categories.

Within HSPF, the numeric designations of PERLND and IMPLND are limited to three digits. To allow for generation of consistent designations of PERLND, a numbering convention was developed that incorporated the slope, land use, and contributing precipitation gage. For IMPLND only land use and location was used. For a given PERLND the slope designation would contribute the PERLND numeric designation in the hundreds place, land use would occupy the tens place, and the precipitation gage designation (location) would occupy the ones place. Using this approach, 55 PERLND were established. Table 4-2 lists the categories developed for the Kaʻelepulu Pond watershed project and the numeric values associated with each classification. For modeling, the Cultivated Lands and Open Space Developed land uses were incorporated into the same PERLND designations.

Table 4-2. PERLND Classification Categories and Associated Numeric Values

CCAP Land Use	PERLND Designations
Bare Lands	161, 261, 361, 362, 461, 462
Cultivated Lands	134, 434
Evergreen Forest	141, 142, 241, 242, 341, 342, 441, 442
Grassland	131, 132, 232, 331, 332, 431, 432
Open Space Developed	133, 134, 233, 234, 333, 334, 433, 434
Emergent Wetland	194, 391, 491
Forested Wetland	193, 393, 493
Scrub/Shrub Wetland	195
R-10 Residential	181
R-5 Residential	183, 283, 383, 483
R-7.5 Residential	185, 186, 285, 385, 485
Scrub/Shrub	171, 172, 271, 272, 371, 372, 471, 472
Unconsolidated Shore	111

For the PERLND designations shown in Table 4-2, odd numbers are PERLND assigned to the Kailua Fire Station precipitation gage and even numbers are assigned to Maunawili precipitation gage. The 100-400 values are related to soil slopes with 100 being flat and 400 being extremely steep.

Once the PERLND designations were completed, the initial hydrologic parameters for each were estimated using the soil depths, INFILTs, and moisture storage capacity of the soils provided in the NRCS soil database. Using past experiences in developing HSPF models in Hawaii and the Pacific Northwest, initial hydrologic values were developed related to the soil properties found in the NRCS data. The initial soil parameters were estimated based on weighted averages for all the soils found within each PERLND. The initial UZSN and LZSN values were estimated based on the layer thickness and the corresponding water storage capacity in the NRCS data. The initial INFILTs were based on permeability values from the NRCS. This approach has been found to provide reasonable starting values that may require adjusting during calibration.

The key initial HSPF parameters estimated in this manner were UZSN, LZSN, and INFILT. These parameters are important in determining whether precipitation enters the soil column or results in surface water runoff. The weighted average for all soils associated with each PERLND took into account, and is based on, the relative areas of each soil, with more abundant soils having a proportionally greater influence on the hydrologic properties. Based on the distribution of the soils in the PERLND, the weighted average INFILT, UZSN, and LZSN initial values were estimated.

For the IMPLND classifications, the impervious surface GIS coverage was combined with the land use dataset. Also included in the IMPLND classification is the whether the IMPLND will be assigned the Upper or Kailua rain gage (Figure 3-5). This approach establishes the areal extent of impervious surface based on land use. The information presented in Table 4-3 illustrates the potential IMPLND classifications determined using this approach.

Table 4-3. IMPLND Classification Categories and Associated Numeric Values

IMPLND Land Use Classification	IMPLND Designations
Church Roofs	23
Commercial Roofs	24
Fire Station Roofs	25
Golf Course Facility Roofs	26
HDOT Maintenance Roofs	27
Highway (Kalanianaole)	11, 12
Jail Facility Roofs	28
Multi-Family Roofs	29
Open Water	99
Parking Lot	41
Public Recreation Facility Roofs	43
School Roofs	44, 45
Single Family Roofs	21, 22
Streets	31, 32
CCAP Impervious Surface	13, 14

4.4 Reach Reservoirs

HSPF uses PERLND and IMPLND together to represent the hydrologic characteristics within a watershed. This model estimates the amount of flow resulting from a storm event that will enter into a channel and be conveyed downstream through the watershed using a model element called a reach reservoir (RCHRES). The RCHRES describes the hydraulic character of the flow conveyance in each subbasin, such as slope and length of the channel. The hydraulic flow capacity and storage (stage – storage relationship) for each RCHRES is represented in the HSPF using Function Tables (FTables).

FTables are used within HSPF to model flow conveyance through a stream channel reach as well as in channel and overbank storage. The FTable provides a generalized description of the hydraulic character of a river reach or reservoir (RCHRES) segment by defining the functional relationship between water depth, surface area, water volume, and outflow in the segment. The FTable has columns for depth, surface area, volume, and outflow with each row containing values corresponding to a specified water depth (EPA 2007). Initial FTables for each of the RCHRESs were developed in the EPA BASINS Program (EPA 2015a). This process uses terrain data to estimate channel slope and length. Based on drainage area, general regional relationships were used to estimate stream channel geometry leading to the development of the FTables. For subbasins with piped conveyance, the FTables were generated using the HSPF Webtools.

The FTable representing the Kapaa silt basin was based on information from available information including geo-referenced aerial photography and site reconnaissance data. There are limited information related actual design calculations and drawings for the facility. The FTable is designed to simulate the storage capacity of the facility as well as the attenuation capability of the site during larger storm events.

5 HSPF MODEL CALIBRATION

5.1 Overview

Calibration and validation of a continuous simulation hydrologic model refers to fine-tuning parameters so that the resulting modeled hydrologic parameter such as flow resembles recorded records at the same location within the study area for the same time. For most watershed models, calibration is an iterative procedure of parameter evaluation and refinements, as a result of comparing simulated and observed values of interest. Model validation is an extension of the calibration process (Donigian, Jr. 2002). For the Kaʻelepulu Pond watershed model calibration will be carried out first for stream flows and then for the WQ parameters TSS, TN and TP.

Although conducted over a simulation period with varying seasonal precipitation and ET, calibration is based on a “snapshot” of the land use and land cover conditions of a watershed for a given date. Assuming a static distribution of land uses throughout the simulation period may impact calibration efforts by under- or overestimating the distribution of pervious and impervious land surfaces. When calibrating, changes within a watershed are considered, particularly in areas of recent development. If the models continually over- or underestimate flow peaks and volumes, then issues related to possible land use changes within the watershed may need to be investigated to determine if these changes explain the modeling results.

For the Kaʻelepulu HSPF modeling effort, adequate continuous flow records were not available. With no long term flow data available for Kaʻelepulu Pond, neighboring watersheds where flow data did exist were investigated. It was assumed that adjacent watersheds with similar hydrologic properties such as topography, soils, and land use would produce similar, scalable hydrologic responses to precipitation. Using surrogate watersheds with similar hydrologic properties is a common practice. The approach is referred to as “paired watershed approach” (EPA 1993). Typically, the approach involves developing a calibrated/validated model of the gaged watershed and then using the refined hydrologic parameter values as inputs to the ungaged watershed.

A review of neighboring watersheds found that Makawao Stream in the Maunawili watershed maintained a USGS flow gage. The Makawao Stream is located just on the other side of Mt Olomana from the Kaʻelepulu watershed. Table 5-1 identifies the USGS gage information. The Makawao Stream watershed is similar to the upper Kaʻelepulu Pond watershed, comprised of mostly forested area. Because of the watershed similarities with relation to forested cover and precipitation as well as proximity to each other, it was assumed that hydrologic parameters calibrated in the Makawao Stream watershed should be transferable to the Kaʻelepulu Pond upper watershed.

Table 5-1. USGS Gages Used for Kaʻelepulu Pond HSPF Validation

USGS Gage Name	USGS Gage ID	Drainage Area (square miles)	Mean Annual Precipitation
Makawao Stream near Kailua, Oahu	16254000	2.03	80.6 inches

5.2 Balancing Flow Volume

Typically, balancing the annual and seasonal flow volume based on gains and losses in the watershed is the first step in calibrating an HSPF hydrologic model. Losses within the watershed are typically related to diversions, ET, and deep percolation groundwater recharge. The Makawao watershed contains a small irrigation diversion. The Kaʻelepulu watershed does not contain an active diversion so all losses will be attributed to groundwater aquifer recharge and ET. Using the approach outlined in BASINS/HSPF

Training Exercise 6 (EPA 2000), the model parameters associated with the water volumes were adjusted to provide comparable flow volumes. This typically involves adjusting the fraction of flow lost to deep recharge and the upper and lower zone storage volume (UZSN and LZSN respectively). The two storage parameter impact the volume of water available for plants to use and soil evaporation. The results are provided in Table 5-2. The water years shown were selected because they provide the greatest number of data points (most complete) in the data meteorological and flow data set.

Table 5-2. Comparison of the Makawao Stream Gaged and HSPF Flows for Annual and Seasonal Flow Volumes

	Annual Volume, acre-feet		Seasonal Volumes, acre-feet			
			Wet Season		Dry Season	
Water Year	**2009**	**2010**	**2009**	**2010**	**2009**	**2010**
Makawao Gage	3702	2312	2528	1743	1174	569
HSPF Model	4090	2201	2882	1639	1208	562
% diff	+10.5%	-4.8%	+14.0%	-6.0%	2.9%	-1.3%
Total Precipitation	**85.9**	**50.9**	**65.2**	**40.9**	**20.7**	**10.0**

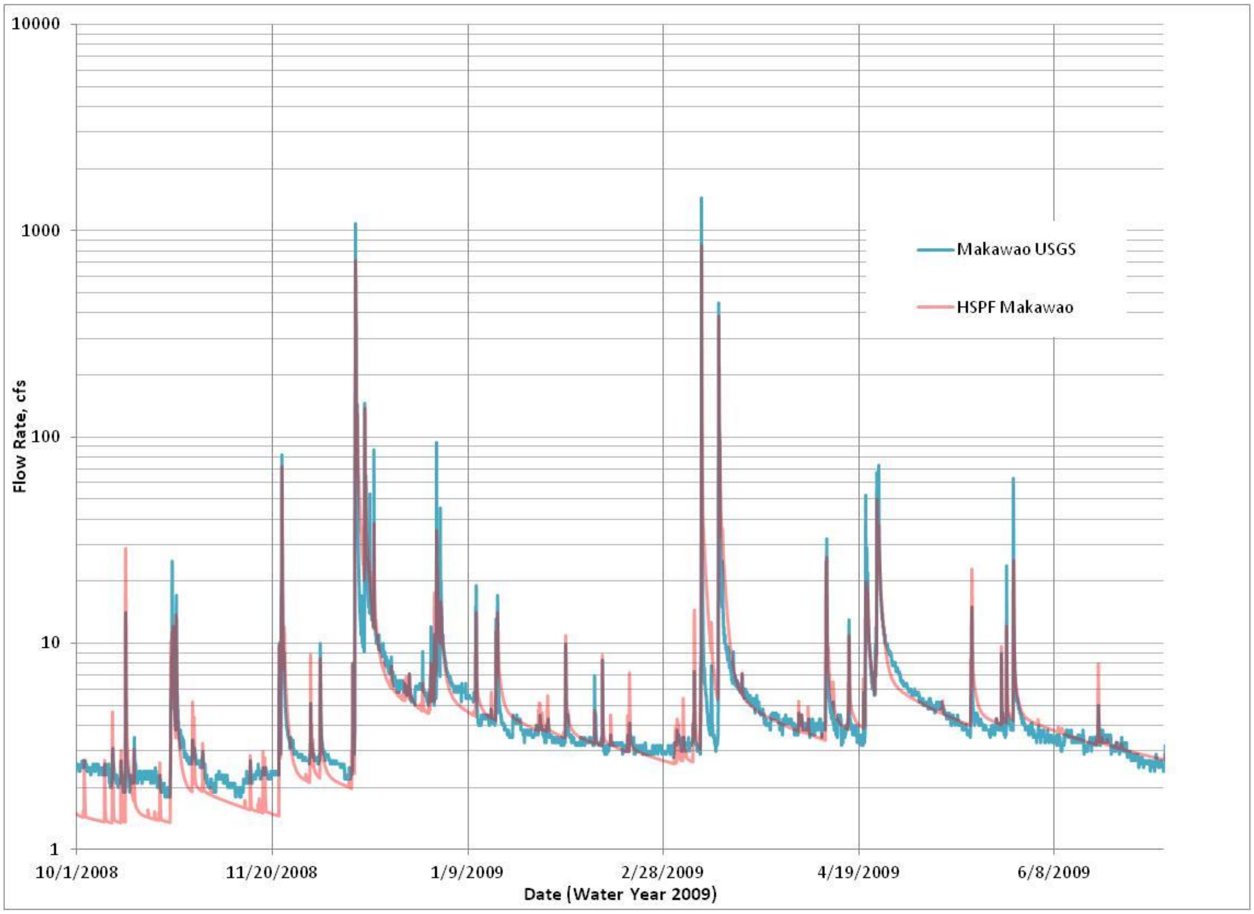
HSPF workshops conducted by EPA suggest that a percent difference under 10 percent is very good, 10 to 15 percent is considered good, and 15 to 25 percent is fair. These values are based on annual and monthly flow volume estimation and typically reference calibrated models. The Makawao HSPF model flow volume calibration is based on 15 minute data intervals.

5.3 Comparing Hydrograph Shape

Following the flow volumes comparison effort, the next step in HSPF is to adjust model parameters to reproduce hydrograph peaks and shape. Typically, these model adjustments focus on the INFILT and the recession curve coefficients associated with interflow and base flow. In each case where a parameter was modified, the reduction was applied to all PERLND. This means that if the INFILT was assumed to be too high, all the PERLND infiltration values were reduced by the same factor. This methodology has been used multiple times by the project modelers for calibration efforts and has proven to be a reliable approach.

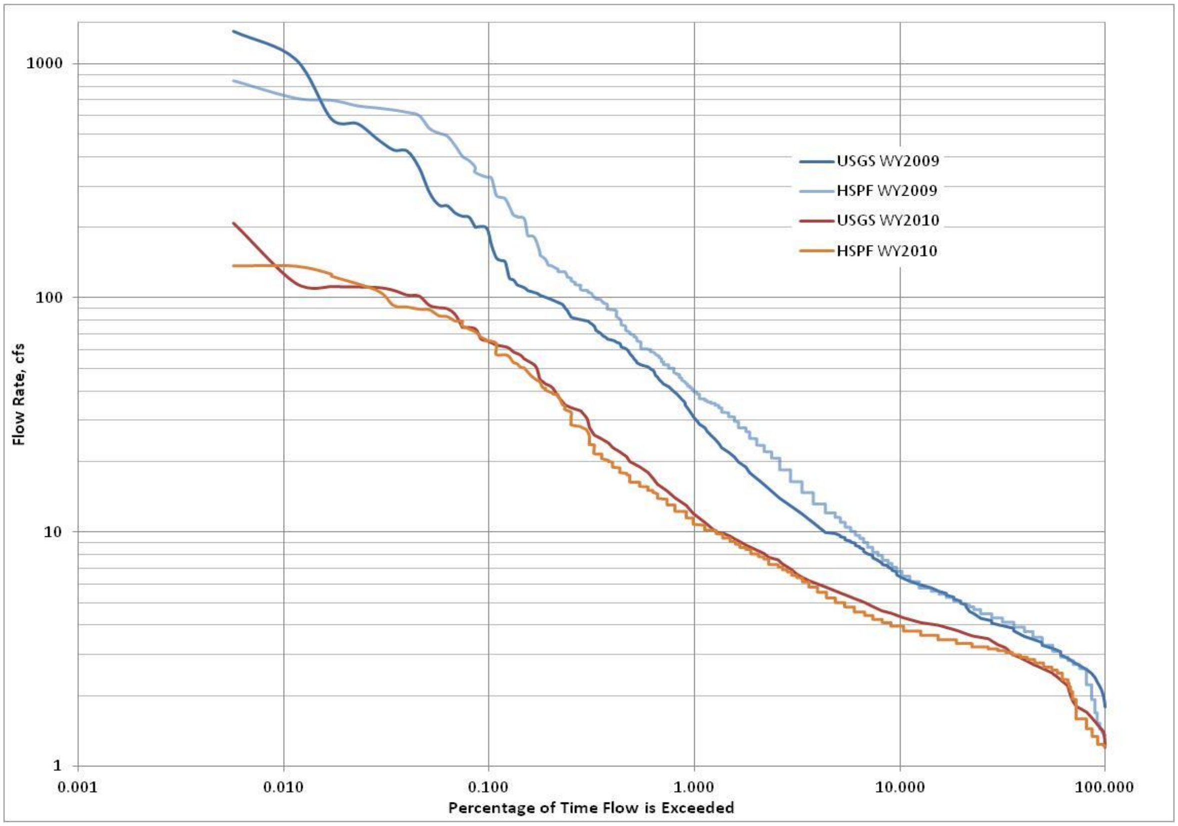
As the hydrographs in Figure 4-1 show, the Makawao HSPF result provides similar hydrograph peak timing and recession limb shapes. The Maunawili precipitation gage is located in the middle of the watershed and may not provide for the higher precipitation found in the upper peaks of the Pali. The result is the HSPF model does not always calibrate to the flow peaks associated with larger flow events.

Figure 5-1. Flow Hydrographs for Water Year 2003



Validation of the Makawao HSPF model was conducted by comparing the flow duration curves for the Makawao watershed. A flow duration curve is used to illustrate the distribution of flows at a location for a given period of time. For this analysis the 2009 and 2010 water years were used. The duration curves shown in Figure 5-2 duration illustrate the HSPF model simulates similar flow characteristics to the USGS flow gage.

Figure 5-2. Flow Duration Curves for Water Years 2009 and 2010



The procedures used to calibrate the Makawao watershed HSPF model were used to refine the initial hydrologic parameters. As the Makawao watershed is not as developed as the Ka‘elepulu watershed additional calibration and validation may be required, particularly related to residential land uses. The continued hydrologic calibration for the Ka‘elepulu watershed is detailed in the following sections.

5.4 Ka‘elepulu Watershed Flow Calibration and Validation

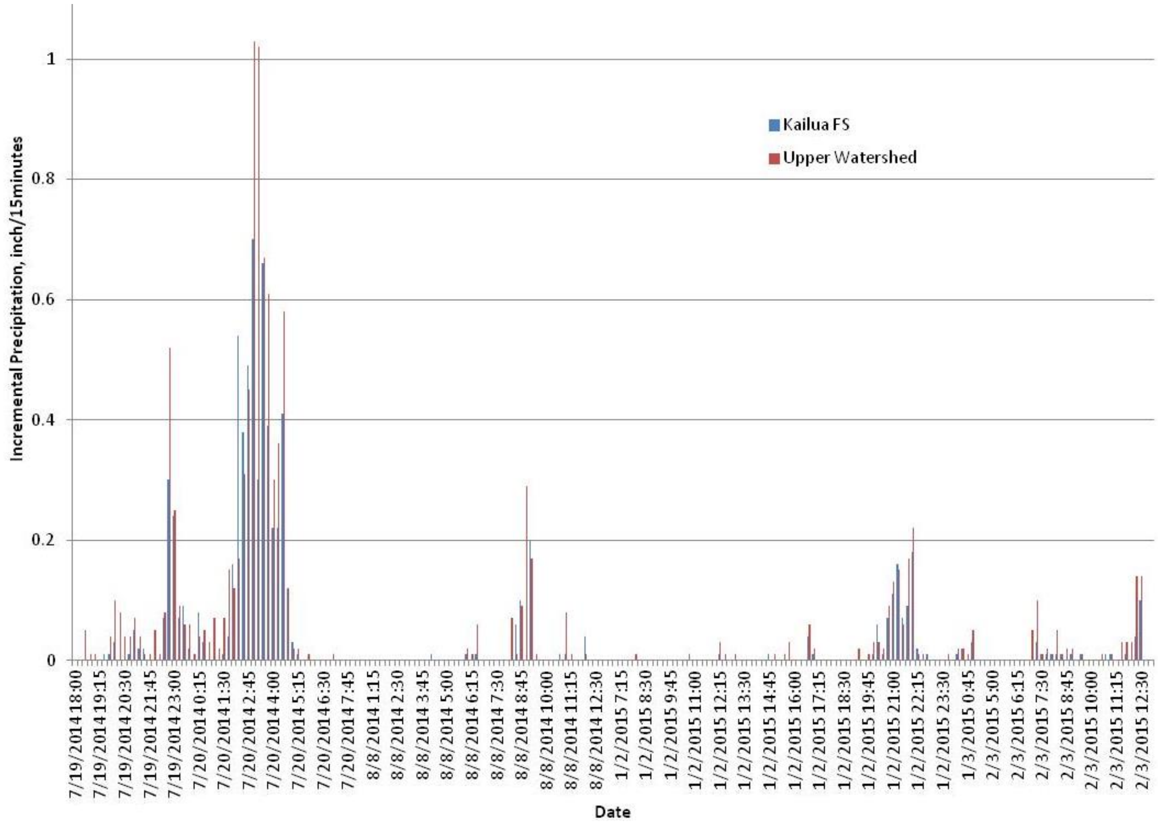
The approaches described for calibrating and validating the Makawao HSPF model were used to create the initial Ka‘elepulu HSPF model parameters. Flow monitoring and WQ sampling were conducted at multiple locations in the watershed. Table 5-3 lists the monitoring locations as well as the HSPF model element identification for each of the sites. An additional sampling location on the Hamakua wetland was not included in the hydrologic model calibration because the flow sampling was impacted by backwater conditions in the wetlands. The locations of each of the sampling points are shown in Figure 2-1.

Table 5-3. HSPF Elements Designations for the Flow and Water Quality Sampling Locations

Flow Gage/WQ Sampling Site	HSPF RCHRES	RCHRES ID
Aleka Place	KE3D1	336
Kaopa Lined Channel	KE3A	331
Akipola Concrete Channel	AK1	101
Keolu Lined Channel	KE1	301
Hele Channel	HE2	502

Calibrating the Ka'elepulu HSPF models was limited to storm events that provided flow data and also WQ concentrations. The WQ sampling and flow hydrographs were generally recorded for four storm events from July 2014 through early February 2015. Figure 5-3 illustrates the recorded rainfall at the two precipitation gages associated with the modeling effort. As expected the upper precipitation gage recoded higher peak intensity and overall storm event volume. The recorded events also provided a range of watershed responses based on having a larger event and three smaller events.

Figure 5-3. Precipitation Hyetographs during the Water Quality Sampling Period.



The land use associated with each of the flow gage locations allows for a systematic approach to calibration. The Aleka Place gage is predominately forested, similar to the Makawao location, so calibration of the Ka'elepulu HSPF model starts with that location. Table 5-4 listed the general land uses associated with each of the calibration points. The calibration process was carried out in the order the locations are presented in the Table 5-3, which basically is working from the upper watershed to the lower watershed. Once an HSPF parameter was calibrated in the previous sampling locations, that parameter was no readjusted in subsequent calibration points.

5.4.1 Aleka Place

The approximately 75 acres of tributary area to the flow gage is mostly forested with steep terrain. Field reconnaissance found the watershed to be in good conditions. Transmission losses, where flows in the channel are infiltrated into the underlying ground not reaching the flow monitoring location, were identified during field reconnaissance efforts. Based on the recorded data, calibration of the HSPF model at the Aleka Place (HSPF ID 336) flow gage was limited as only one flow event during the sampling period, July 20, 2014. Due to natural condition of the Aleka Place drainage area, it is assumed the smaller events did not created runoff in the watershed.

Table 5-4. Land Use for Sampling Locations

General Land Use	Aleka	Kaopa	Akipola	Keolu	Hele
Bare Land				1.33	
CCAP	0.1	3.41	1.2	9.53	1.15
Emergent Wetland				3.02	
Forest	74.44	62.43	14.26	398.1	2.01
Forest Wetland		0.3		7.21	
Grassland		0.04		1.29	6.29
Highway		2.69		10.08	
Open Space Dev	0.05	1.28	0.88	8.37	0.45
Parking Lot			1.12	2.81	0.92
Residential 5		5.6	62.09	94.39	17.33
Residential 7.5					92.67
Non-Res Roof			12.78	1.17	0.38
Scrub/Shrub		3.57	43.78	38.73	47.77
Residential Roof		3.19		37.14	64.4
Streets	0.28	3.34	7.89	29.71	41.45
Wetland				3.44	
Grand Total	**74.87**	**85.85**	**144**	**646.32**	**274.82**

As shown in Figure B-1, the recorded flows associated with the watershed's response only occurred for a relatively short period, approximately 1-hour. The HSPF model was able to reduce the modeled flow peaks to approximately 0.40 cubic foot per second but it could not simulate the rapid change in flows. The impact of the calibration at Aleka Place will not impact the validity of the modeling results as the majority of the flows and pollutants are generated in the lower watershed and the volume of runoff generated in the upper natural areas is small.

5.4.2 Kaopa Lined Channel

The Kaopa lined channel location is adjacent to the Aleka Place watershed. The Kaopa site is also forested, natural area in the upper watershed, but the lower portion adds some residential areas. Because of the impervious areas associated with the developed areas, the Kaopa location recorded flows for all four storm events. As with the Aleka Place location, the HSPF calibration effort required using channel losses to replicate the infiltration in the upper watershed while taking into account the impervious surface generated runoff.

As the Figures B-2a through B-2d illustrate, the HSPF modeling results provide similar flow peak responses but also provide for greater flow volumes. It is likely the channel losses in the upper watershed are greater than the model was able to simulate. For the February 2015 storm event, the HSPF model did not reproduce the recorded flow peaks. It is likely the recorded rainfall used in the modeling of this particular event did not accurately represent the rainfall experiences in the watershed.

5.4.3 Akipola Concrete Channel

The Akipola sampling location includes increased impervious area, therefore the recorded and modeled stormwater responses to precipitation are greater in magnitude. As the series of hydrographs shown in Figures B-3a through B-3d illustrate, the HSPF model resulted in a range of flows similar to the recorded flows. The shape and timing of the modeled hydrographs represent a good simulation of recorded watershed response.

As with the all the sampling locations, the distribution of precipitation in the HSPF modeling effort is based on two locations. Due to the local variations the HSPF model misses some stormwater runoff events such as shown in Figure B-3d. It can be assumed that throughout the simulation period the variation of precipitation across the Kaelepulu watershed will balance itself out so the overall volumes of runoff are reasonable.

5.4.4 Keolu Channel

The Keolu channel recorded data appears to have an issue. As shown in Figure B-4a through B-4d, only the September 2014 event recorded significant flows. For this event, the HSPF model simulated similar peak flows and overall runoff volume. The HSPF hydrograph is translated approximately 2 hours earlier than the recorded flows. This could be an error in the recording device set up or perhaps the distribution of rainfall in the study area.

For the other three events the recorded flows appears to be under represented. It is likely that the sampler malfunctioned during these events as the watershed responses should be similar to the Akipola site but with larger peaks. Because of this issue the modeling calibration had to focus on just the September 2014 event.

5.4.5 Hele Channel

The Hele channel sampling site is mostly developed with residential land uses. The HSPF modeling results shown in Figures B-5a through B-5d compare well to the recorded storm responses. For the 4 sampled storm events the HSPF simulated flow peaks and hydrograph shapes well.

One issue with the Hele Channel site involves “noise” in the recorded data. As illustrates in the recorded data for the two 2015 events, there are recorded flows that are not simulated by the HSPF model. It is assumed the recorded flows occurring before and after the flow peaks are associated with backwater conditions at the sampling site. The data recorded only collects water level readings which are then converts to flows based on a determined relationship. It is assumed the water level recording are reflecting back water conditions within the pond that inundated the sampling site.

5.5 Hydrologic Model Result Discussion

As mentioned above, the HSPF model is considered to provide reasonable simulations of the rainfall-runoff in the Kaelepulu Pond watershed. With limited recorded data as well as the potential for the data to be inaccurate, calibration of the model was limited. The model results shown in Appendix B illustrate the HSPF model can simulate a range a watershed responses representative of the variable land uses in the study area. The variability of the modeled results compared to the recorded data also reflects the effect of Hawaiian micro-climates.

The Island of Oahu, as well as the other Hawaiian Islands is comprised of multiple micro-climates. Steep terrain, narrow stream valleys, and variable winds, create areas of differing climates within close proximity to each other. Tropical forests are found in watershed next to areas with cacti, reflecting the different climates and precipitation. Due to the potentially high variability in precipitation across the Kaʻelepulu Pond watershed, the use of only two precipitation gages might not accurately represent the distribution of rainfall. This issue is illustrated in the how the HSPF calibration results compared to recorded flows. As shown in the calibration hydrograph in Appendix B, the recorded flows do not always show up in the modeled flows, or the volume of precipitation applied in the model is not capable of generating the flow peaks or volumes recorded.

One an individual storm basis this may be result in under or over estimating flows and potentially pollutants, but it must be understood that for every storm that is under represented during the year by a particular rain gage, there is a storm that is over estimated. So for an extended duration simulation the annual average annual results are likely representative of the actual study area.

6 WATER QUALITY MODEL PARAMETER DEVELOPMENT AND CALIBRATION

6.1 Water Quality Modeling Overview

Once the hydrologic modeling was completed, the second step in the HSPF modeling effort was to calibrate the pollutant loading to the Kaʻelepulu Pond. Pollutant loading calibration was conducted based on the WQ sampling results presented in Table 2-2. The sampling locations used in the WQ calibration effort are listed along with the corresponding HSPF elements that represent the sampling locations in Table 5-3.

WQ modeling is understood to have a high predictive uncertainty (Stow et al. 2007). As WQ modeling loading and calibration is based on the calibrated HSPF flows, any uncertainty in the estimated flows impacts the ability of the model to estimate WQ parameter loading. In addition, WQ modeling does not have the ability to simulate random pollutant loading events, such as landslides or spills leading to potentially under estimating extreme loading events. Instead of matching loading peak during specific sampled storm events, the WQ model calibration attempts to recreate a range of loading similar to the multiple sampled storms.

6.2 Sediment Modeling

Within the Kaʻelepulu Pond watershed, stormwater runoff samples were collected and analyzed for total suspended solids (TSS). HSPF models suspended sediment concentration, which is commonly considered equivalent to TSS in HSPF studies (Martin, Zarriello, and Shipp 2001). For typical HSPF modeling of TSS, the two components of estimated sediment erosion includes sediment washoff processes associated with individual land uses and also channel erosion/deposition.

As most of the channels (RCHRES) modeled within the Kaʻelepulu Pond study area are either concrete channels or piped, channel erosion and deposition was considered negligible. Most of the natural channels in the study area are either in the upper watershed or are canals hydraulically connected to the pond itself. In the upper watershed the stream channels were found to be stable with no signs of considerable bank erosion or deposition. The canals typically appear to have stable vegetated banks, although some locations show minor erosion.

Within the Kaʻelepulu watershed, sediment erosion entering the pond was model in HSPF based on multiple processes associated with Pervious and Impervious land surfaces:

- Detachment of sediment from the soil matrix due to precipitation impact and splash.
- Removal the detached sediment from the land surface due to transport capacity of the sheet flow.
- Consolidation of detached material between rainfall events.
- Deposition/Removal of material from natural and man-caused sources.

In general, the modeling approach assumes an unlimited supply of soil with pervious surface. Impervious surface have a limited supply of sediment based on modeled accumulation rates between storm events. During rainfall events volume of soil particles are detached and made available for sheet flow erosion. If the volume of sheet is large enough all the detached material is removed. If the sheet flow capacity is less than the volume of material available, some of the detached material is left in place. Between rainfall events the detached material is re-compacted into the matrix. Additionally, detached material may be deposited naturally through wind energy. The naturally deposited material is assumed to remain as detached material until the next rainfall event where it is available as a source of sediment.

The initial TSS model parameters associated were estimated using numerous sources. The HSPF documentation (EPA 2015b) provided sediment parameter values for the following land uses: forest, urban, agriculture, barren land, and wetland. Where applicable, initial WQ modeling parameters were based on similar land use classifications such as forest or wetland. Scrub/shrub, grassland, and open space developed PERLND were assumed to have parameter values between forest and bare land values.

6.3 Sediment Calibration

The sediment calibration involved specific steps starting by comparing broad parameter and then refining to more specific results. The initial calibration step taken for the Ka‘elepulu HSPF model was the review of detached material available for transport during a rainfall event. In general, the accumulated soils with each of the pervious and impervious land surface should fluctuate depending on number of rainfall events and duration between them. Although there is a fluctuation, the long term trend should be neither continually increasing nor decreasing.

Once the initial estimated parameters were incorporated into the HSPF model, the model was run and the results to compared to the WQ sample values to determine how best to calibrate the model. Based on the initial comparison of simulated and sampled loadings, the appropriate sediment transport parameters were modified. The major parameters used to calibrate the volume of sediment in the HSPF model are shown in Table 6-1. As shown two parameters each are used for pervious and impervious land surfaces.

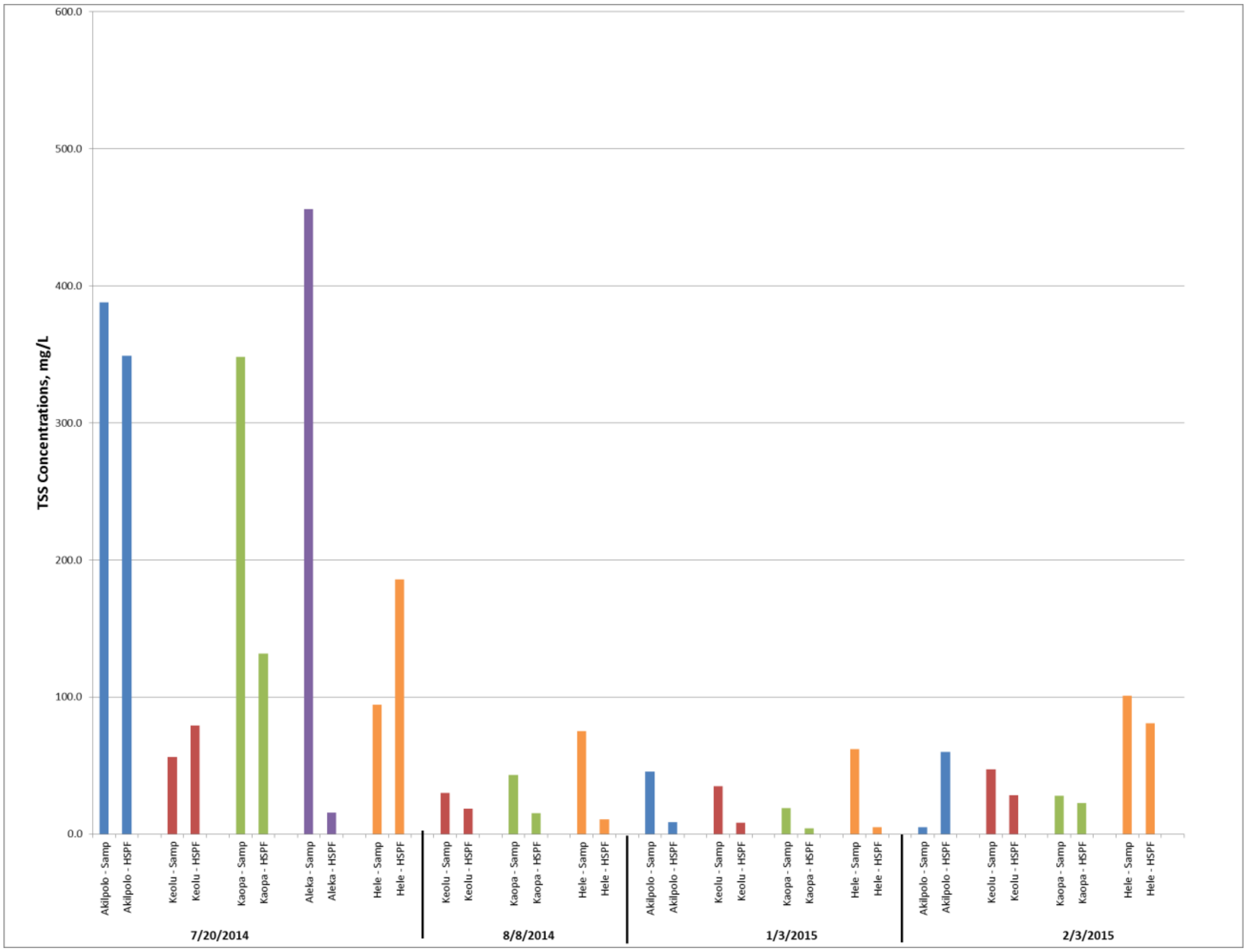
Table 6-1. Primary Sediment Erosion Parameters Used in Calibration

HSPF Parameter	Impacted Surface	Description	Typical Range of Values	
			Minimum	Maximum
KRER	Pervious Surface	Coefficient in Soil Detachment	0.15	0.45
KSER	Pervious Surface	Coefficient in Sediment Washoff	0.5	5.0
KEIM	Impervious Surface	Coefficient in Impervious Surface Washoff	0.5	5.0
ACCSDP	Impervious Surface	Accumulation Rate of Solids on Impervious Surface	0.0	2.0

The initial sediment modeling effort focused on calibrating to average annual loading based on land use. It is recommended to estimate target sediment loads for typical land uses (EPA 2015b). Target loading rates can vary widely, from 0.05 tons/ac/year for forested land to over 15 tons/ac/year for highly erodible land. Typical ranges of expected erosion rates for urban areas range from 0.2 to 1.0 tons/ac/year (Source: HSPF Lecture 10).

Through multiple WQ modeling calibration simulations the final TSS loadings for each of the sampled storms are shown in Figure 6-1.

Figure 6-1. TSS Modeling Calibration Results



The HSPF TSS modeling results in Figure 6-1 illustrates the variability of the WQ modeling. As the TSS results are correlated to the hydrology modeling, the variability found in the hydrology results controlled the TSS results. In conducting the calibration efforts, it was found, calibrating to the three smaller events severely over-estimated the TSS values for the larger events. The final model focused on finding a middle ground.

6.4 Nutrient Modeling

Generally, in HSPF nutrient model calibration occurs once sediment is reasonably modeled as some nutrients may adsorb to, and be highly correlated with sediment loading. Thus, uncertainty in sediment modeling can impact the ability to model nutrients. As shown in Table 2-2, along with sediment, the WQ sampling included:

- Ammonia Nitrogen
- Nitrate+Nitrite
- TP

The approach used for WQ modeling of nutrients within the Ka'elepulu HSPF model is based on a relationship between the WQ parameter and the surface runoff and/or sediment transport for each of the designated pervious and impervious land surfaces (PERLND/IMPLND). The volume of material in runoff for each of the WQ parameter is estimated based on accumulation rate of the parameter, the maximum storage volume for each and the washoff potency factor of the parameter during a surface runoff event.

For phosphorus loading from the landscape is usually particle related. It is simulated in the model based on a. As such, the quality of the phosphorus calibration is largely dependent on the sediment calibration. The TN loading from the landscape is simulated as ammonia and nitrate-nitrite. Nitrate-nitrite represents the oxidized inorganic nitrogen loads from the landscape and is represented as a buildup/washoff parameter on the land surface and is associated with groundwater and interflow. Unlike phosphorus, nitrate-nitrite is not simulated as sediment associated (sediment dependent) variable.

The approach to modeling nitrogen and phosphorus for Ka‘elepulu watershed was similar to the approach described in the Buffalo River Watershed HSPF Modeling (MPCA 2013) report. Initial modeling parameters required for each of the WQ parameters were based on available national dataset. The HSPF WQ parameters used in this Ka‘elepulu HSPF model effort were:

- The washoff potency factor (POTFW) for direct surface water washoff
- The scour potency factor (POTFS) associated with surface flow scour of the soil matrix
- Accumulation rate
- Maximum storage volume
- Rate of surface runoff that will remove 90 percent of the stored volume

The primary calibration parameters related to orthophosphate loading are POTFW and POTFS (the washoff/scour potency factors, which are the ratios of constituent yield to sediment (washoff or scour) outflow. Note that orthophosphate was only associated with sediment for pervious land, not impervious land. The calibration focused on achieving reasonable WQ concentration when compared to the sampling efforts within the study area. Figure 6-2 through Figure 6-4 illustrate the WQ parameters sampled results compared to the HSPF modeled results

Figure 6-2. Nitrate+Nitrite Modeling Results

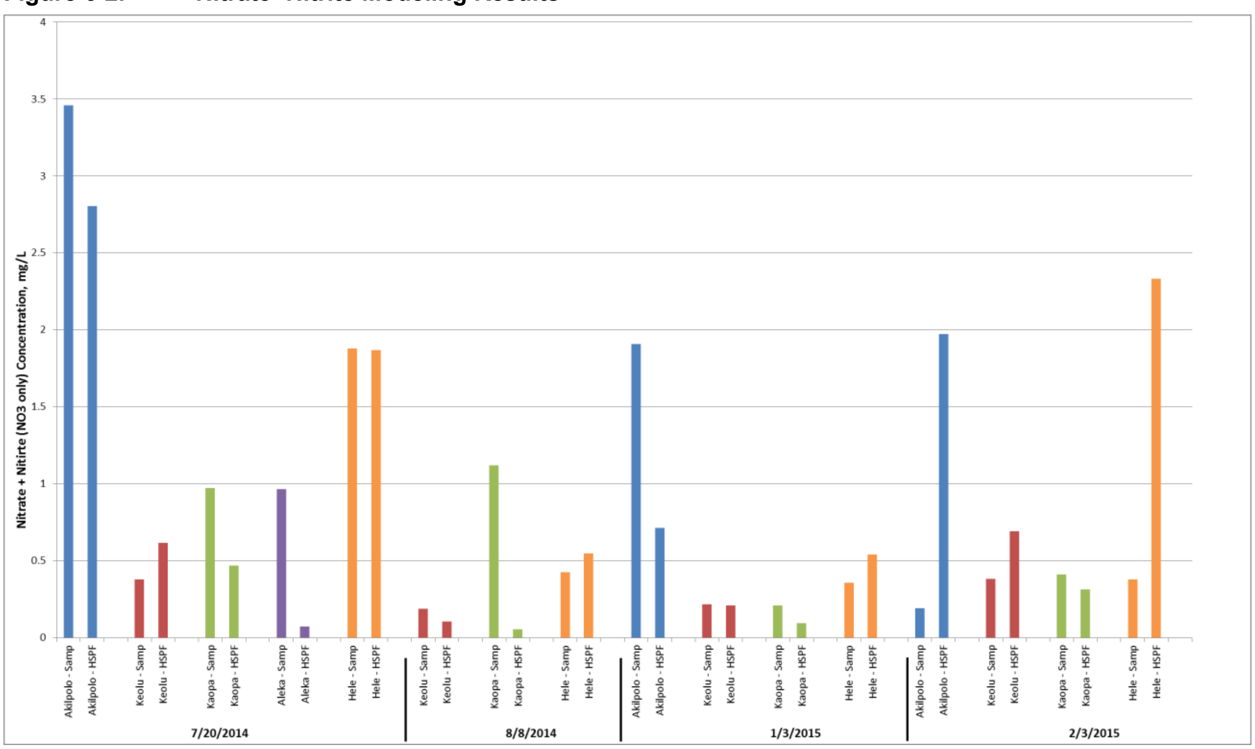


Figure 6-3. Ammonia Nitrogen Modeling Results

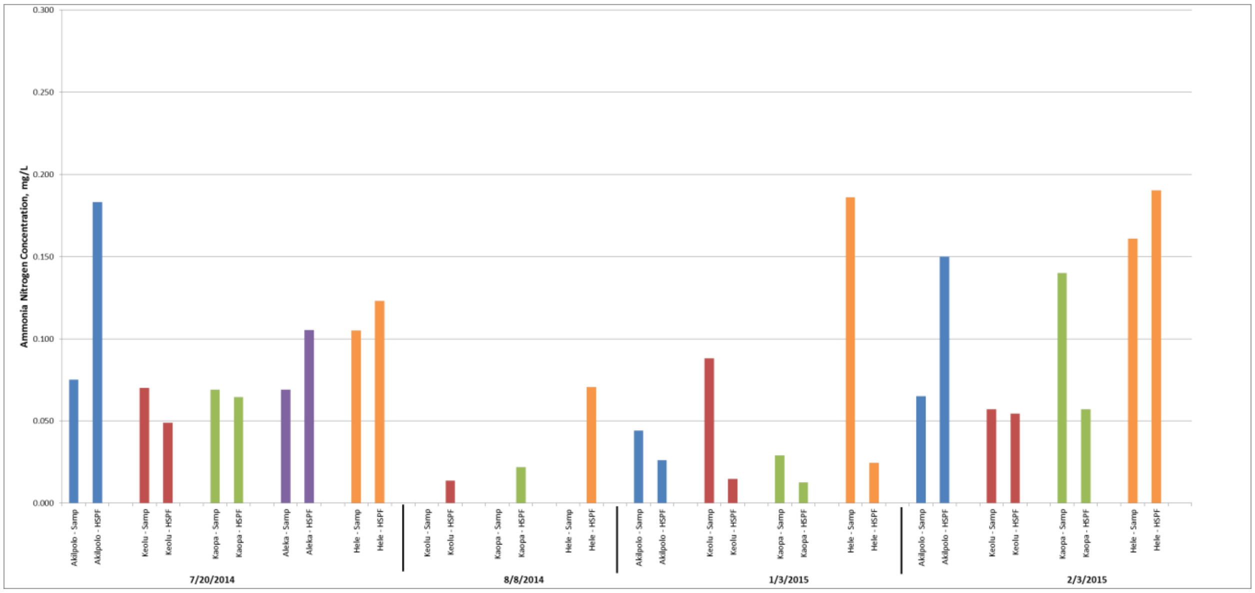
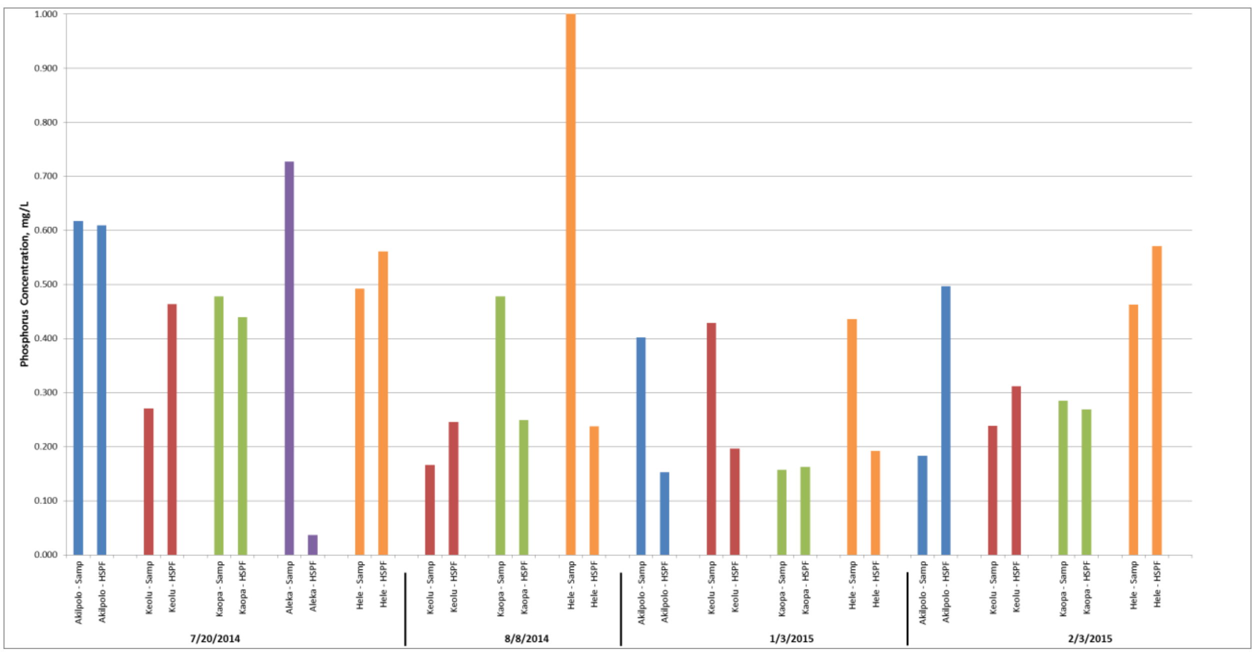


Figure 6-4. Total Phosphorus Modeling Results



The WQ modeling results illustrate a good calibration between the sampled and modeled values for most storm events and locations. Once again the variability in the results reflects both the margin of error with the hydrology as well as the margin of error with the sampling data. With any WQ sampling, there is the potential for specific sampling events to reflect one-time occurrences in the watershed such as a contaminant spill, which will not be reproducible with the HSPF model.

7 FLOWS AND POLLUTANT LOADING TO KAʻELEPULU POND

7.1 WQ Modeling Results

Following the calibration of the Kaʻelepulu HSPF model for both hydrology and pollutant loading, the model was used to estimate the annual pollutant loading to Kaʻelepulu Pond. Table 7-1 lists the estimated total volume of pollutants entering the pond for the water years (October 1 through September 30) listed.

Table 7-1. Kaʻelepulu Pond Loading Estimates from HSPF Model

Water Year	Annual Flow Volume (ac-ft)	Annual Pollutant Loading			
		TSS (tons)	Ammonia (lbs)	Nitrate (lbs)	Phosphorus (lbs)
2006	6,546	1,028	724	13,640	11,560
2007	1,954	134	348	2,489	931
2008	2,686	272	599	4,624	3,510
2009	4,095	536	566	7,191	5,416
2010	1,809	106	479	4,107	1,488
2011	4,935	636	746	12,900	9,327
2012	2,351	253	581	5,485	3,461
2013	1,944	68	348	2,798	1,107
2014	2,966	194	544	5,927	3,242
Average	**3,254**	**358**	**548**	**6,573**	**4,449**

Based on the estimated TSS loading volumes in Table 7-1, approximately 3,600 tons of sediment was discharged to Kaʻelepulu Pond during the 9 year simulation. Assuming a unit weight of 150 pounds per cubic foot, the sediment loading converts to approximately 175 cubic yards of material entering the pond. The values shown in Table 7-1 are only related to material discharging directly to the Kaʻelepulu Pond. The areas discharging the Kawai Nui channel and Kaʻelepulu Stream contribution are shown in Table 7-2.

Table 7-2. Loading Estimates from HSPF Model for Kaʻelepulu Stream and Kawai Nui Channel

Water Year	Annual Flow Volume (ac-ft)	Annual Pollutant Loading			
		TSS (tons)	Ammonia (lbs)	Nitrate (lbs)	Phosphorus (lbs)
2006	4,124	848	534	10,610	8,571
2007	956	3.3	337	2,012	589
2008	1,755	226	590	4,049	1,455
2009	2,589	324	511	5,760	2,511
2010	1,187	8.6	436	3,124	792
2011	4,073	608	692	10,930	4,532
2012	1,637	198	570	4,558	1,520
2013	1,273	4.8	367	2,839	842
2014	2,079	137	502	5,094	1,333
Average	**2,186**	**262**	**504**	**5,442**	**2,461**

Not only did the generation of pollutants fluctuate due to the volume of precipitation, but the distribution of the pollutants sources changed depending on the rainfall. Figure 7-1 through Figure 7-3 illustrate how the annual precipitation total impacts the sources of TSS. For wet years, such as 2006, the pervious surfaces contribute the largest percentage of the TSS. While for dry years, such as 2010, impervious surface contribute the largest percentage. This is due to the fact, in dry years a greater percentage of the total precipitation is infiltrated by pervious surfaces and also the increased precipitation exhausts the sediment supply from impervious surfaces. Figure 7-3, Water Year 2014, is provided to represent an average year based on runoff volume.

Figure 7-1. TSS Contribution by Land Use for Water Year 2006 – Wet Year

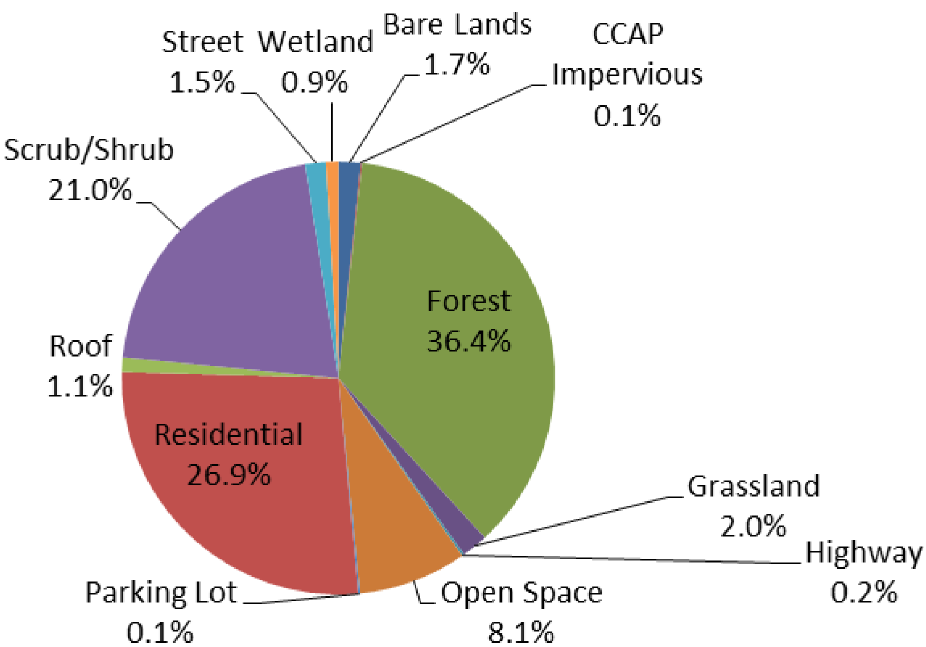


Figure 7-2. TSS Contribution by Land Use for Water Year 2010 – Dry Year

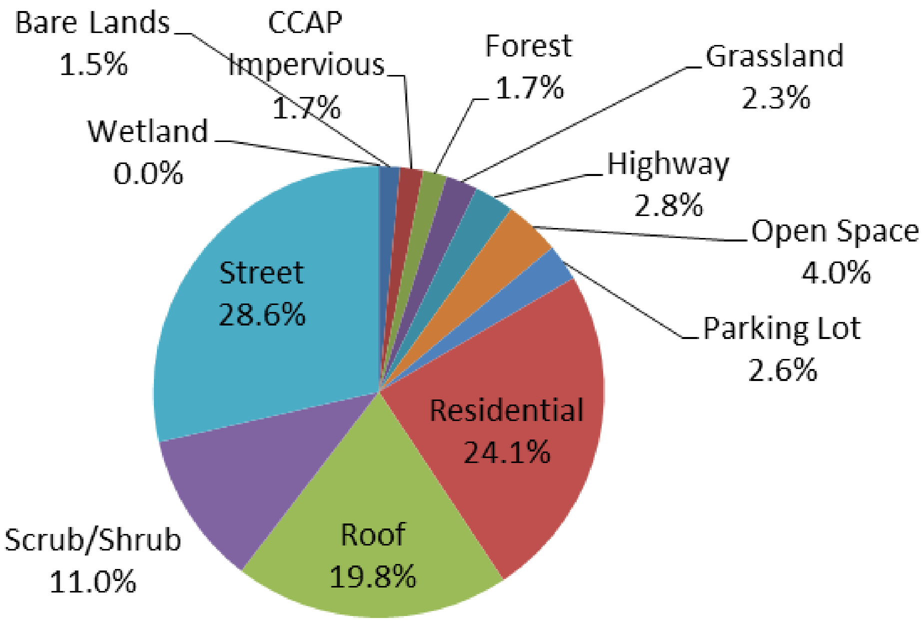
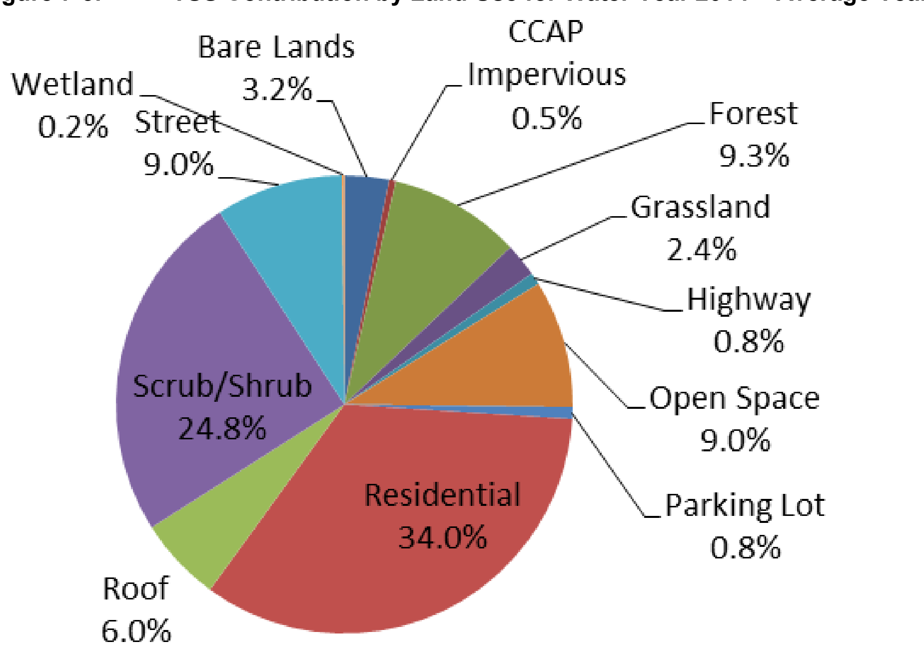


Figure 7-3. TSS Contribution by Land Use for Water Year 2014 – Average Year



8 STORMWATER BMP IMPLEMENTATION

8.1 WQ Treatment Approaches

Recommended stormwater BMPs are provided in the report *Kaʻelepulu Watershed Stormwater Water Quality Analysis Planning Study* (AECOM 2018) which was prepared in conjunction with this report. The accompanying report made the following recommended BMPs for implementation in the Kaʻelepulu Watershed:

- *Kapaa Silt Basin Modifications:* Repair the low flow berm within the facility located at the upper end of the Keolu Channel. As the existing facility is located in the upper watershed it is only capable of treating the forested areas and the recently developed residential areas.
- *Constructed Wetlands:* Provide delineated, man-made wetlands designed to concentrate sediment accumulation within a defined location. These facilities are intended to treat larger drainages so they are likely only applicable to areas along the western portion of the pond.
- *Hydrodynamic Separators:* These facilities are intended to be retrofitted into the existing stormwater system throughout the watershed. These BMPs have limited design flows so hydrodynamic separators are required throughout the watershed.
- *Green Infrastructure:* The City will work with provide landowners to develop stormwater infiltration swales and rain gardens throughout the watershed. Initial focus may be directed to parking lots associated with commercial activities, churches, and schools.

The potential locations for the BMPs are shown in the figure in Appendix C.

The Kaʻelepulu HSPF modeling presented in this report allows for a quantitative approach to reducing stormwater pollutants from entering the pond based on the recommended BMPs. In deciding the effective approaches to reducing stormwater pollutants from entering Kaʻelepulu Pond it is important to understand where the largest sources of pollutant are located and what the sources are. As shown in Table 8-1 pervious land associated with Residential and Forest land use make up almost 50 percent of the total watershed area but as shown in Figure 7-3, for an average year, Residential areas create 34 percent of the total sediment entering the pond with Forest producing 9 percent annually.

Table 8-1. Land Use Distribution and Annual TSS Loading

Land Use	Percentage of Watershed	Estimated Annual TSS Loading (tons)		
		2006 (Wet)	2010 (Dry)	2014 (Average)
Residential	26.3	277	25.6	66
Forest	21.6	374	1.8	18
Roof	13.1	11.3	21.0	11.6
Scrub and Shrub	10.2	216	11.7	48
Street	8.7	15.4	30.3	17.5
Open Space	5.7	83.3	4.2	17.5
CCAP Imp	2.8	1.0	1.8	1.0
Parking Lot	2.1	1.0	2.8	1.6
Grassland	1.8	20.6	2.4	4.7
Wetlands	1.2	9.3	0.0	0.4
Highway	0.7	2.1	3.0	1.6

Bare Land	0.2	17.5	1.6	6.2

The land use loading shown in Table 8-1, are listed based on the percentage of the total Kaʻelepulu watershed area from largest to smallest. When assessing how to most effectively address reducing pollutants entering the pond via stormwater runoff it appears addressing residential areas and streets are the best locations. The majority of the Forest areas in the watershed are tributary to the existing Kapaa Retention Basin at the upper end of the Keolu Channel. As suggested, repairs to the Kapaa basin will reduce sediment transport to the pond generated from the upper watershed.

The typical approach to improving stormwater quality issues is to address TSS. The processes involved in treating TSS also have positive impacts on TP and TN. Many of the sources of TP and TN are best addressed with source control methods implemented at the landowner level, such as using less fertilizer, planting cover vegetation on bare grounds, and reducing impervious surfaces.

Based on the estimated annual loadings provided in Table 8-1, and illustrated in Figure 7-3 the greatest potential for improving WQ would result from addressing stormwater generated from the urban environment including the Residential land use classification. Approaches in dealing with stormwater quality in a residential landscape include items individuals can utilize on a small scale to large scale approaches driven by the CCH.

Using the design considerations presented in the planning study document (AECOM 2018) for treatable area and BMP costs Table 8-2 illustrates the number of BMP units required and the costs associated with each along with the potential reduction in sediment entering the pond and stream.

Table 8-2. Potential Annual Stormwater Quality Pollutant Reductions

BMP	Total Tributary Area	# of BMPs	BMP Cost	Removal Eff	TSS	
					Reduction lb/yr	Cost $/lb
Kapaa Silt Basin	625 acres	1	$2,076,400	TSS – 70% TN – 35% TP – 45%	31,500	$66
Green Infrastructure	980	UNK	$5,632,300	TSS – 80% TN – 50% TP – 65%	170,700	$33
Hydrodynamic Separators	980	133	$1,378,800	TSS – 50% TN – N/A% TP – 17%	143,000	$9.64
Constructed Wetlands	269 acres	2	$761,600	TSS – 67% TN – 28% TP – 49%	29,100	$26.17

$/lb U.S. dollar per pound
lb/yr pound per year
Hydrodynamic separators – maximum 2 acres o

It should be noted that the implementation of the projects listed will provide treatment to all land uses that drain to them. Meaning projects within a residential area will treat streets, roofs, grass, bare lands, etc. In all cases, the potential projects also come with maintenance costs. The HSPF modeling effort provides an estimate of the potential volume of material entering the projects. These values should assist in developing a maintenance schedule for removing accumulated material.

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Appendix A.
NRCS Soil Parameters Used in HSPF Modeling Setup

Table A-1. HSPF Soil Parameters

Soil	Soil Name	UZSN		LZSN		INFILT (in/hr)	Slope (%)
		Depth (in)	Wat Cap (in/in)	Depth (in)	Wat Cap (in/in)		
AeE	Alaeloa Silt Clay	10	0.13	60	0.12	3.3	15 - 35%
ALF	Alaeloa Silt Clay	10	0.13	60	0.12	3.3	40 -70%
BS	Beaches	6	0.04	54	0.04	13	0%
CR	Coral Outcrop	6	0.01	54	0.01	3	0%
EmA	Ewa silt Clay Loam	29	0.13	10	0.01	1.3	0 - 2%
FL	Fill Land	60	0.09	10	0.01	1.1	0
HLMG	Helemano Silt Clay	10	0.11	50	0.09	4	30 - 90%
HnA	Hanalei Silt Clay	13	0.17	23	0.17	1.1	0 - 2%
HnB	Hanalei Silt Clay	13	0.17	23	0.17	1.1	2 - 6%
HoB	Hanalei Silt Clay	13	0.15	23	0.17	1.1	2 - 6%
JaC	Jaucas Sand	13	0.045	47	0.06	13	0 - 15%
KHME	Kaneohe Silt Clay	14	0.12	46	0.12	3.3	15 - 30%
KHMF	Kaneohe Silt Clay	10	0.12	50	0.12	3.3	30 - 65%
KlaB	Kawaihapai Stony Clay	22	0.115	32	0.13	3.3	2 - 6%
KmA	Keaau Clay	15	0.13	42	0.09	1.1	0 - 2%
KtC	Kokokahi Clay	14	0.13	30	0.14	0.33	6 - 12%
KTKE	Kokokahi Very Stony	14	0.085	30	0.1	0.33	0 - 35%
LPE	Lualualei Extr Stony Clay	10	0.09	50	0.09	0.33	3 - 35%
Ms	Mokuleia Loam	14	0.105	43	0.07	4	0%
Mt	Mokuleia Clay Loam	14	0.11	46	0.08	4	0%
MZ	Marsh	10	0.27	50	0.27	4	0%
PkB	Pohakupu Silty Clay	13	0.13	63	0.13	3.3	0 - 8%
PkC	Pohakupu Silty Clay	13	0.13	63	0.13	3.3	8 - 15%
PYD	Papaa Clay	12	0.11	38	0.087	0.33	6 - 25%
PYE	Papaa Clay	12	0.11	38	0.087	0.33	20 - 35%
PYF	Papaa Clay	12	0.11	38	0.087	0.33	35 - 70%
rRK	Rock Land	8	0.09	12	0.01	1.3	50%
rSY	Stony Steep land	10	0.09	50	0.09	4	50%
W	Water	0	0	0	0	0	0%
WkA	Waialua Silty Clay	12	0.14	48	0.14	1.1	0 - 3%

in/hr inch per hour
in/in inch per inch

Appendix B. HSPF Hydrograph Comparisons

Figure B-1. Aleka – September 20, 2014

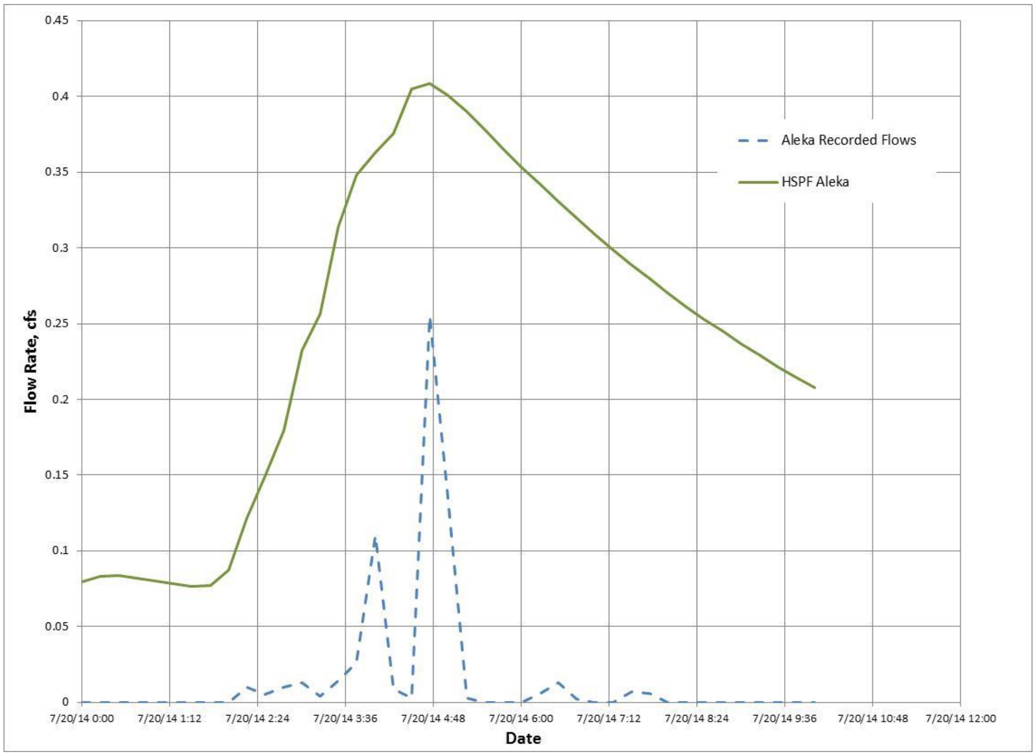


Figure B-2a. Kaopa – September 7, 2014

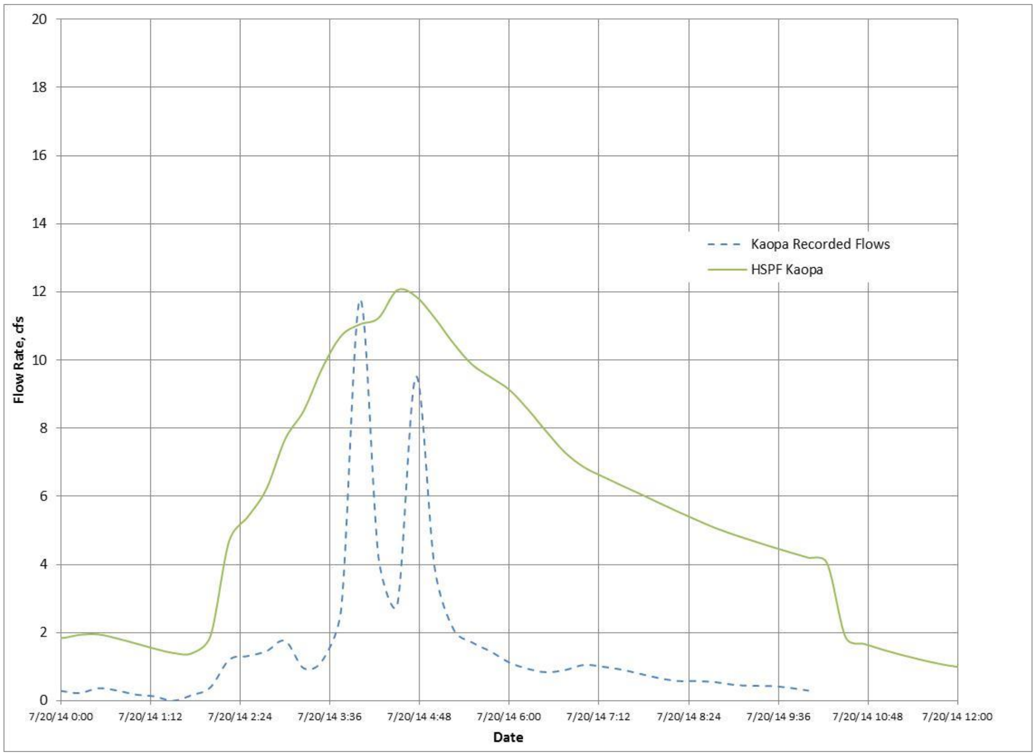


Figure B-2b. Kaopa – August 8, 2014

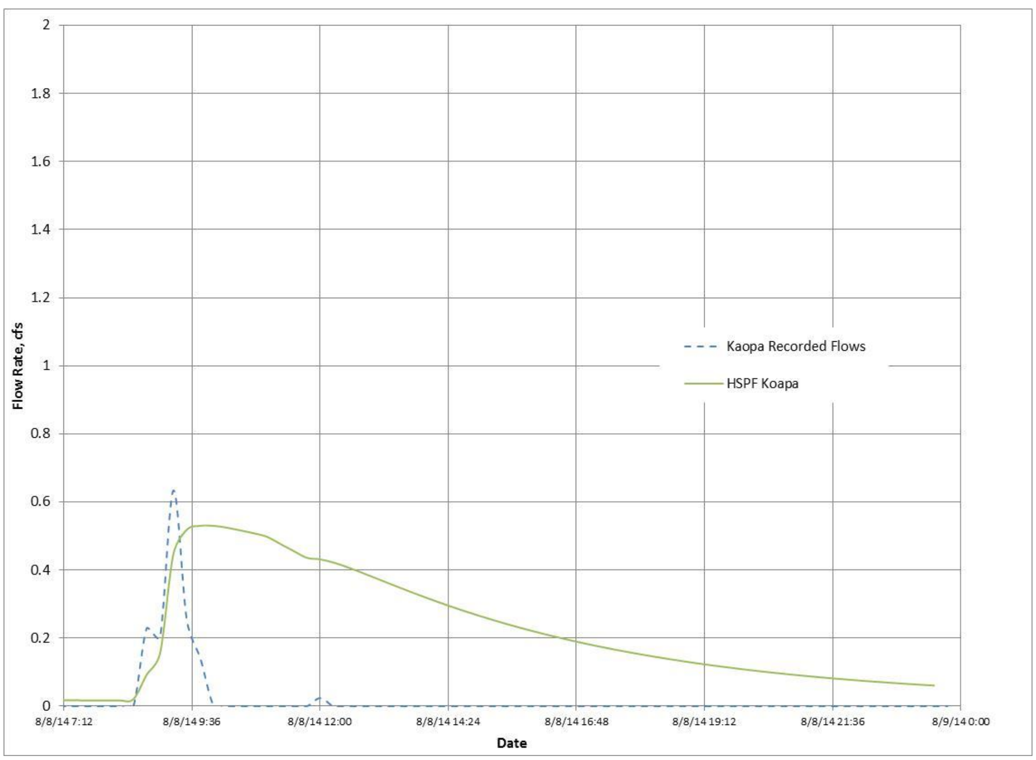


Figure B-2c. Kaopa – January 2, 2015

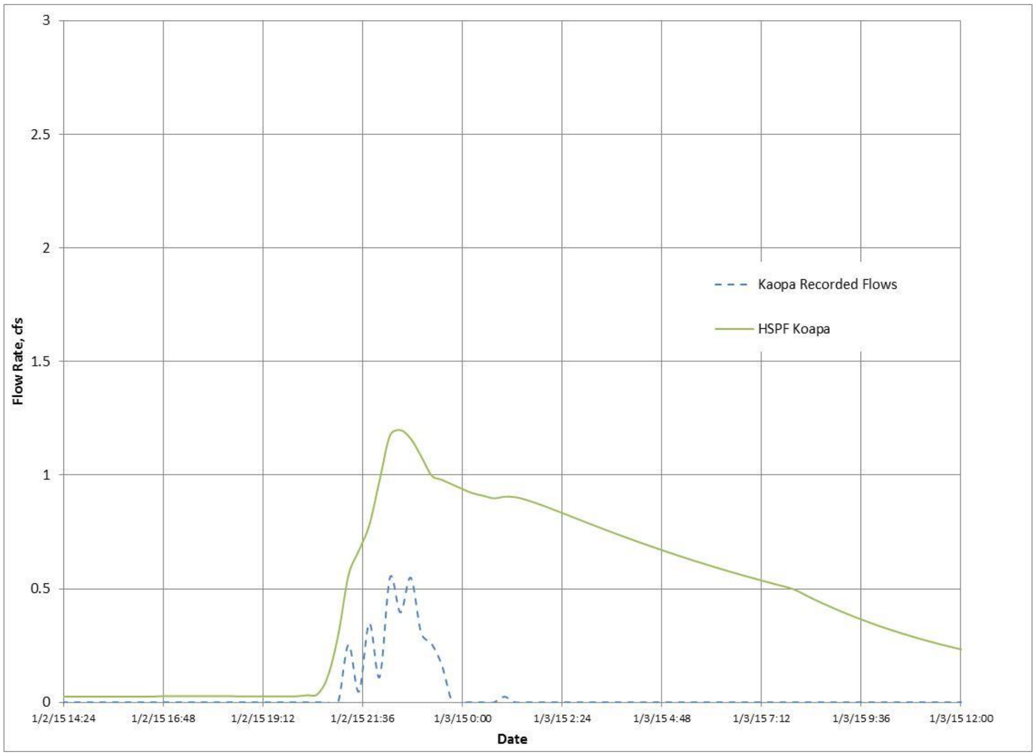


Figure B-2d. Kaopa – February 3, 2015

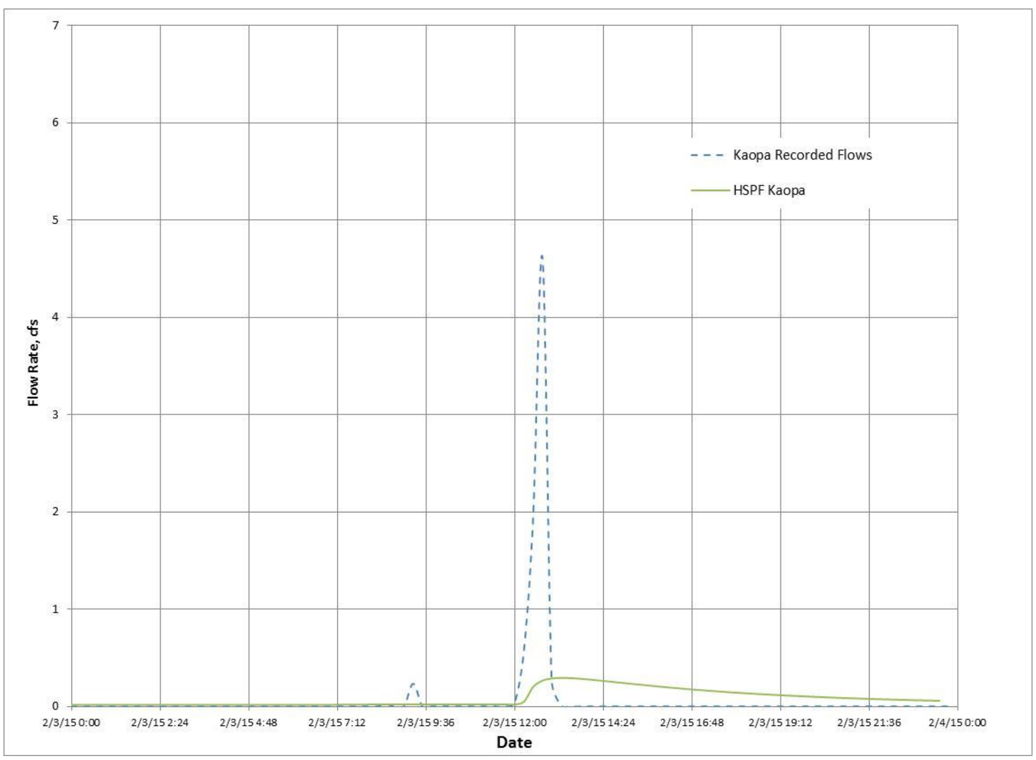


Figure B-3a. Akipola Channel – September 20, 2014

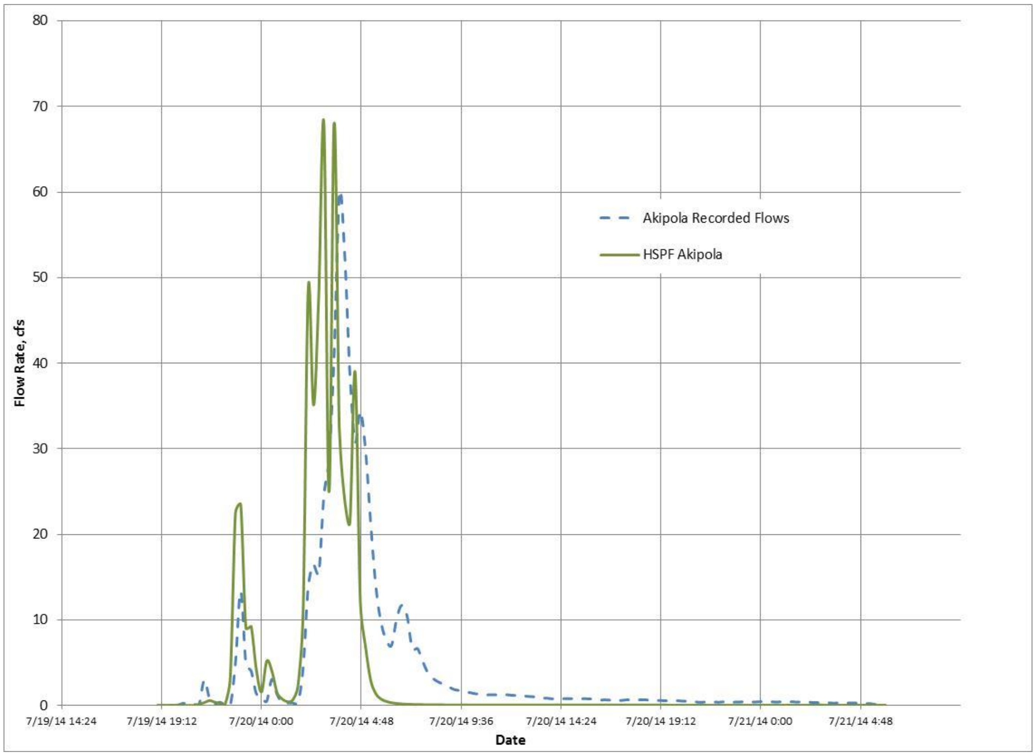


Figure B-3b. Akipola Channel – August 8, 2014

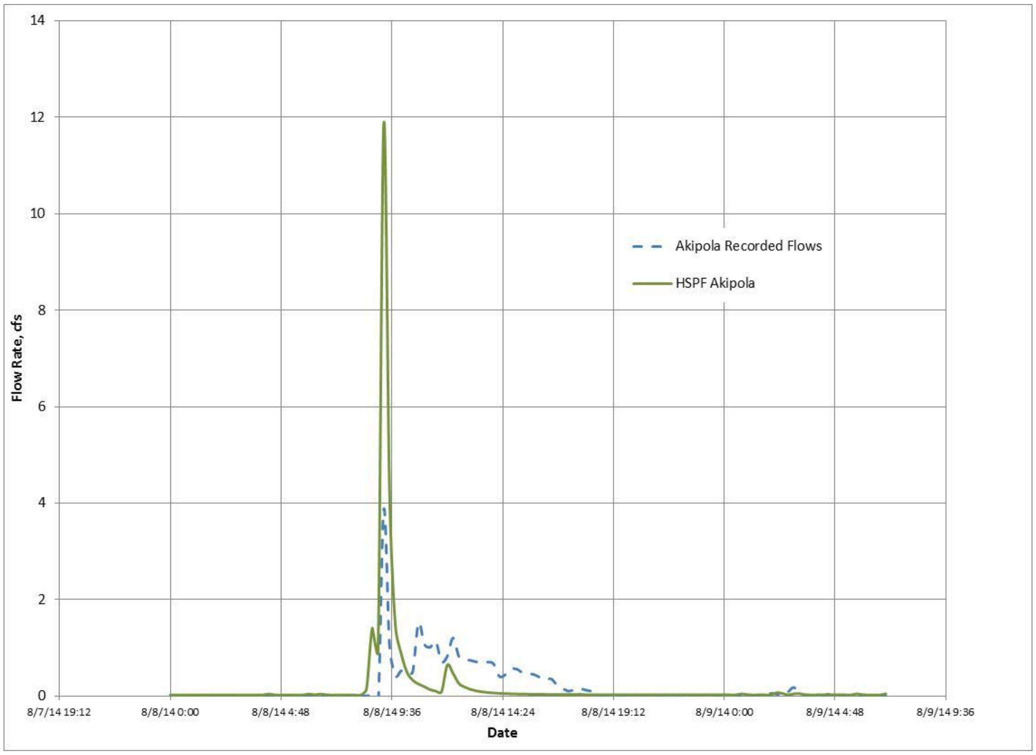


Figure B-3c. Akipola Channel – January 2, 2015

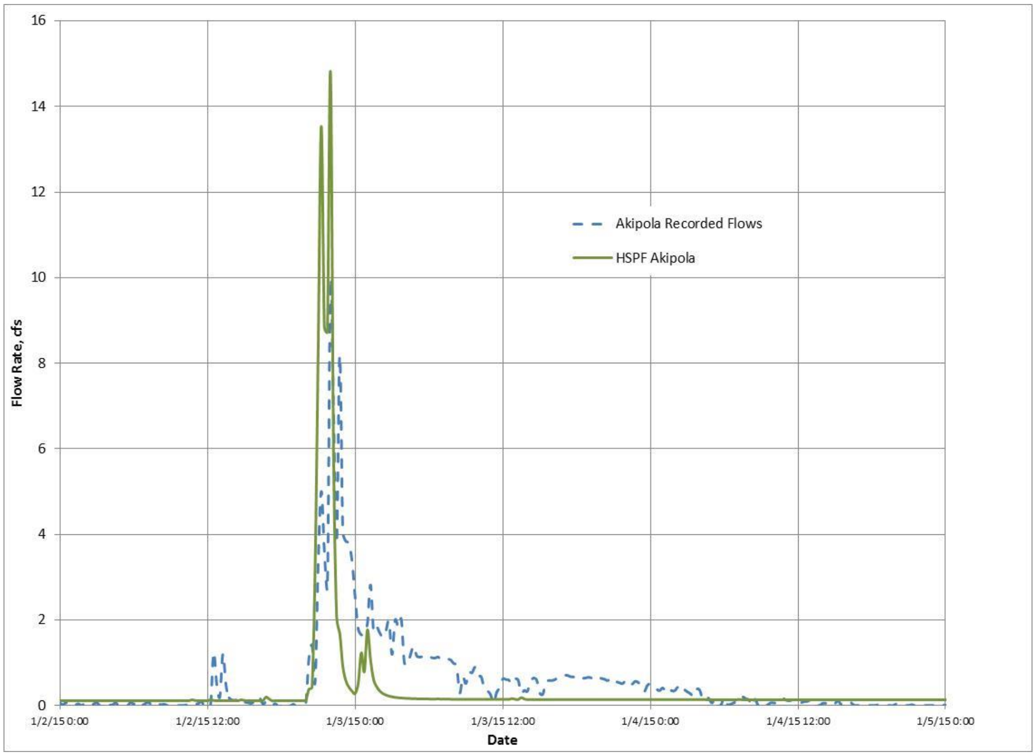


Figure B-3d. Akipola Channel – February 3, 2015

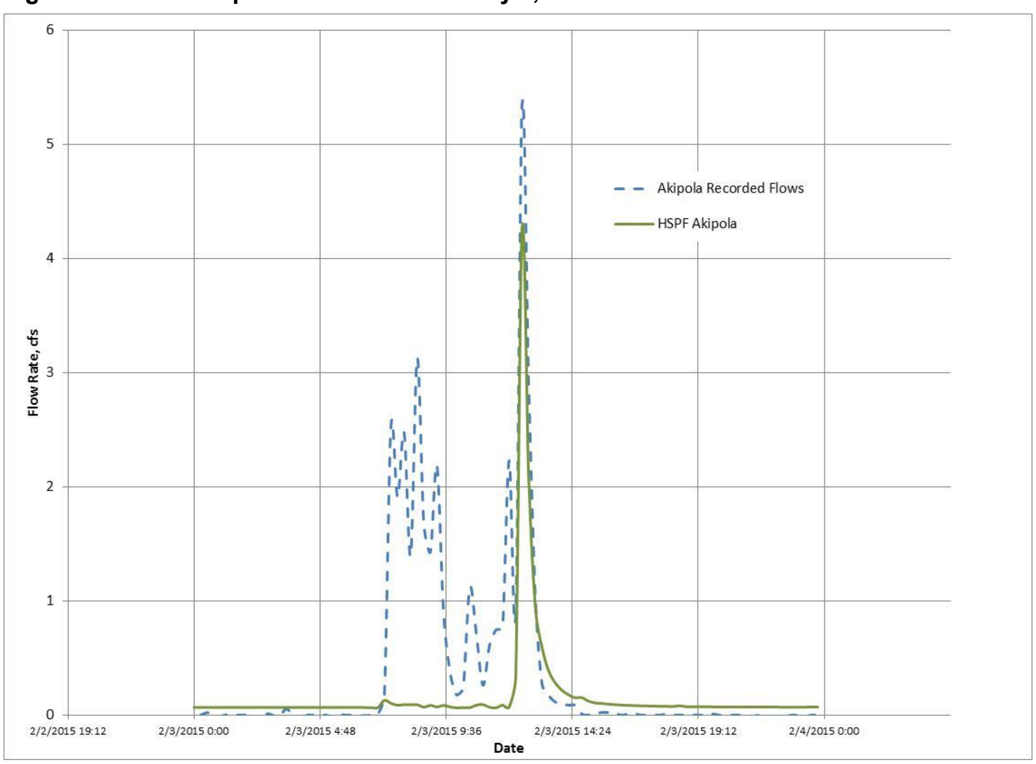


Figure B-4a. Keolu Channel – September 20, 2014

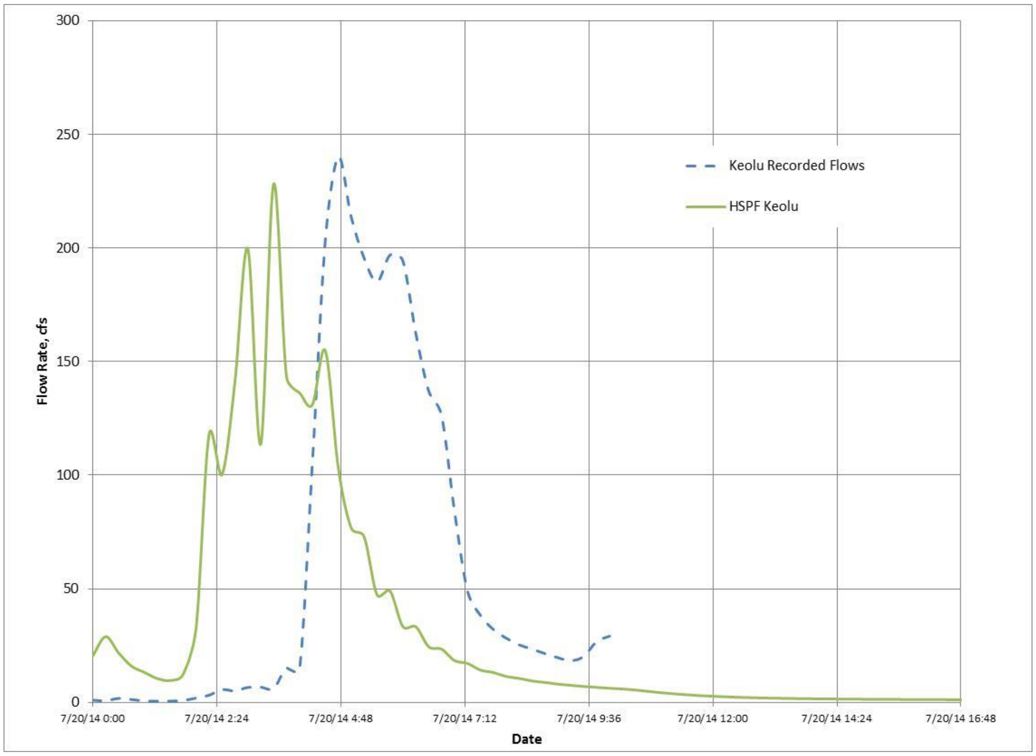


Figure B-4b. Keolu channel – August 8, 2014

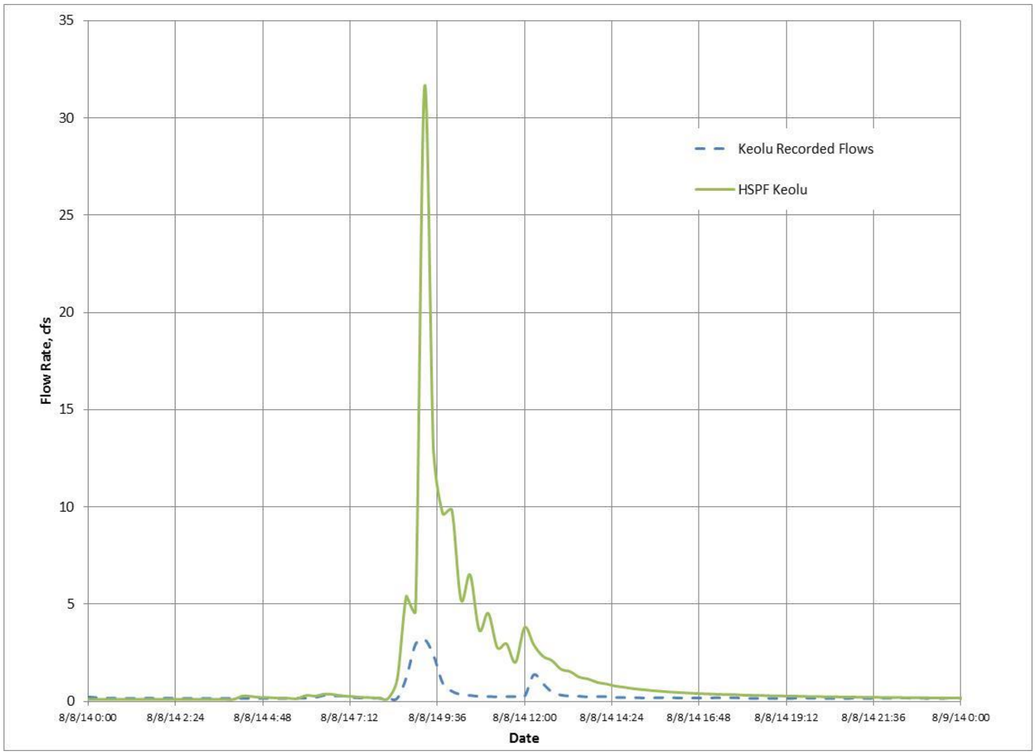


Figure B-4c. Keolu Channel – January 2, 2015

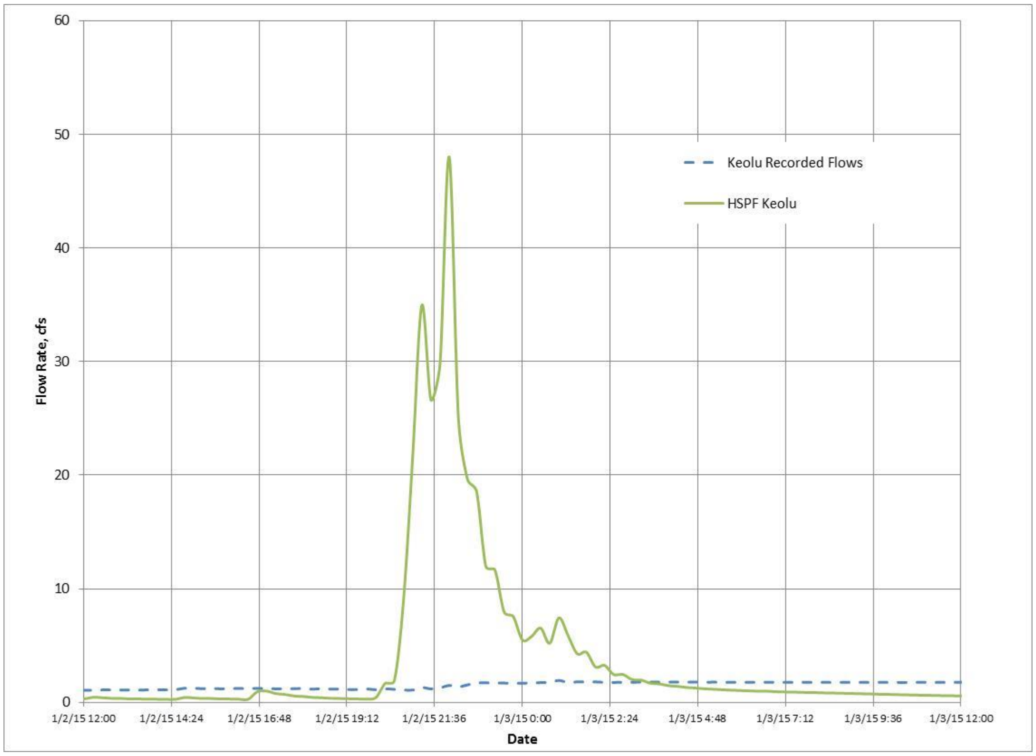


Figure B-4d. Keolu Channel – February 3, 2015

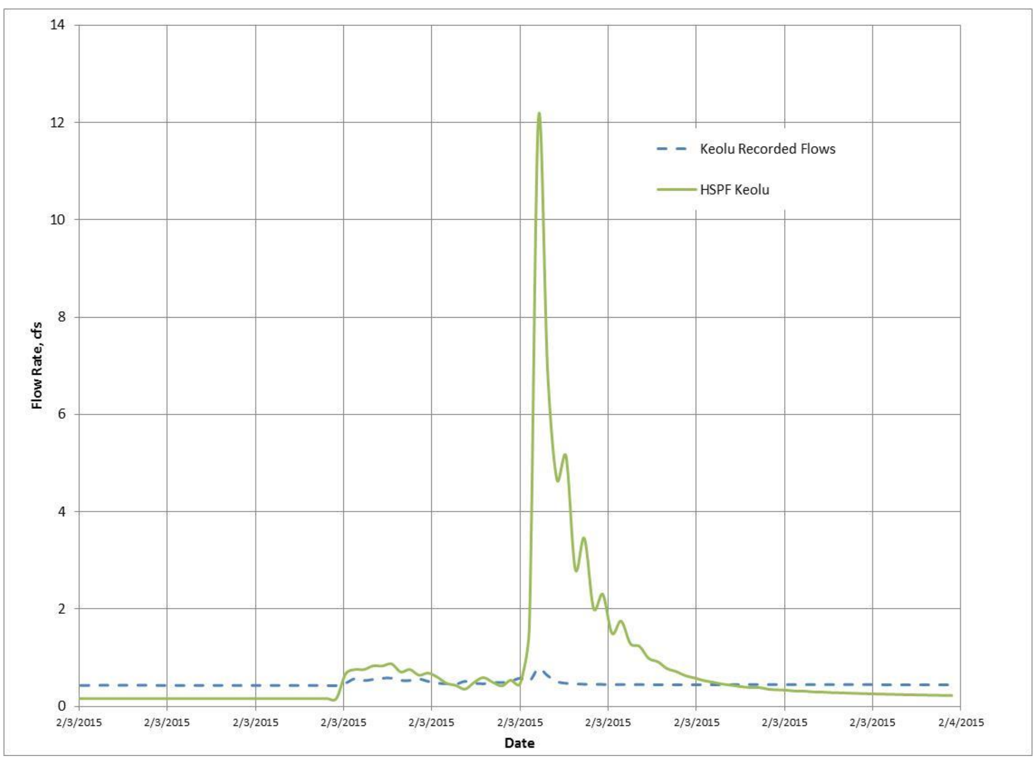


Figure B-5a. Hele Channel – September 20, 2014

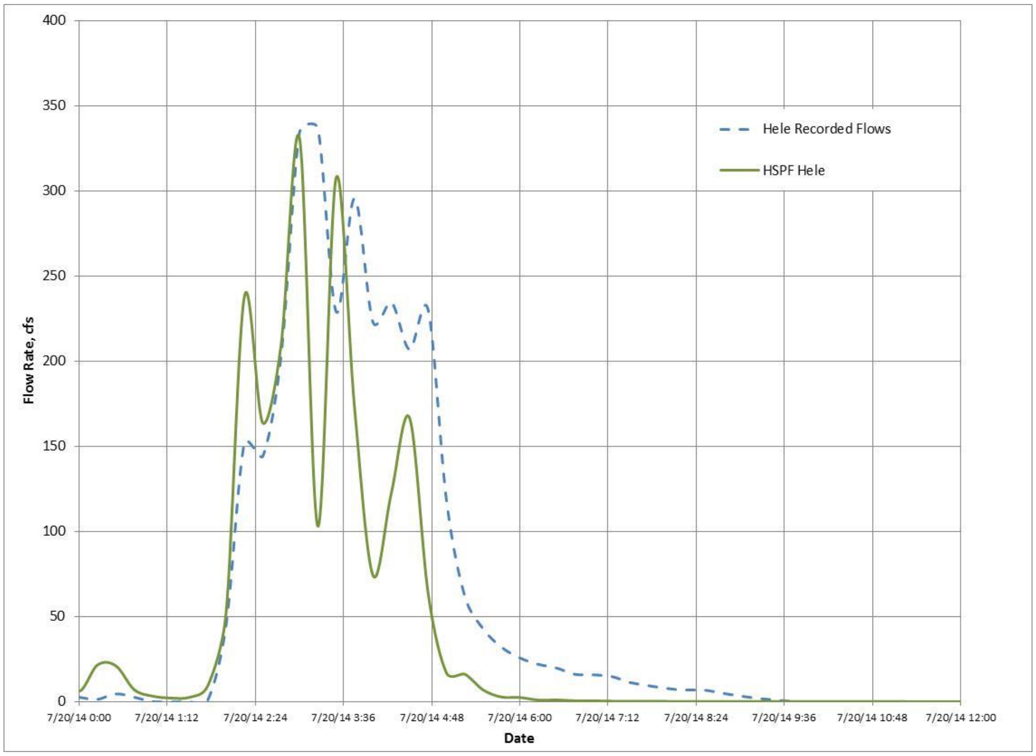


Figure B-5b. Hele Channel – August 8, 2014

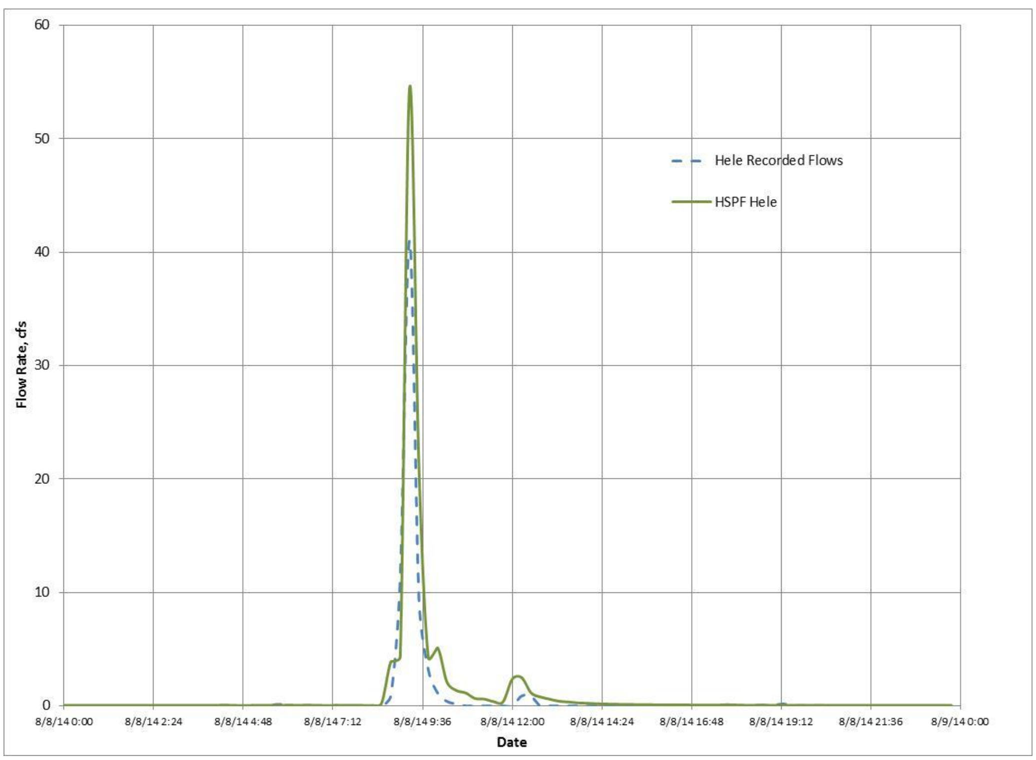


Figure B-5c. Hele Channel – January 2, 2015

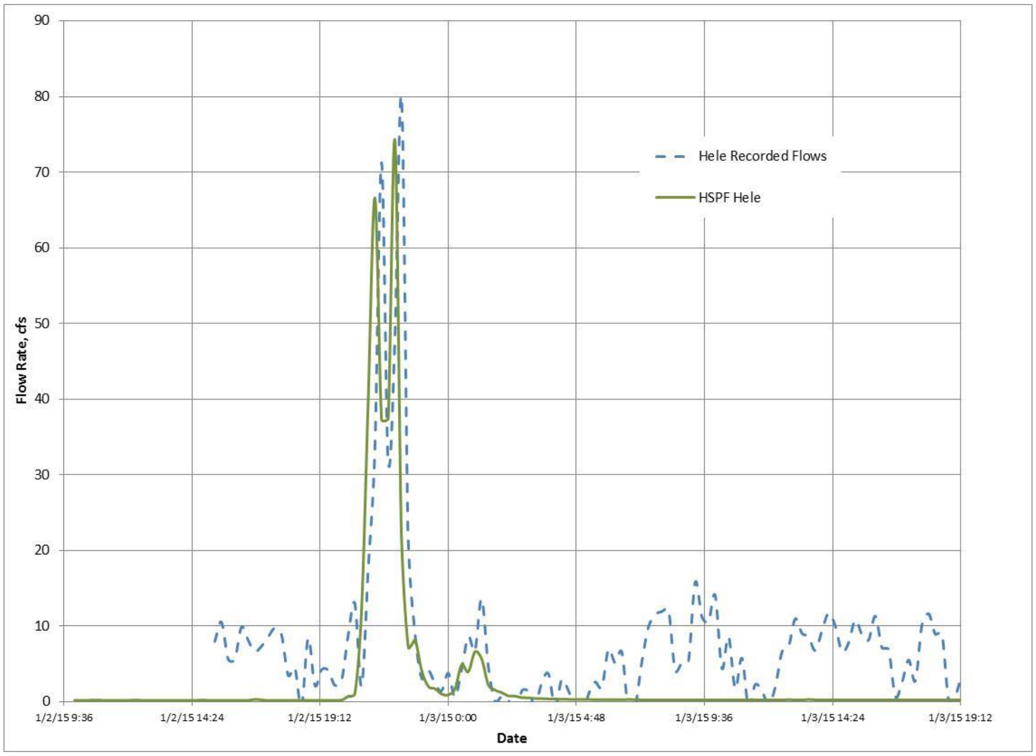
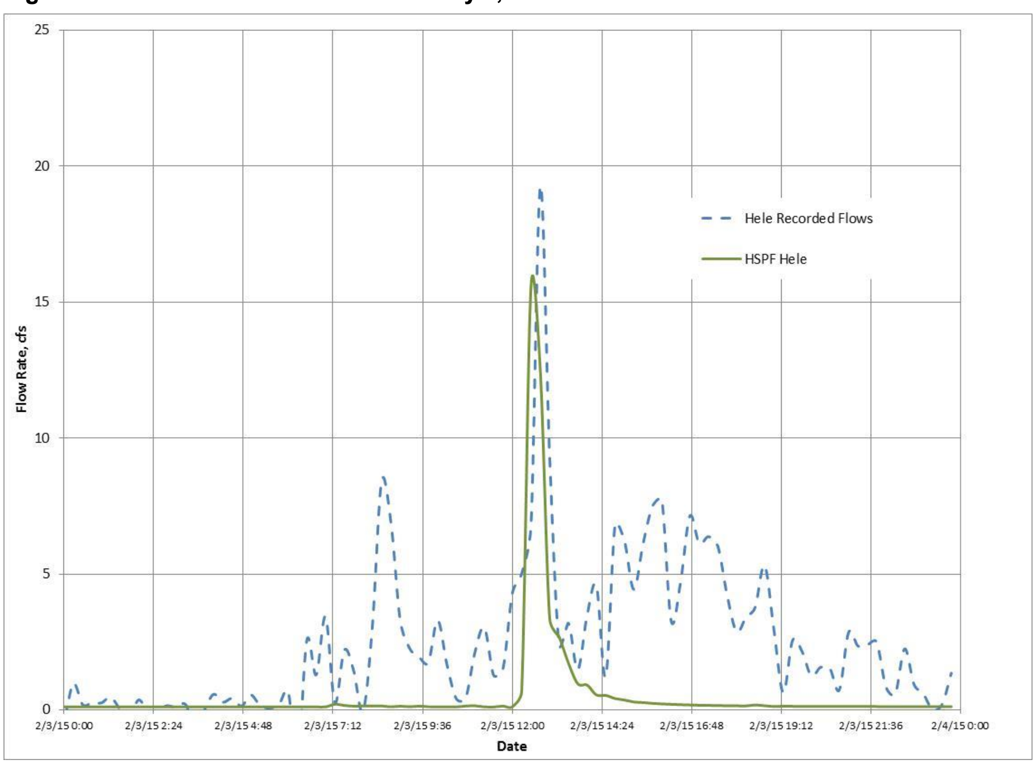


Figure B-5d. Hele Channel – February 3, 2015



Appendix C
Project Implementation Locations

Potential Project Locations for Ka'elepulu Watershed