Turbidity, Sediment, and Nutrient Total Maximum Daily Loads for the Waikele Watershed
Oahu, Hawaii

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Prepared for:
USEPA Region 9
Hawaii Department of Health

Prepared by:
Tetra Tech, Inc.
350 Indiana Street, Suite 500
Golden, Colorado 80401

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List of Abbreviations

BMP	Best management practice
C-CAP	Coastal Change Analysis Program
CCH	City and County of Honolulu
CDF	Cumulative distribution function
CFR	Code of Federal Regulations
CWA	Clean Water Act
DOE	Department of Education
DOH	Hawaii State Department of Health
DOT	Department of Transportation
GIS	Geographic information system
HAR	Hawaii Administrative Rule
HoLIS	Honolulu Land Information System
HSPF	Hydrologic Simulation Program – Fortran
KGD	Kilograms per day
KG/YR	Kilograms per year
LA	Load allocation
μG/L	Micrograms per liter
MG/KG	Milligrams per kilogram
MG/L	Milligrams per liter
MOS	Margin of safety
MS4	Municipal Separate Storm Sewer System
NCDC	National Climatic Data Center
NEXRAD	Next Generation Weather Radar
NHC	Northwest Hydraulic Consultants
NO_2	Nitrite
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NTE	Not to exceed
NTU	Nephelometric turbidity units
NWR	National Wildlife Refuge
NWS	National Weather Service
SSC	Suspended sediment concentration
SSURGO	Soil Survey Geographic
STATSGO	State Soil Geographic Database
STORET	Storage and Retrieval Data Warehouse
TMDL	Total Maximum Daily Load

TN	Total nitrogen
TP	Total phosphorus
TSS	Total suspended solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WLA	Wasteload allocation
WQC	Water quality criteria
WQS	Water quality standards

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Executive Summary

The Waikele watershed is located in Hawaii on the island of Oahu and covers a 45 square-mile drainage area (Izuka 2012). The watershed includes Waikele Stream and its main tributaries, Waikakalaua and Kipapa streams. Waikele Stream flows approximately 17 miles from its source to its mouth where it empties into Pearl Harbor (Oceanit 2007; Englund 1998). Waikele Stream has been included on Hawaii's section 303(d) list due to non-attainment of nutrient and turbidity water quality criteria (WQC) since 2002 (DOH 2018). The waterbody is specifically listed for turbidity, total nitrogen, and nitrite-nitrate impairments.

A Total Maximum Daily Load (TMDL) is established in this document to meet the requirements of section 303(d)(1)(C) of the Clean water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations (40 Code of Federal Regulations Part 130) that require the establishment of a TMDL for the achievement of water quality standards (WQS) when a waterbody is water quality-limited. A TMDL is composed of the sum of individual wasteload allocations (WLA) for point sources of pollution and load allocations (LA) for nonpoint sources of pollution and natural background loads. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. A TMDL represents the amount of a pollutant the waterbody can assimilate while maintaining compliance with applicable WQS.

Analyses of the available water quality data include a comparison of water quality monitoring results to applicable WQC including summary statistics, spatial patterns, relationships between pollutants, and correlation to streamflow analyses. These analyses support the nutrient and turbidity impairments in the watershed and also identified impairments for total phosphorus and TSS. Available data were also used to configure, calibrate, and validate a modeling framework developed to support estimation of existing loads and TMDL calculations. The modeling framework consists of the Hydrologic Simulation Program – Fortran [HSPF] watershed model, which predicted pollutant loadings for each of the five primary model subgroups draining the Waikele watershed.

The HSPF model simulates concentrations of pollutants in the waterbody by assigning unique runoff and pollutant generation rates that are based on land use, land cover, soil type and precipitation. The model was configured using key datasets to represent hydrology, water quality, and land practices in the Waikele watershed. These datasets, which include watershed boundaries, meteorological data, land cover, soils, reach characteristics, and water quality data, were incorporated into the HSPF model during model setup. The HSPF model was then calibrated and validated for both hydrology and water quality for October 1997 through September 2011. Model results were compared to observed flow and water quality data during this process. The HSPF model achieved a good fit between modeled and observed results.

HSPF model output was used to assess source-specific contributions to the total existing watershed load for each pollutant. Source loading was roughly equivalent for agricultural, urban, and conservation/open space contributions during both dry and wet seasons for total nitrogen and nitrite-nitrate. Contributions from urban lands were highest for nitrite-nitrate followed by total nitrogen (approximately a quarter of the loading during both dry and wet seasons). Relative pollutant contributions by land use demonstrated that agricultural uses contribute over half of the wet weather sediment loads. The agricultural contributions for all other pollutants and seasons ranged from a quarter to a third of the total loading. Proportional loading from conservation lands was the highest for sediment during the dry season. The overall watershed contributions were supplemented by land use-specific contributions for each subgroup, which demonstrated the land uses in each subgroup that have the largest influence on pollutant loading.

In addition to calculating existing loads based on current conditions, output from the HSPF model was used to determine the loading capacity and allocations for total nitrogen, nitrite-nitrate, and sediment in the Waikele watershed. Turbidity is not a mass-based constituent and loads cannot be calculated; therefore, sediment TMDLs (represented by TSS) were used as a surrogate for turbidity TMDLs. The TMDL values were compared against existing loads to determine the load reductions necessary to meet the TMDL numeric targets.

TMDLs were calculated using the geometric mean (GM) and 10 and 2 percent not-to-exceed numeric targets and are separated by the wet and dry seasons. The TMDLs associated with the GM criteria are the primary focus for TMDL compliance. The 10 and 2 percent NTE criteria are applicable in situations where the GM criteria do not apply. WLAs and LAs for each contributing source of the Waikele watershed TMDLs for total nitrogen, nitrite-nitrate, and sediment are summarized in the tables below. Overall, based on the modeling analyses, loads associated with point sources (and received WLAs) were approximately 16 percent of the total loading capacities for each pollutant.

Total nitrogen reductions to achieve the geometric mean WQS are 89 percent and 83 percent for the dry and wet seasons, respectively. Nitrite-nitrate existing concentrations are estimated to need dry and wet season reductions of 97 and 93 percent, respectively, to achieve the geometric mean WQS. Model results indicated that for sediment, the existing conditions are currently meeting the geometric mean numeric target. Additional analyses were performed to illustrate exceedances of the 10 and 2 percent not-to-exceed sediment targets, indicating that over a 95 percent reduction in sediment loads are necessary, especially during large loading events.

In addition to loading capacity calculations, supplemental information describing the methodology to calculate the load-based TMDLs are presented in Appendix C. Estimates of existing loads based on the simulation results for all sources explicitly included in the watershed model is also included. These sources include the MS4 areas, agriculture, conservation, the State of Hawaii, and the Department of Education. The proportion of simulated loading for each source was also used to assign WLAs and LAs for the TMDLs.

TMDL effectiveness will be evaluated on a watershed or regional scale, as is consistent with TMDL development. Compliance with WLAs and LAs will be implemented through the application of Best Management Practices (BMPs). WLAs will be enforced through their NPDES permit conditions (HAR §11-55). The State will pursue implementation of LAs through Hawaii's Nonpoint Source Management Plan (DOH 2015), Hawaii's Coastal Nonpoint Pollution Control Program Management Plan (State of Hawaii 1996), and Watershed-based Plans and TMDL Implementation Plans that address the nine elements required by USEPA guidance for awarding additional Clean Water Act §319(h) incremental funds (USEPA 2003b).

Load-based total nitrogen allocations and load reductions required to achieve geometric mean TMDLs

TMDL Component	Geometric Mean TMDL		Modeled Existing Load	
	Dry Season* Load (kgd)	Wet Season* Load (kgd)	Dry Season* Load (kgd)	Wet Season* Load (kgd)
Loading Capacity	7.01	16.24	N/A	N/A
Wasteload Allocations				
City County of Honolulu MS4	0.38	1.13	3.72	6.96
U.S. Army Garrison Hawaii MS4	0.09	0.42	0.87	2.60
State of Hawaii DOT MS4	0.07	0.16	0.69	0.96
Construction Stormwater General and Individual Permits	0	0	0	0
Industrial Stormwater General and Individual Permits	0	0	0	0
Reserve WLA for Future Growth (5%)	0.35	0.81	—	—
Load Allocations				
City County of Honolulu	0.68	1.98	6.54	12.23
U.S. Army Garrison Hawaii	0.16	0.75	1.56	4.66
State of Hawaii DOT (and other)	0.39	0.87	3.82	5.36
State of Hawaii DOE MS4	0.05	0.15	0.53	0.94
Agriculture	3.62	7.52	35.04	46.40
Conservation Land	1.21	2.45	11.73	15.09
Total Existing Load			64.48	95.22
Load Reduction			57.47	78.98
Percent Reduction			89%	83%

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.
Acronyms: kgd = kilograms per day, N/A = not applicable; “—” = not explicitly modeled

Load-based nitrite-nitrate allocations and load reductions required to achieve numeric targets

TMDL Component	Geometric Mean TMDL		Modeled Existing Load	
	Dry Season* Load (kgd)	Wet Season* Load (kgd)	Dry Season* Load (kgd)	Wet Season* Load (kgd)
Loading Capacity	1.17	4.55	N/A	N/A
Wasteload Allocations				
City County of Honolulu MS4	0.09	0.34	3.31	5.08
U.S. Army Garrison Hawaii MS4	0.02	0.12	0.88	1.72
State of Hawaii DOT MS4	0.01	0.05	0.55	0.78
Construction Stormwater General and Individual Permits	0	0	0	0
Industrial Stormwater General and Individual Permits	0	0	0	0
Reserve WLA for Future Growth (5%)	0.06	0.23	—	—
Load Allocations				
City County of Honolulu	0.15	0.60	5.82	8.92
U.S. Army Garrison Hawaii	0.04	0.21	1.58	3.07
State of Hawaii DOT (and other)	0.08	0.29	3.08	4.34
State of Hawaii DOE MS4	0.01	0.04	0.42	0.62
Agriculture	0.67	2.33	26.17	34.82
Conservation Land	0.03	0.35	1.28	5.16
Total Existing Load			43.09	64.52
Load Reduction			41.92	59.98
Percent Reduction			97%	93%

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.
Acronyms: kgd = kilograms per day, N/A = not applicable; "—" = not explicitly modeled

Load-based sediment allocations and load reductions required to achieve 10% NTE TMDLs

TMDL Component	Geometric Mean TMDL		Modeled Existing Load	
	Dry Season Load (kgd)	Wet Season Load (kgd)	Dry Season Load (kgd)	Wet Season Load (kgd)
Loading Capacity	4,991.0	18,997.2	N/A	N/A
Wasteload Allocations				
City County of Honolulu MS4	117.8	185.8	2,349.1	3,686.8
U.S. Army Garrison Hawaii MS4	41.1	129.0	819.8	2,559.1
State of Hawaii DOT MS4	32.1	269.8	640.2	5,353.4
Construction Stormwater General and Individual Permits	0	0	0	0
Industrial Stormwater General and Individual Permits	0	0	0	0
Reserve WLA for Future Growth (5%)	249.6	949.9	—	—
Load Allocations				
City County of Honolulu	207.0	326.4	4,127.6	6,478.1
U.S. Army Garrison Hawaii	73.5	230.6	1,466.2	4,576.9
State of Hawaii DOT (and other)	178.8	1,502.5	3,565.5	29,815.2
State of Hawaii DOE MS4	13.6	19.4	272.0	385.8
Agriculture	2,286.7	13,440.9	45,600.7	266,723.2
Conservation Land	1,790.7	1,942.9	35,709.7	38,555.7
Total Existing Load			94,550.8	358,134.2
Load Reduction			89,559.8	339,137.0
Percent Reduction			95%	95%

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.
Acronyms: kgd = kilograms per day, N/A = not applicable; “—” = not explicitly modeled
Shaded loading values are intended for informational purposes only, and reductions are not required

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1. Introduction

Section 303(d)(1)(C) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations (40 CFR Part 130 [note: CFR is the Code of Federal Regulations]) require the establishment of a Total Maximum Daily Load (TMDL) to achieve state water quality standards (WQS) when a waterbody is water quality-limited. A TMDL identifies the amount of a pollutant that a waterbody can assimilate and still comply with applicable WQS. TMDLs quantify the amount a pollutant must be reduced to achieve a level (or "load") that allows a given waterbody to fully support its designated uses. TMDLs also include an appropriate margin of safety (MOS) to account for uncertainty or lack of knowledge regarding the pollutant loads and the response of the receiving water. The mechanisms used to address water quality problems after the TMDL is developed can include a combination of best management practices (BMPs) for nonpoint sources and/or effluent limits required through USEPA's National Pollutant Discharge Elimination System (NPDES) permits for point sources.

The TMDL process begins with the development of a technical analysis which includes the following components: (1) a **Problem Statement** describing which beneficial uses are impaired; (2) identification of **Numeric Targets** that will result in attainment of the water quality criteria (WQC) and protection of beneficial uses; (3) a **Source Analysis** to identify all of the point and nonpoint sources of the impairing pollutant in the watersheds and to estimate the current pollutant loading for each source; (4) a **Linkage Analysis** to calculate the loading capacity of the waterbodies for the pollutant; i.e., the maximum amount of the pollutant that may be discharged to the waterbodies without causing exceedances of WQC and impairment of beneficial uses; (5) a **Margin of Safety** to account for uncertainties in the analyses; (6) the division and **Allocation of the TMDL** among each of the contributing sources in the watersheds, wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint and background sources; (7) a description of how **Seasonal Variation and Critical Conditions** are accounted for in the TMDL determination; and (8) **Reasonable Assurance** that the allocations will be met. In addition, (9) an **Implementation Plan** to meet the WLAs and LAs (this includes **monitoring recommendations**) may be included.

The State of Hawaii Department of Health (DOH) and the USEPA have coordinated a watershed assessment and modeling study with the City and County of Honolulu (CCH) to support the calculation of total nitrogen (TN), nitrite-nitrate (NO_2/NO_3), and turbidity TMDLs for Waikele Stream in the Waikele watershed, which is listed as impaired on Hawaii's 2014 section 303(d) list (DOH 2014a). These TMDLs are presented as WLAs for point sources and LAs for nonpoint sources. The load reductions required (from existing loading levels) to achieve the TMDLs are also included. Since turbidity is not a mass-based constituent and loads cannot be calculated, sediment TMDLs were used as a surrogate for turbidity TMDLs.

This document presents the results of the study and describes each TMDL component listed above, as it pertains to the Waikele watershed receiving waters. Specifically, Section 2 presents a summary of the water quality problems, Section 3 describes the numeric targets used for TMDL analyses, Section 4 compares the observed monitoring data to the WQC and analyzes water quality and hydrology monitoring data over the wet and dry seasons, Section 5 presents a source analysis, Section 0 describes the linkage analysis (including the Hydrologic Simulation Program Fortran [HSPF] watershed modeling analysis), Section 7 addresses the TMDL calculation methodology and results, Section 8 presents implementation and monitoring recommendations and Section 9 discusses the public participation process. To provide context for this discussion, the remainder of this section describes the environmental setting for the Waikele watershed.

1.1. Project Area Description

The Waikele watershed covers a 45 square-mile drainage area to the West Loch area of Pearl Harbor (Izuka 2012). This drainage area includes Waikele Stream and its main tributaries, Waikakalaua and Kipapa streams (Figure 1). The Waikele watershed is the second largest watershed on the island of Oahu, draining the plain situated between the Ko’olau and Wai’anae mountains. The confluence of Waikele Stream and its tributaries occurs on the Schofield Plateau, where Waikele Stream flows southward into Pearl Harbor. Waikakalaua Stream originates atop the Ko’olau Mountains, joining Waikele Stream toward the lower end of Wheeler Army Airfield. Located south of Waikakalaua Stream, Kipapa Stream also finds its source atop the Ko’olau Mountains. The two streams run parallel until Waikakalaua Stream flows to its confluence with Waikele Stream (Oceanit 2007).

The Waikele hydrologic unit includes areas draining directly to Pearl Harbor as well as the Waikele Stream drainage (see the red outline in Figure 1). The area contributing solely to Waikele Stream at the assessment point has been defined as the TMDL Area (see the black subwatershed boundaries in Figure 1) and this area is the focus of the remainder of this report.

1.2. Population

Mililani is the largest urban area in the Waikele watershed. The town is located near the center of the watershed and consists of two census-designated places, Mililani Town and Mililani Mauka. Mililani Town has a population of 27,629 and Mililani Mauka has a population of 21,039 for a total population of 48,668 people (US Census 2010). The lower reaches of Waikele Stream also flow through a portion of the town of Waipahu before entering Pearl Harbor. Waipahu has a population of 38,216 (US Census 2010).

1.3. Topography

The elevation in the Waikele watershed ranges from 0 feet at the mouth to over 3,000 feet in the mountains at the headwaters of the watershed (Figure 2). The central-leeward side of the Ko’olau Mountains in the Waikele watershed are dissected by narrow, v-shaped valleys while the windward and southeast-leeward flanks of the Ko’olau Mountains have relatively wide, alluviated, flat-floored valleys (Izuka 2012). The Wai’anae Mountain valleys are wider and more extensively alluviated than in the leeward-central Ko’olau Mountains (Izuka 2012).

1.4. Soils and Geology

Soils in the Waikele watershed consist of Wai‘anae Mountain soils in the western headwaters and Ko’olau Mountain soils in the eastern headwaters with silty-clay soils in the valleys (Figure 3). The island of Oahu was built by two Tertiary-age volcanoes. The Ko’olau and Wai’anae Mountains are the remnants of these volcanoes. The Schofield Plateau is a high saddle that formed between the two mountains as lava flows from the younger Ko’olau volcano buried the eroded northeastern flank of the older Wai‘anae volcano (Izuka 2012).

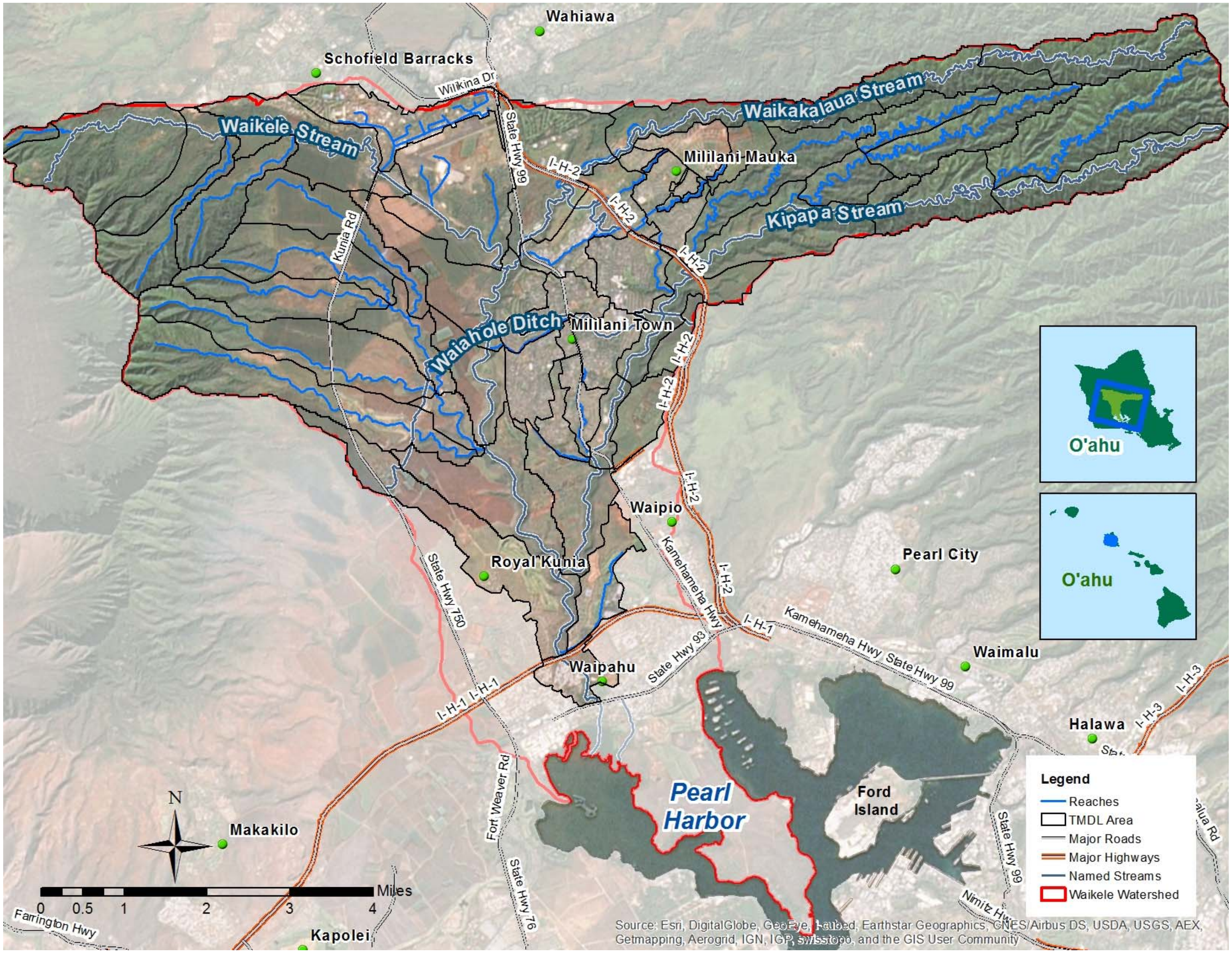


Figure 1. Location of the Waikele watershed

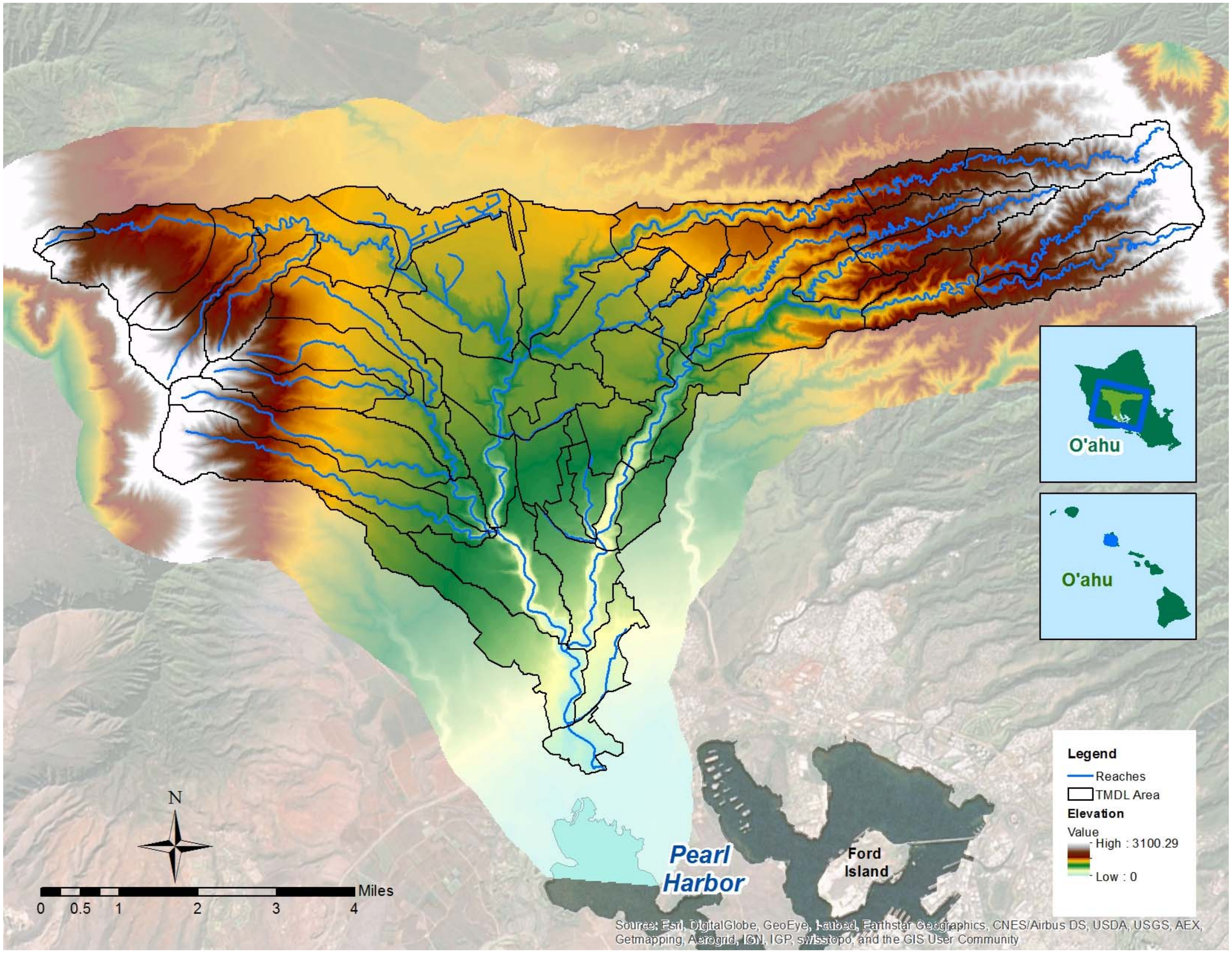


Figure 2. Topography in the Waikele watershed

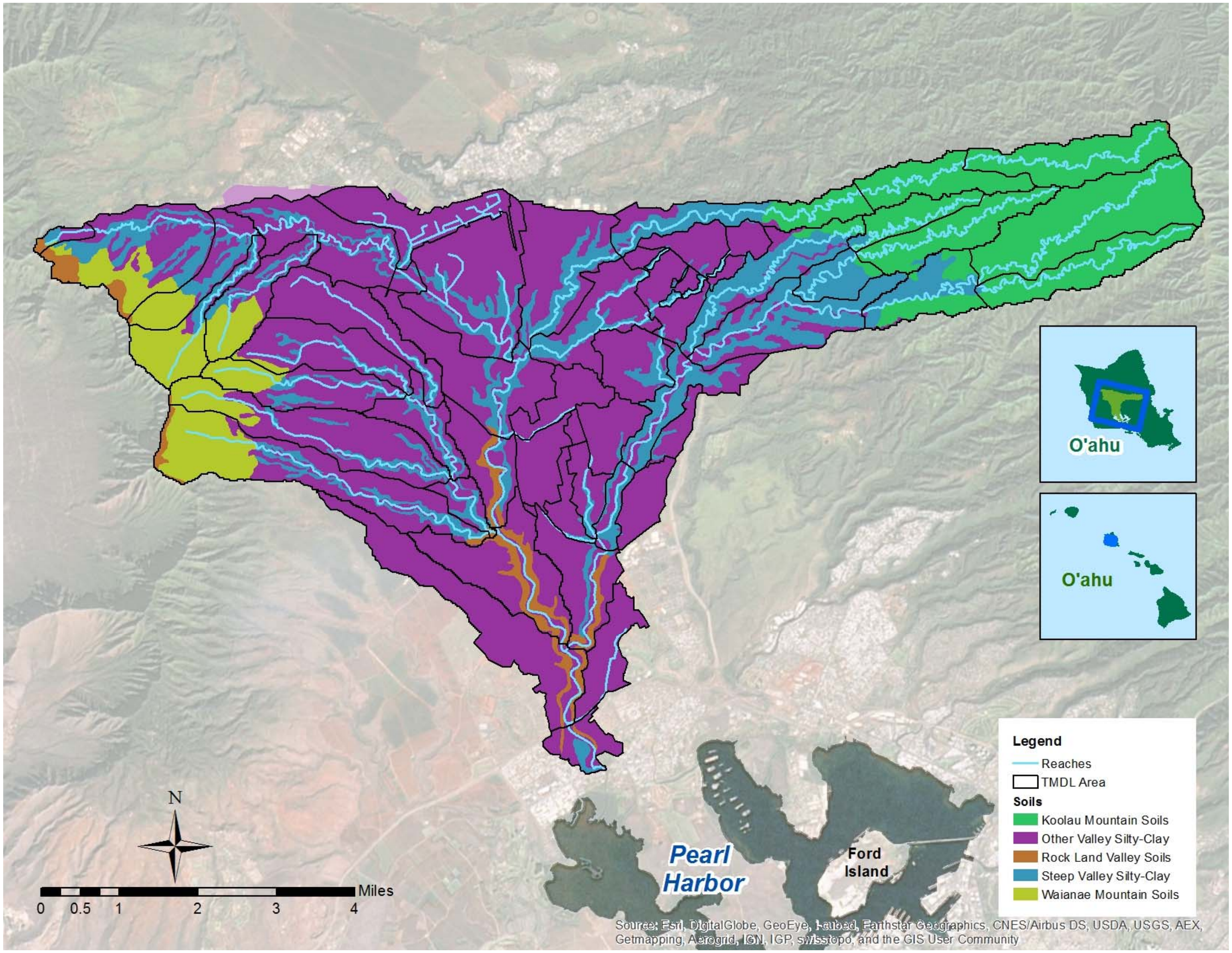


Figure 3. Soils in the Waikele watershed

Izuka (2012) provides a detailed summary of soils and geology in the watershed. In the middle reaches of the watershed, Waikele Stream and its tributaries have cut gulches as much as a few hundred feet deep into the Schofield Plateau. Chemical weathering has transformed the basalt lava flows at the surface into soft residual saprolite that may be as much as 100 feet thick. Alluvium exists at the bottom of the gulches. However, in some places alluvium is thin or is absent and weathered bedrock is exposed at the stream bottoms. Alluvium throughout the Waikele watershed consists mostly of boulders and cobbles, but finer sediment may predominate in some stream reaches. The basaltic rocks that form mountains in Hawaii are composed mostly of finely crystalline mafic minerals that weather quickly to clays and oxides. Alluvial pebbles, cobbles, and boulders form from residual kernels of unweathered basalt and are loosened from the otherwise weathered bedrock during erosion. Small pebbles and sand are often composed of highly weathered basalt that can disintegrate during stream transport and contribute to the suspended sediment load.

1.5. Hydrology and Waterbody Characteristics

Streams on Oahu are typically flashy because of small drainage areas and steep gradients. While exact measurements are not available, the Waikele watershed has both perennial and intermittent reaches. In perennial reaches, the storm-flow peaks are superimposed on persistent baseflow generated by groundwater discharge. In intermittent reaches, water seeps from the stream into the ground. Most reaches of Waikele Stream and its tributaries (except near the coast) are intermittent because the groundwater table is a few tens to hundreds of feet below the land surface. This is especially true in the upper reaches of the Waikele watershed, which typically only have continuous flow after rainfall events (USACE 2015). Springs surrounding Pearl Harbor, including springs that discharge into lower Waikele Stream, result in continuous baseflow in the lower reaches of Waikele Stream (Izuka 2012).

1.6. Climate

The climate of Oahu is characterized by mild temperatures, moderate humidity, and northeasterly trade winds. Rainfall distribution is influenced by the orographic effect and the prevailing northeasterly trade winds (Izuka 2012). The southern portion of the Waikele watershed, near its mouth, receives approximately 25 inches of rainfall per year. The Ko'olau Mountains, which contain the headwaters of the Waikakalaua and Kipapa streams, receive more than 240 inches of rainfall per year (Figure 4). Mean monthly rainfall is highest in January and lowest in June and July (Izuka 2012). Monthly average high temperatures range from the low to high-80s, with the average annual temperature for Honolulu being 77.6°F (U.S. Climate Data 2016). Monthly relative humidity percentages range from the high 50s to the mid-60s. The annual relative humidity is 60 percent (ClimaTemps 2016).

The rainfall patterns tend to follow the elevation contours in the region, with higher rainfall occurring in the higher elevations. Many of the higher elevation areas also have very steep slopes. This combination of steep slopes and high precipitation has a significant potential for erosion; thus contributing to the high turbidity values observed further downstream (see Section 4).

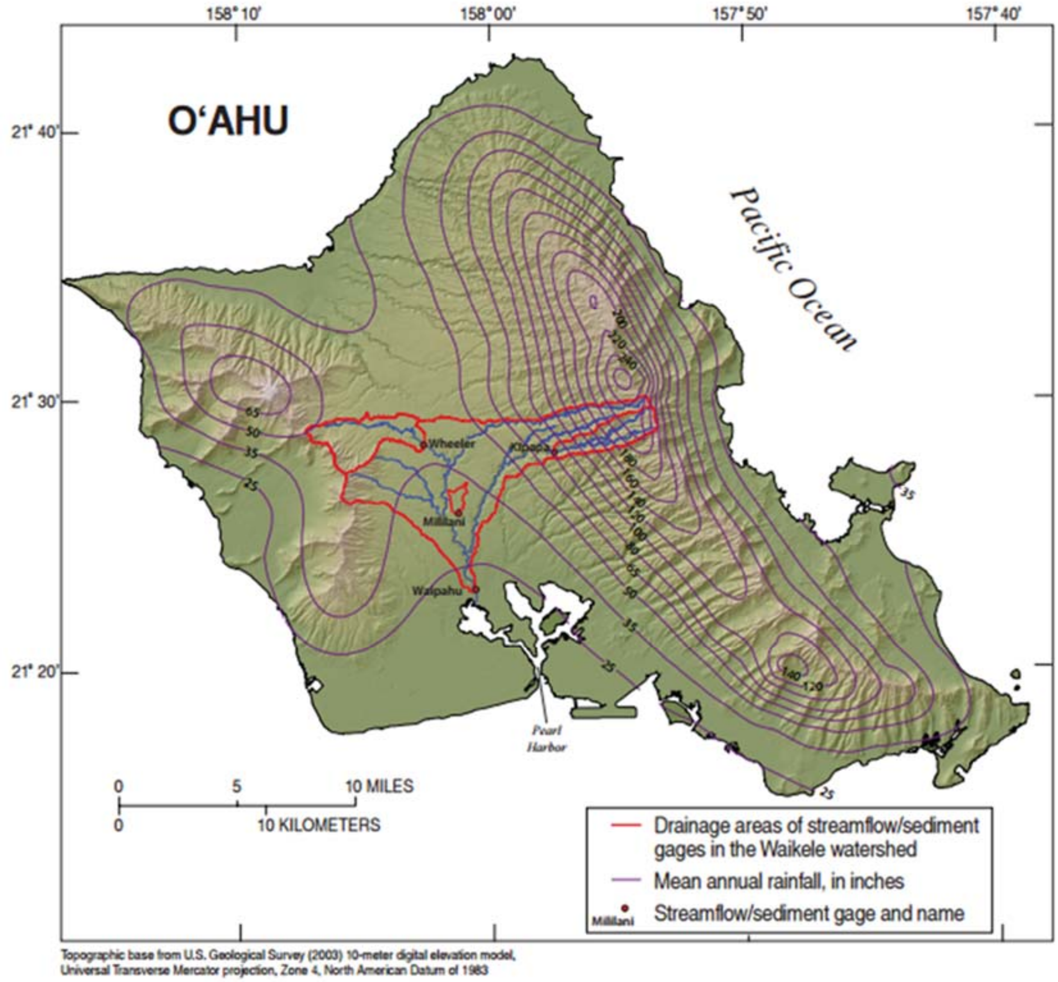


Figure 4. Mean annual rainfall on Oahu (source: Izuka 2012)

1.7. Land Cover and Land Use

The Waikele watershed includes a variety of land cover and land uses, including agriculture and urban development, as well as undeveloped conservation land in the mountains (Izuka 2012). The headwaters of Kipapa Stream and Waikakalaua Stream are located in a forested area of the watershed that is part of the Oahu Forest National Wildlife Refuge (Oahu NWR). The Oahu NWR was created in December 2000 to protect and recover endangered, threatened, and other rare and native wildlife. The forest contains some of the last remaining intact native forests on Oahu (USFWS 2012). The NWR and other forested areas make up a majority of the land cover in the watershed (46 percent), with most of these forested areas existing in the headwaters.

In addition to the conserved forest land in the headwaters, agriculture, grassland, and urban areas are drained before Waikele Stream and its tributaries discharge to Pearl Harbor (Figure 5 shows the spatial distribution of land cover in the watershed). The urban areas, which are represented by impervious surfaces in Figure 5 (shown in grey), are primarily located in the center of the watershed in Mililani, the Wheeler Army Airfield, and Schofield Barracks as well as near the mouth in Waipio and Waipahu (Figure 5). The impervious surfaces and rooftop area is approximately 14 percent of the watershed (over 4,000 acres of the 29,500-acre watershed).

Although Waikakalaua Stream flows through some conservation land in the Oahu NWR, the rest of the land surrounding this tributary is highly developed urban land including the Kamehameha Highway and the H-2 Freeway. The land to the west of Kipapa Stream, is also developed. Agricultural areas cover a significant amount of land draining to Kipapa Stream (Oceanit 2007). Similarly, Waikele Stream itself transitions from forest and urban land in the western and northern headwaters, respectively, to grassland and agricultural areas before joining Kipapa Stream near the highly urbanized mouth of the watershed (Figure 5).

Available land cover data (NOAA 2011; illustrated in Figure 5) were supplemented in the watershed modeling analysis (Appendices A and B) with an evaluation of land ownership and land use. Land use categories provide further detail for some of the land cover categories to more accurately represent the pollutant generating potential of the land use type. For example, cultivated land in the land cover category was divided into different types such as pineapple, seed corn, and truck crop and impervious surfaces were separated by their urban land use type (i.e., residential, commercial, etc.). As summarized in Table 1, the land uses incorporated in the watershed modeling analysis were also divided into ownership categories that provided the basis for the TMDL allocations (Section 7.1 and Appendix C).

Table 1. Estimated land use area by ownership category

	Estimated Land Use Areas by Ownership Category (acres)						
Land Use Category	**City and County of Honolulu**	**Military**	**State of Hawaii**	**Department of Education**	**Agriculture**	**Conservation**	**Total**
Commercial	120	0	0	90	0	0	**210**
Commercial-Industrial	180	190	0	0	290	0	**670**
Right of Way/Parking (not-swept)	950	460	250	10	0	0	**1,680**
Right of Way/Parking (swept)	0	0	120	0	0	0	**120**
High Density Residential	630	1,120	0	10	0	0	**1,770**
Low-Medium Density Residential	1,900	0	30	10	220	0	**2,180**
Golf Course	510	160	0	0	0	0	**670**
Open Space	540	1,490	100	0	3,970	0	**6,110**
Conservation	0	0	0	0	0	8,270	**8,270**
Fallow	0	230	90	0	2,520	0	**2,840**
Pasture	10	0	0	0	10	0	**20**
Pineapple	0	0	460	0	2,540	0	**3,000**
Seed Corn	0	0	60	0	760	0	**820**
Truck Crop	0	20	0	0	1,070	20	**1,110**
Total	**4,860**	**3,690**	**1,120**	**120**	**11,380**	**8,290**	**29,470**

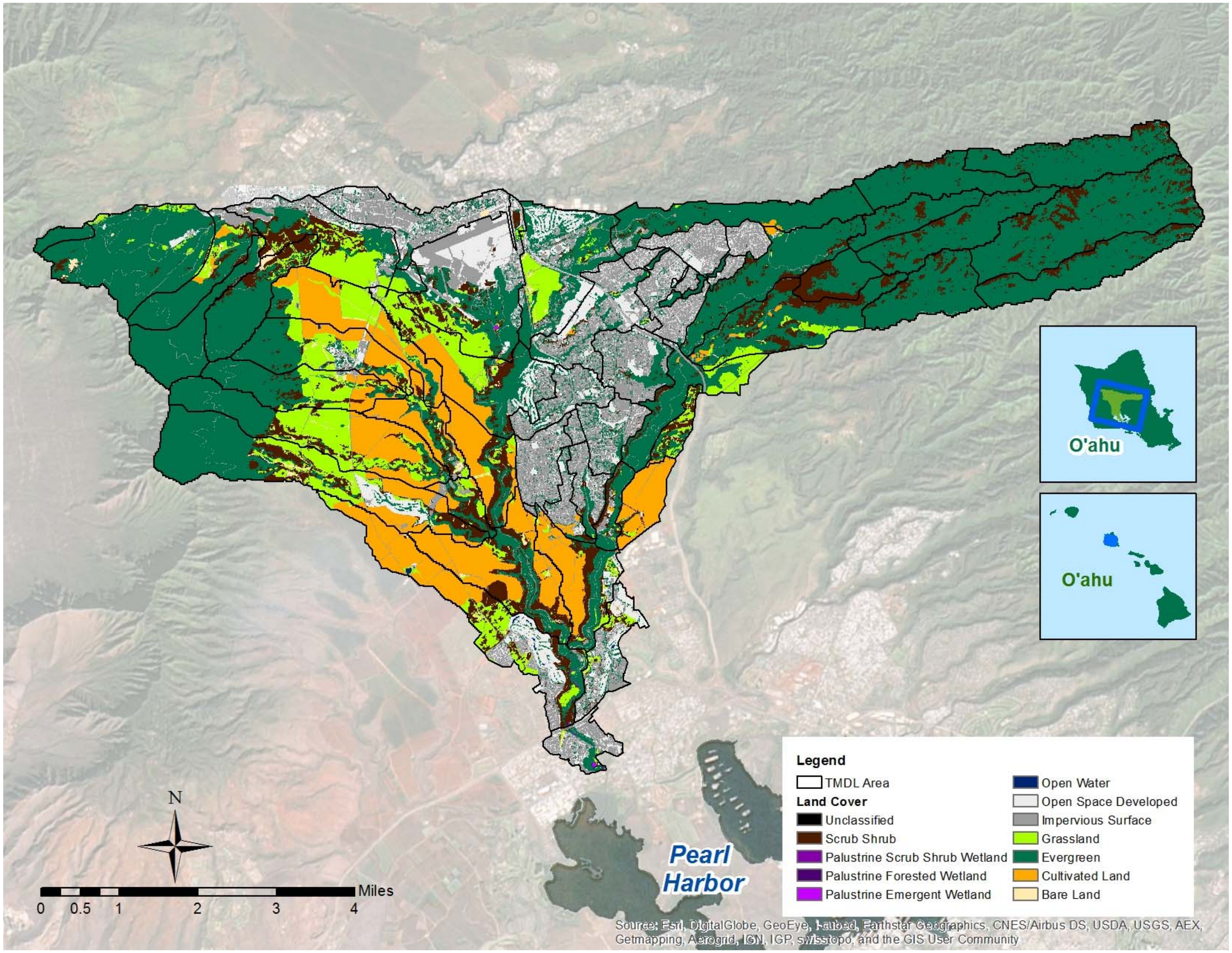


Figure 5. Land Cover and land use in the Waikele watershed (source: NOAA 2011)

2. Problem Statement

Waikele Stream is the largest stream on the island of Oahu and flows approximately 17 miles from its source to its mouth where it empties into the West Loch of Pearl Harbor (Oceanit 2007; Englund 1998). The watershed supports a variety of natural and anthropogenic activities, which may contribute loads of various pollutants.

A 2004 U.S. Geological Survey (USGS) study (Anthony et al. 2004) indicated that the highest concentrations of nutrients in Waikele Stream were typically detected during fair weather base flow supplied by groundwater as opposed to stormwater runoff. The likely source of these high base flow nutrient concentrations was fertilizers applied to agricultural land in the Waikele watershed. Flow-weighted mean concentrations of total nitrogen in Waikele Stream ranked in the middle 50 percent of 497 streams sampled nationwide and mean concentrations of total phosphorus (TP) ranked in the highest 25 percent of streams (Anthony et al. 2004). Another USGS study found that runoff from hillslopes (the areas between channel storage) during large storms was the main source of suspended sediment to Waikele Stream, while agricultural areas accounted for most of the sediment delivered to streams (Izuka 2012). Only a small percentage of suspended sediment came from channel storage. Agricultural land use was the largest source of suspended sediment in the watershed. Excess sediment deposition can affect aquatic life and habitats as well as human activities such as recreation, navigation, and water supply (Izuka 2012). Sediment can also carry other contaminants such as nutrients and toxic chemicals to waterbodies. Nutrients and suspended sediment are a management concern for Hawaiian coastal waters because of their potential effects on nearshore coral reefs, which are an important biological resource and an integral part of Hawaii's economically important tourist industry (Anthony et al. 2004).

Waikele Stream is included on Hawaii's 2018 section 303(d) list for turbidity, total nitrogen and nitrite-nitrate impairments (Table 2; DOH 2018). The original listings date back to 2002 and include the entire network (EN) (DOH 2018). Separate wet and dry season WQC (defined as November to April and May to October, respectively) are applicable for streams (see Section 3) and the season(s) associated with each pollutant is identified in Table 2.

Table 2. Waikele Stream section 303(d) listing information from Hawaii's 2018 Integrated Report

Waterbody	Geocode ID	Pollutant	Basis for Listing	Season*	Cycles Listed
Waikele Stream	3-4-10	Total Nitrogen	numeric assessment	dry season; wet season	2002, 2004, 2006, 2010, 2014, 2016, 2018
Waikele Stream	3-4-10	Nitrite-nitrate	numeric assessment	dry season; wet season	2002, 2004, 2006, 2010, 2014, 2016, 2018
Waikele Stream	3-4-10	Turbidity	numeric assessment	wet season	2002, 2004, 2006, 2010, 2014, 2016, 2018

*Streams have wet and dry season standards (November to April and May to October, respectively) (see Table 3 for more detail).
Source: (DOH 2018)

Turbidity is included on the section 303(d) list due to turbidity measurements exceeding the wet season (November – April) numeric WQC (DOH 2018). Turbidity measures the degree to which light is scattered and absorbed rather than transmitted in straight lines in a sample. It is caused by suspended matter (such as sediment, algae, bacteria, etc.) and provides an estimate of the opacity of the water. In addition to turbidity, total suspended solids (TSS) or suspended sediment concentration

(SSC) are often evaluated to characterize potential sources and quantify loadings of sediment. Sediment loadings are associated with anthropogenic activities, including livestock, agriculture, and construction and municipal activities, as well as natural conditions, such as wildlife, high precipitation, and steep slopes. Sediment and turbidity sources in the Waikele watershed are further described in Section 5. A USGS study evaluated suspended-sediment concentrations in the Waikele watershed from 2008 to 2010. This study found an increase of suspended sediments over the three-year period that was 3.5 times higher than the average yield during the 21 years prior (Izuka 2012). Comprehensive data analyses of both turbidity and TSS data confirm sediment problems at stations located throughout the watershed (Table 8 and Section 4.3.1) and indicate that these problems may occur year round, not just during the wet season.

The total nitrogen and nitrite-nitrate listings are due to measurements of these nutrients exceeding the stream's associated wet and dry season (year-round) numeric WQC (DOH 2018). Nutrient loadings are associated with several watershed sources that are discussed in Section 5. These sources include sediment, wildlife, and fertilizers. Based on a USGS study from 1999 to 2001, Waikele Stream has more than 10 times the amount of dissolved nitrate concentrations of typical forested and urban Oahu streams. This is suspected to be associated with agricultural fertilizer present in the watershed that reaches lower Waikele through groundwater (Anthony et al. 2004). Evaluation of nutrient geometric mean values confirm the nitrite-nitrate and total nitrogen exceedances and also suggest that total phosphorus may be another pollutant of concern (Table 8 and Section 4.3.1).

3. Water Quality Standards and TMDL Numeric Targets

WQS designate the “uses” to be protected (e.g., recreation; support and propagation of aquatic life, agricultural and industrial water supplies, shipping, and navigation) and the “criteria” for their protection (e.g., how much of a pollutant can be present in a waterbody without impairing its beneficial uses). TMDLs are developed to meet applicable WQS, which may be expressed as numeric water quality criteria or narrative criteria for the support of beneficial uses. The TMDL numeric target identifies the numeric goals or endpoints for the TMDL that equate to attainment of the WQS. When a numeric WQC is available, the TMDL target is set equal to this value. Alternatively, the TMDL target may represent a quantitative interpretation of a narrative (or qualitative) WQC. This section reviews the applicable WQS and identifies appropriate targets for calculation of the nutrient and turbidity TMDLs for Waikele Stream.

3.1. Applicable Water Quality Standards

Hawaii Administrative Rules (HAR) Title 11, Department of Health Chapter 54 establish WQS for the waters of Hawaii (DOH 2014). These include both the beneficial uses to be protected and the WQC necessary to protect the uses, as described below. State WQC are defined for both inland and marine waterbodies. The inland WQC apply to the Waikele watershed.

3.1.1. Beneficial Uses

When calculating TMDLs, numeric targets are established to meet WQC and subsequently ensure the protection of uses. Beneficial uses in inland receiving waters are Class 1 or Class 2, depending upon underlying land use designations and regulations, as described below:

Class 1 It is the objective of Class 1 waters that these waters remain in their natural state as nearly as possible with an absolute minimum of pollution from any human-caused source. To the extent possible, the wilderness character of these areas shall be protected. Waste discharge into these waters is prohibited. Any conduct which results in a demonstrable increase in levels of point or nonpoint source contamination in Class 1 waters is prohibited (DOH 2014).

Class 1.a. The uses to be protected in Class 1.a waters are scientific and educational purposes, protection of native breeding stock, baseline references from which human-caused changes can be measured, compatible recreation, aesthetic enjoyment, and other nondegrading uses which are compatible with the protection of the ecosystems associated with waters of this class (DOH 2014).

Class 1.b. The uses to be protected in Class 1.b waters are domestic water supplies, food processing, protection of native breeding stock, the support and propagation of aquatic life, baseline references from which human-caused changes can be measured, scientific and educational purposes, compatible recreation, and aesthetic enjoyment. Public access to these waters may be restricted to protect drinking water supplies (DOH 2014).

Class 2 The objective of Class 2 waters is to protect their use for recreational purposes, the support and propagation of aquatic life, agricultural and industrial water supplies,

> shipping, and navigation. The uses to be protected in this class of waters are all uses compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters. These waters shall not act as receiving waters for any discharge which has not received the best degree of treatment or control compatible with the criteria established for this class. No new treated sewage discharges shall be permitted within estuaries (DOH 2014).

Waikele Stream and its tributaries fall within the Class 1.a, 1.b, and Class 2 inland waters (Figure 66). The Class 1.b inland waters are located in the eastern headwaters, while Class 1.a waters are the eastern headwaters that are part of the Oahu NWR. While not fully evaluated for this watershed, the protection of native breeding stock is likely the most sensitive of these uses for both of these areas. For Class 2 waters, the designated uses include protection for recreational purposes, the support and propagation of fish and other aquatic life, and agricultural and industrial water supplies. The impaired segment of Waikele Stream is a Class 2 waterbody.

3.1.2. Water Quality Criteria

The Waikele watershed consists of Class 1.a, Class 1.b, and Class 2 waters. The inland water criteria identified in the HAR Title 11, Department of Health Chapter 54, Water Quality Standards, which were approved on November 15, 2014 (DOH 2014) apply to these waters. These season-specific WQC for the Waikele watershed are presented in Table 3, where terms have the following meanings:

Geometric mean	The geometric mean of all time-averaged samples should not exceed this value. The geometric mean is calculated as the n^{th} root of the multiple of all samples, where n represents the total number of samples.
Not to exceed more than 10% of the time	No more than 10% of all time-averaged samples exceed this value.
Not to exceed more than 2% of the time	No more than 2% of all time-averaged samples exceed this value.

These WQC are limits or levels that were established for the protection of beneficial uses of the waters of the state. Therefore, attainment of these WQC will result in restoration and protection of the Class 1 and Class 2 beneficial uses. The WQC for this TMDL are presented in milligrams per liter (mg/L), micrograms per liter (µg/L; equivalent to 1,000 times the mg/L value), or Nephelometric turbidity units (NTU).

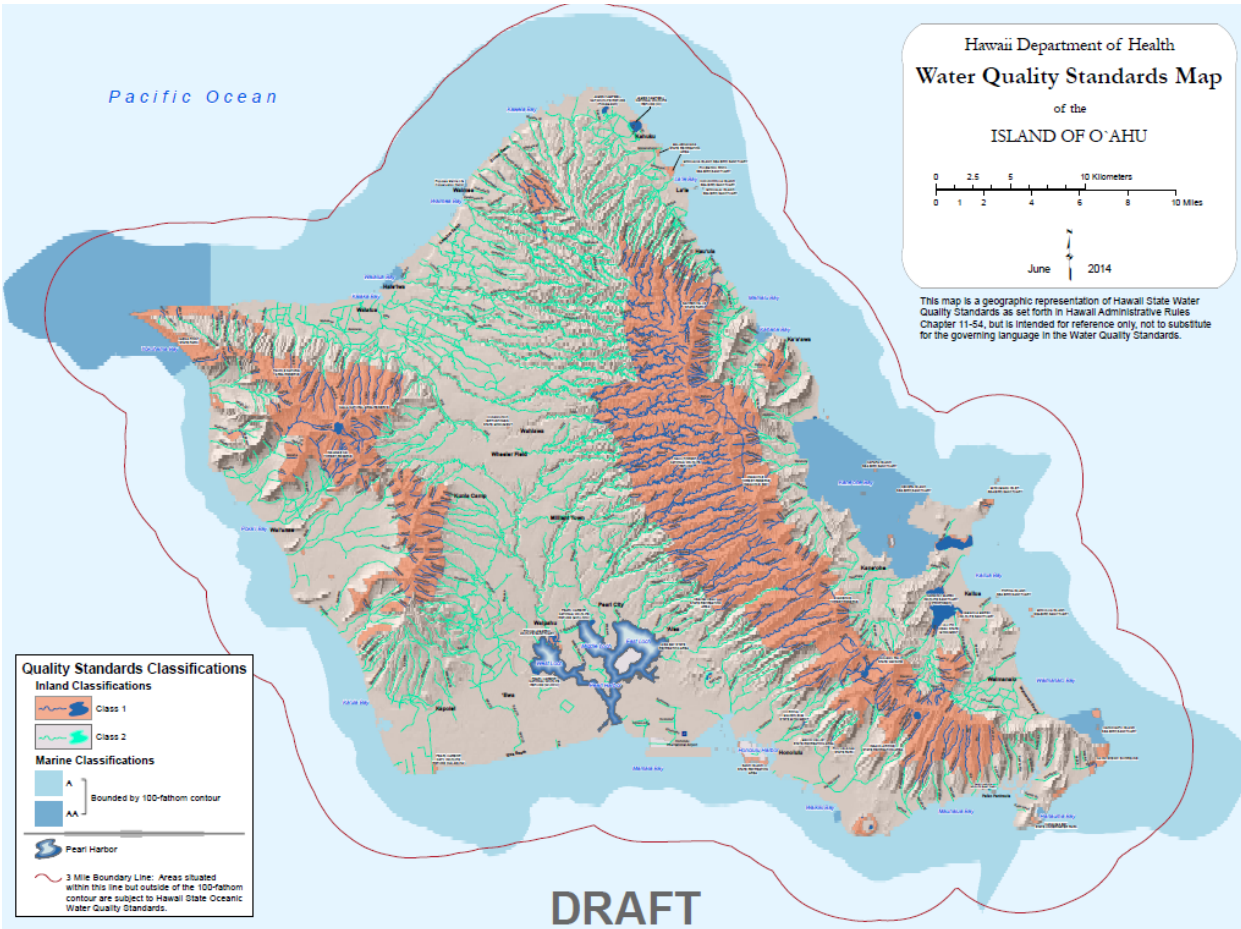


Figure 6. Water quality standards map for Oahu[1]

Table 3. Stream water quality criteria (DOH 2014)

Parameter	Geometric mean		10% exceedance value		2% exceedance Value	
	Wet Season[a]	Dry Season[a]	Wet Season[a]	Dry Season[a]	Wet Season[a]	Dry Season[a]
Total Nitrogen (µg/L)	250	180	520	380	800	600
Nitrite + Nitrate Nitrogen (µg/L)	70	30	180	90	300	170
Turbidity (NTU)	5	2	15	5.5	25	10
Total Phosphorus[b] (µg/L)	50	30	100	60	150	80
Total Suspended Solids[b] (mg/L)	20	10	50	30	80	55

[a] Wet season = November 1 through April 30; Dry season = May 1 through October 31

[b] Waikele Stream was not listed for total phosphorus or total suspended solids (TSS); however, these WQC were used for analyses in this TMDL report.

[1] http://health.hawaii.gov/cwb/site-map/clean-water-branch-home-page/water-quality-standards/

3.2. Antidegradation

Hawaii's WQS (DOH 2014) also include an antidegradation policy, which states that existing water uses and the level of water quality necessary to protect the existing uses must be maintained and protected. The policy also states that high quality waters must be maintained and protected unless the state finds that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the water is located. In allowing degraded water quality, the state must ensure water quality adequate to fully protect existing uses of the water.

All discharges will be treated and controlled to achieve the highest statutory and regulatory requirements for point sources and all cost-effective and reasonable BMPs for nonpoint sources. The antidegradation policy also requires that state waters that are designated as an outstanding national resource must be maintained and protected. In such waters, no degradation of water quality is allowed.

3.3. TMDL Numeric Targets

Where possible, the TMDL numeric targets are a direct translation of the WQC presented in the HAR (DOH 2014) identified to protect the Class 1 and Class 2 designated uses. For the Waikele watershed, the numeric targets selected in the TMDL depend on whether the impairment is associated with dry and/or wet season conditions (Table 4).

As described in Section 2, Waikele stream is currently listed as impaired for turbidity, total nitrogen, and nitrite-nitrate (DOH 2018). Data analyses confirmed these impairments and also identified total phosphorus and TSS as additional pollutants consistently exceeding their WQC (Section 4.3.1). Loadings and load reductions were calculated for total phosphorus, however, it is not included in the TMDL allocations because it is not officially listed as impaired on the 303(d) list. As indicated previously, turbidity is not a mass-based pollutant and cannot be used to calculate loads. Sediment TMDLs (represented by TSS numeric targets) were used as a surrogate for turbidity TMDL and allocation calculations (see Figure 21 and Section 4.3.2.1 for a discussion on the relationship between turbidity and TSS) and it is assumed that achieving the sediment TMDL will result in attainment of the turbidity WQS. TMDLs were calculated for total nitrogen, nitrite-nitrate, and TSS (also representing turbidity) using the TMDL numeric targets presented in Table 4. The numeric targets, which are a direct translation of the WQC, were used to calculate the loading-based TMDLs.

Table 4. TMDL numeric targets

	Geometric mean		10% exceedance value		2% exceedance value	
Parameter	Wet Season[a]	Dry Season[a]	Wet Season[a]	Dry Season[a]	Wet Season[a]	Dry Season[a]
Total Nitrogen (μg/L)	250	180	520	380	800	600
Nitrite + Nitrate Nitrogen (μg/L)	70	30	180	90	300	170
Total Phosphorus (μg/L)	50	30	100	60	150	80
Total Suspended Solids (mg/L)[b]	20	10	50	30	80	55

[a] Wet season = November 1 through April 30; Dry season = May 1 through October 31

[b] Total suspended solids numeric targets were used as a surrogate for turbidity impairments

4. Data Inventory and Analysis

Data from numerous sources were used to represent the watershed, characterize the water quality conditions and impairments, identify potential sources associated with sediment and nutrients, configure and calibrate a watershed model, and support the calculation of TMDLs. This section provides an inventory of the observed data, a summary of hydrologic conditions in the watershed, and analyses to review water quality conditions in the watershed. This data analysis section characterizes conditions based on samples collected and quantified throughout the reaches of the Waikele watershed. Supplementary information about watershed conditions has been estimated using a model (Appendices A and B).

4.1. Data Inventory

The categories of data used in developing these TMDLs include physiographic data that describe the physical conditions of the watershed (generally in geographic information system [GIS] files) and environmental monitoring data that identify past and current conditions and support the identification of potential pollutant sources. Table 5 presents the various data types and data sources used in the development of these TMDLs. The following sections describe the key datasets used for TMDL development and analyses: water quality, hydrologic, meteorological, and watershed characteristic data.

Table 5. Inventory of data and information

Data Type	Data Source(s)
Environmental Monitoring Data	
Water quality monitoring data	DOH 2001-2004; United States Geological Survey (USGS) 1999-2001, 2007-2010; Storage and Retrieval Data Warehouse (STORET) 2000-2001; United States Army Corps of Engineers (USACE) (2008-2011)
Streamflow data	USGS 1951-present; USACE (2008-2011)
Meteorological data	USGS; National Oceanic and Atmospheric Administration - National Climatic Data Center (NOAA-NCDC); National Weather Service (NWS) Hydronet rain gages; U.S. Fish and Wildlife Service (USFWS); Weather Underground
Physiographic Data	
Stream network	Hawaii Statewide GIS Program (http://planning.hawaii.gov/gis/download-gis-data/); HSPF model reaches (developed by NHC)
Land use and land cover	Hawaii Statewide GIS Program (http://planning.hawaii.gov/gis/download-gis-data/); NOAA Coastal Change Analysis Program (C-CAP) (2011)
MS4 and Stormwater System	Pipes, outfalls, culverts, channels, conduits from Honolulu Land Information System (HoLIS, http://gis.hicentral.com/data.html)
Soils	USDA State Soil Geographic Data Base (STATSGO)
Watershed boundaries	Hawaii Statewide GIS Program (http://planning.hawaii.gov/gis/download-gis-data/); HSPF sub-basins (developed by NHC)
Topographic and elevation data	Hawaii Statewide GIS Program (http://planning.hawaii.gov/gis/download-gis-data/); 10-meter National Elevation Dataset from Geospatial Data Gateway (http://datagateway.nrcs.usda.gov); 5 foot contours from HoLIS (http://gis.hicentral.com/data.html)

4.1.1. Water Quality Data Description

Water quality monitoring data for sediment and nutrients in the Waikele watershed were obtained from the Hawaii DOH Clean Water Branch, Storage and Retrieval Data Warehouse (STORET), U.S. Army Corps of Engineers (USACE), and the USGS. These data were collected at 15 stations located within or tributary to impaired waterbodies. Figure 7 illustrates the spatial distribution of water quality monitoring stations. The stations are presented in five subareas (or subgroups) that were used in the HSPF modeling analysis (Appendices A and B), providing additional spatial context for the analyses. These data, which were collected between 1999 and 2011, were well distributed among the wet and dry seasons, as indicated in Table 6. The number of samples collected at each station varied significantly. With the exception of the SSC data collected by USGS, the records summarized in Table 6 were grab samples. The SSC data were collected using automatic samplers.

Water quality data were analyzed below to characterize general summary statistics by season, relationships between parameters, and spatial distribution of water quality conditions. The results of these analyses are presented in Section 4.3. Some of these data were also used for watershed model configuration and calibration, which are described separately (NHC 2017a, 2017b; see Appendices A and B, respectively).

Table 6. Seasonal distribution of water quality data

Parameter (units)	Number of Samples	
	Wet Season	Dry Season
Sediment		
Turbidity (NTU)	248	113
Total Suspended Solids (mg/L)	316	154
Suspended Sediment Concentration (mg/L)	544	552
Nutrients		
Ammonia (µg/L)	30	16
Nitrate/Nitrate (µg/L)	326	152
Total Nitrogen (µg/L)	291	129
Total Phosphorus (µg/L)	324	156

4.1.2. Hydrologic Data Description

Continuous flow measurements in the watershed include data collected at the USGS gage on Waikele Stream at Waipahu (station 16213000; Figure 7). Continuous flow data have been obtained for this station from the USGS National Water Information System for 1951 to present (http://nwis.waterdata.usgs.gov/nwis). Additional continuous flow data were also obtained for Water Years 2008-2010 for Waikele Stream at Wheeler Field, Kipapa Stream near Wahiawa, and Mililani Storm Drain A at Mililani (stations 16212601, 16212800, and 212604158012700, respectively; Figure 7).

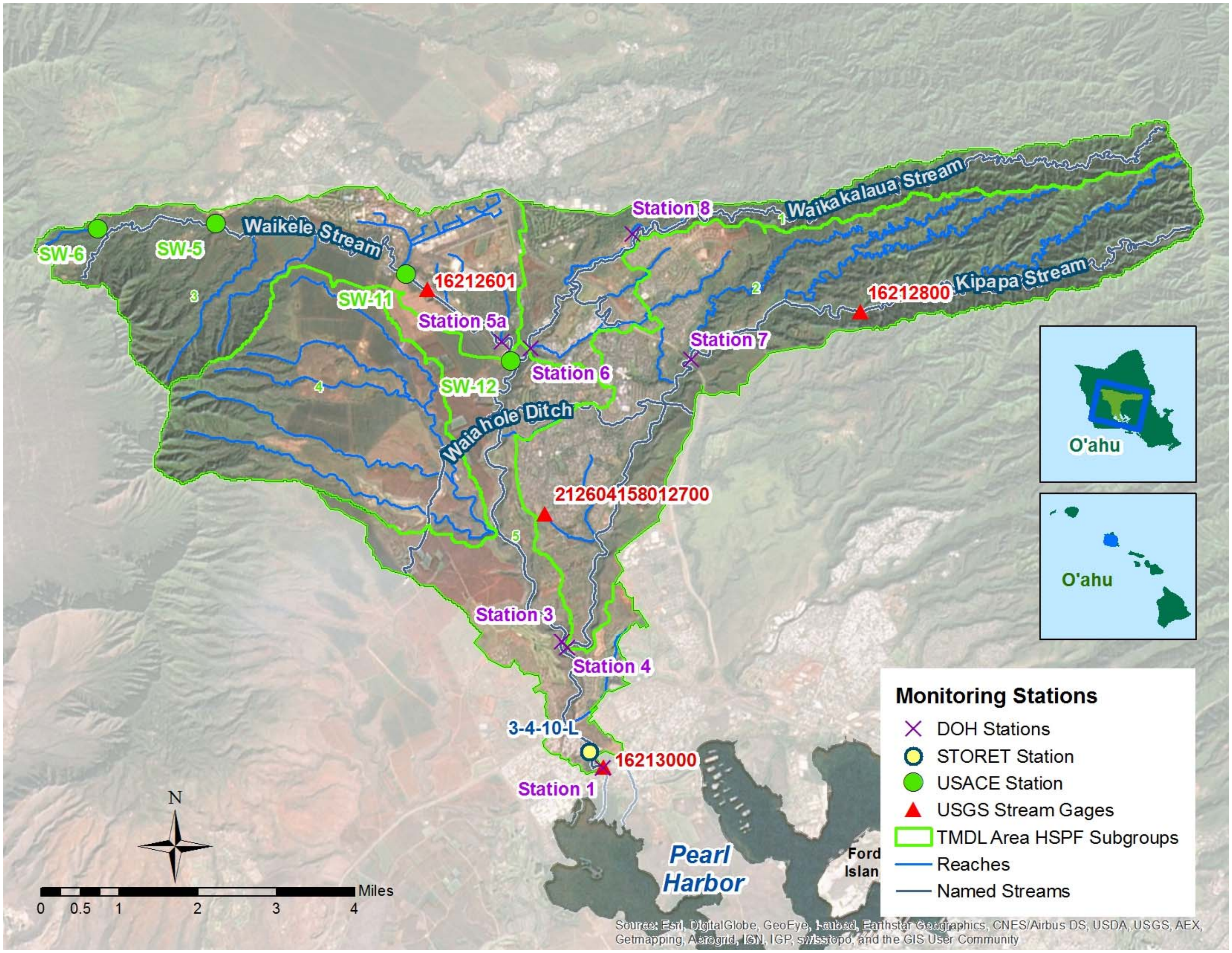


Figure 7. Water quality monitoring stations and HSPF subgroups

4.1.3. Meteorological Data

The Waikele watershed was divided into six precipitation zones for the TMDL study with a unique time-series of precipitation applied to each zone (Figure 8). Multiple precipitation zones were necessary to account for the spatial variability of rainfall in the watershed. Rain gages were applied either as a primary rain gage or for filling in missing information in the primary rain gages. The six precipitation zones were created for the HSPF model using meteorological data from National Oceanic and Atmospheric Administration-National Climatic Data Center (NOAA-NCDC), USGS, U.S. Fish and Wildlife Service (USFWS), National Weather Service (NWS)-Hydronet, and Weather Underground rain gages. The precipitation time-series for each of the six zones used data from the most applicable rain gage, except for select storms when average hourly zonal rainfall was computed from NOAA Next Generation Weather Radar (NEXRAD) data. Figure 8 shows the average annual precipitation isohyetals as well as the six precipitation zones and their associated gages. The eastern edge of the watershed receives the highest average annual precipitation (over 200 inches per year), while the mouth of the watershed is much drier and receives just over 30 inches per year. Section 2 of Appendix A provides greater detail on the precipitation and meteorological data used in the HSPF model.

4.1.4. Watershed Characteristic Data

Various types of watershed characteristic data were incorporated into the modeling study of the Waikele watershed. These data include, but are not limited to, land cover, soils, and elevation. The NOAA Coastal Change Analysis Program (C-CAP) land cover image from a remote sensing study in 2011 was used to represent land cover in the watershed and to supplement the agricultural portions of the statewide land use layer (Figure 5).

Soils data were obtained from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (Figure 3), 10-meter elevation data were obtained from the Geospatial Data Gateway (Figure 2; http://datagateway.nrcs.usda.gov), and elevation contours were obtained from Honolulu Land Information System (HoLIS, http://gis.hicentral.com/data.html).

4.2. Hydrologic Analyses

Thirty years of average daily flows at the USGS gage Waikele Stream station at Waipahu (station 16213000) were evaluated to characterize temporal patterns over a range of hydrologic conditions. Specifically, monthly minimum, maximum, mean, and median flows were calculated based on daily measurements for October 1986 through September 2015. These summary statistics are presented in Table 7 and illustrated in Figure 9.

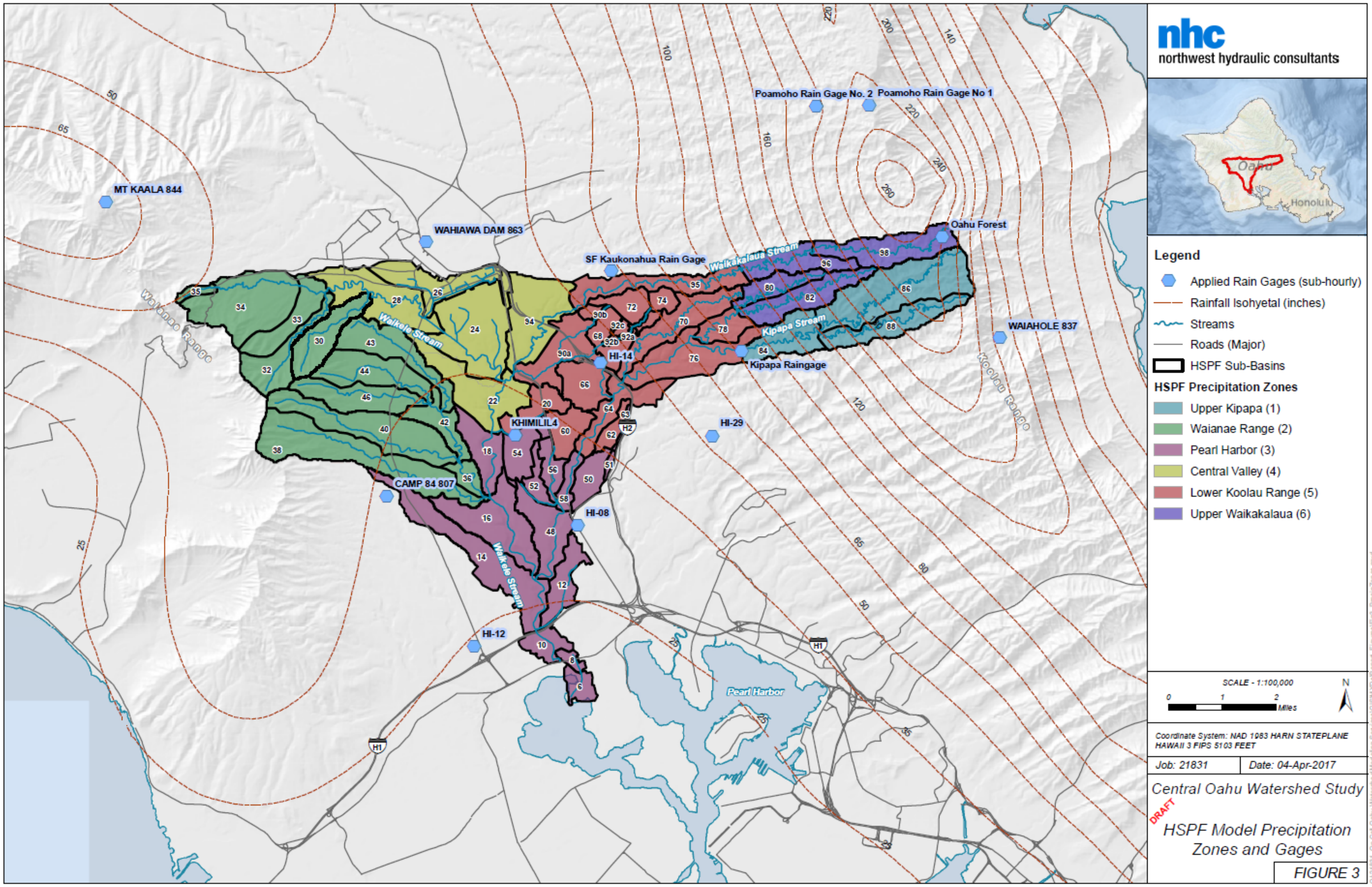


Figure 8. Precipitation zones and gages in the Waikele watershed (source: NHC 2017a)

Table 7. Monthly flow statistics at station 16213000 – October 1986 through September 2015

Month	Flow for October 1986 through September 2015 (cfs)				
	Number of Daily Measurements	Minimum	Maximum	Mean	Median
January	899	10	1,210	46	23
February	819	10	1,570	39	22
March	899	8	2,590	52	22
April	846	9	824	37	25
May	868	9	2,200	33	20
June	840	9	350	25	18
July	868	8	914	29	21
August	888	9	1,050	26	18
September	870	8	452	28	18
October	899	9	1,780	35	19
November	864	8	1,420	48	25
December	899	9	4,270	53	25

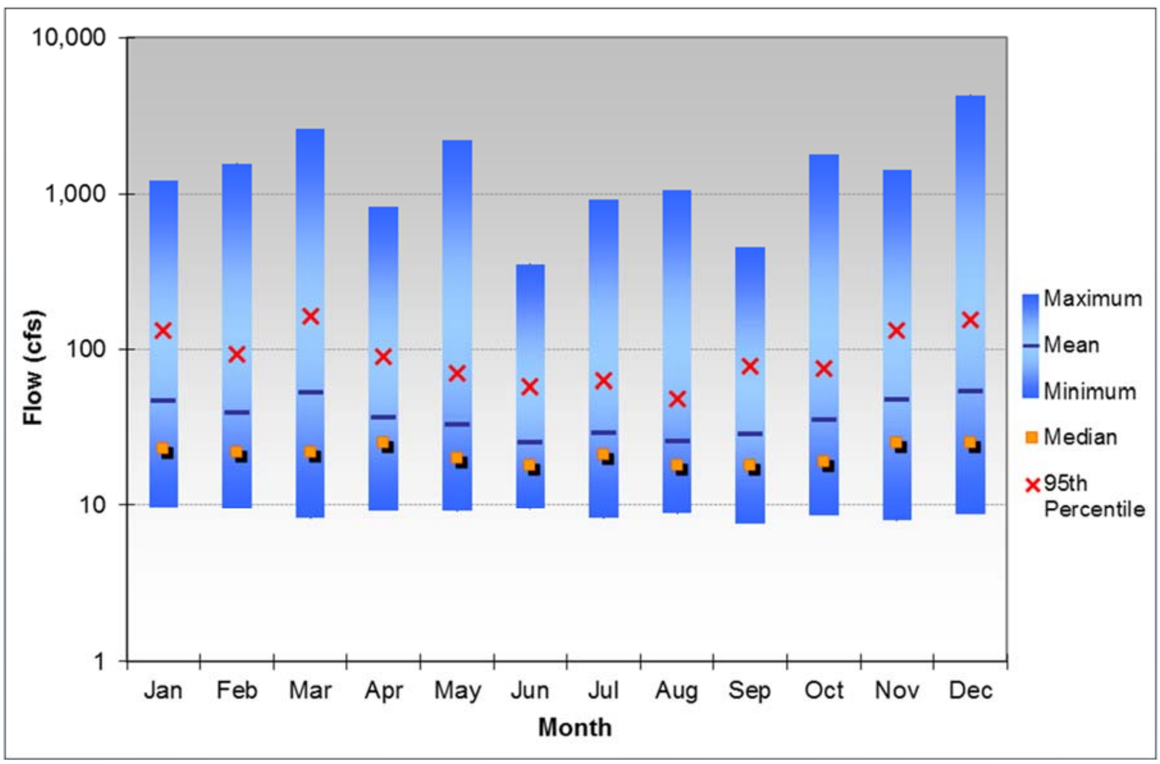


Figure 9. Monthly flow values at station 16213000 – October 1986 through September 2015

The HAR defines the wet season in Hawaii as November 1 through April 30 and the dry season as May 1 through October 31 (DOH 2014). Table 7 and Figure 9 show that November through April have higher mean flows than May through October, which is consistent with the HAR definitions of wet and dry seasons. The minimum flow for each month is similar (range of 8 to 10 cfs) and, as expected, the maximum flows exhibit much wider variability over the 30-year period. In general, November through March have higher maximum flows than the other months, while several dry season months have higher maximum flows than April (a wet month). The 95th percentile values are also illustrated. The wet season 95th percentile values are consistently higher than those in the dry months. These data indicate that although November through April typically have the largest flows, large storms also occur during the dry season, which may result in significant loads to the watershed.

The four stations with continuous flow data for Water Years 2008-2010 were also evaluated (Figure 10). This graph illustrates the variability in flow across stations and through time. The dark blue line represents the main USGS gage at the outlet of the watershed (station 1621300). This gage has the largest drainage area and, as expected, highest flow. The second highest flow was typically measured at station 16212800 on Kipapa Stream (green line), which has the second highest drainage area. Station 16212601 represents Waikele Stream at Wheeler (red line). This station has intermittent flow, likely associated with rainfall events. Mililani Storm Drain A (station 21260415802700) also has intermittent flow; however, flow at this station is more consistent and is measured at a lower rate, likely caused by urban runoff (Figure 10).

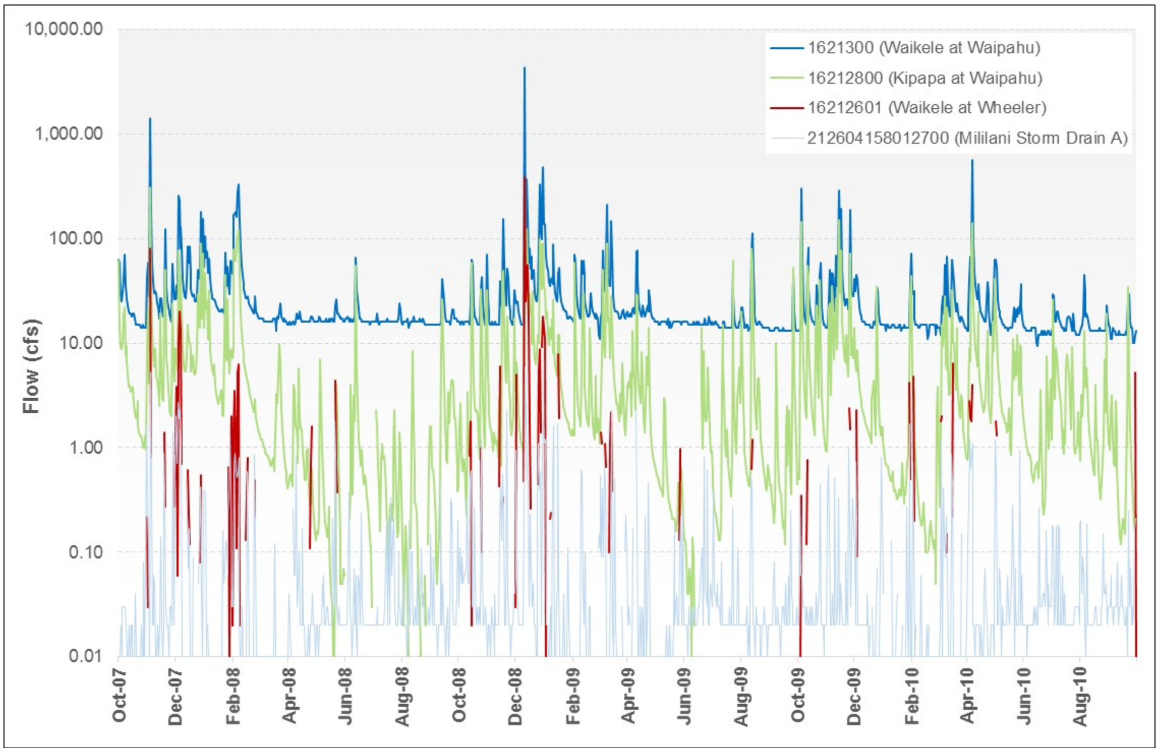


Figure 10. Continuous flow data time series – Water Years 2008-2010

The USACE collected stormflow measurements using automatic samplers along Waikele Stream through the Wheeler Army Airfield area (note: these stations are upstream and downstream of USGS station 16212601; Figure 7). These results generally show similar patterns to USGS station 16212601, with intermittent flow that triggered the automatic samplers only during large rainfall events especially closer to the headwaters (USACE 2015). Some stations only rarely have flow due to infiltration and stream bed losses. USACE noted that the initial flow in the streams is generally observed 4-6 hours after the rainfall event begins, regardless of whether the location is undeveloped or urbanized. They report that the higher and faster runoff from impervious areas has a similar timing to the faster runoff associated with steeper slopes in the undeveloped headwater areas and that peak flow usually occurs between 8 and 12 hours after rain begins (USACE 2015).

4.3. Water Quality Data Analyses

Sediment and nutrients data collected from stream segments were analyzed to provide guidance for the source assessment and to confirm impairments. These data include wet and dry season sampling conducted by DOH, USACE, and USGS as well as those data presented in the STORET database. Most of these data are grab samples (and represent an assortment of baseflow and stormflow conditions); however, USGS and USACE has collected suspended sediment concentration data at four USGS gages, which include baseflow and stormflow samples.

Analyses of the available water quality data include a comparison of water quality monitoring results to applicable WQC including summary statistics, spatial patterns, relationships between pollutants, and correlation to streamflow analyses. Results of these analyses are reported throughout this section.

Table 8 presents a summary of the nitrite-nitrate, total nitrogen, total phosphorus, TSS, and turbidity water quality data available within each HSPF subgroup, separated by wet and dry season. These summaries include the start and end dates of sampling, the number of samples, and the average, minimum, maximum, and geometric mean concentrations by season. The data were distributed among 4 (rather than 5) subgroups, with subgroup 4 not being represented (Figure 7). However, the samples collected at the base of the watershed from HSPF subgroup 5 are assumed to be influenced by all the upstream areas, which includes subgroup 4. The number of samples used to calculate seasonal geometric means ranged from 7 to 230, and the geometric means represent at least 2 sample locations within each of the subgroups identified in the table. Geometric mean exceedances are shown in red.

Table 8. Summary statistics by HSPF subgroup

Subgroup	Stations	Season	Start Date	End Date	Count	Average	Minimum	Maximum	Geomean
Nitrite-Nitrate (µg/L); Geomean WQC: Wet = 70 µg/L and Dry = 30 µg/L									
1	6,8	Wet	11/5/2001	4/1/2002	16	71	13	160	60
		Dry	7/20/1999	9/9/2002	11	72	17	133	61
2	7,4	Wet	11/5/2001	4/1/2002	15	66	1	123	47
		Dry	5/5/2002	10/7/2002	8	117	4	378	61
3	SW-5, SW-6, SW-11, SW-12, 5a	Wet	2/8/2002	4/7/2011	229	291	10	3821	105
		Dry	5/6/2002	6/4/2011	87	215	10	2410	87
5	1,3, 3-4-10L	Wet	3/15/1999	2/23/2004	66	774	22	1820	555
		Dry	5/12/1999	10/20/2003	46	1144	10	6300	614
Total Nitrogen (µg/L); Geomean WQC: Wet = 250 µg/L and Dry = 180 µg/L									
1	6,8	Wet	11/5/2001	4/1/2002	16	1267	102	13700	326
		Dry	7/20/1999	9/9/2002	11	1354	214	5800	789
2	7,4	Wet	11/5/2001	4/1/2002	15	1912	97	11000	559
		Dry	5/5/2002	10/7/2002	8	455	19	884	303
3	SW-5, SW-6, SW-11, SW-12, 5a	Wet	2/8/2002	4/7/2011	207	12615	5	195000	2861
		Dry	5/6/2002	6/4/2011	79	2733	5	22200	952
5	1,3	Wet	3/15/1999	2/23/2004	53	2601	11	16500	1220
		Dry	5/12/1999	10/20/2003	31	1350	11	3990	801
Total Suspended Solids (mg/L); Geomean WQC: Wet = 20 mg/L and Dry = 10 mg/L									
1	6,8	Wet	11/5/2001	4/1/2002	16	90	2	1080	14
		Dry	7/20/1999	9/9/2002	9	1024	0.5	3870	122
2	7,4	Wet	11/5/2001	4/1/2002	15	122	1	792	13
		Dry	5/5/2002	10/7/2002	7	1197	1	4160	79
3	SW-5, SW-6, SW-11, SW-12, 5a	Wet	2/8/2002	4/7/2011	223	1612	4	35220	238
		Dry	5/6/2002	6/4/2011	87	202	0.8	1592	75
5	1,3	Wet	3/15/1999	2/23/2004	62	441	1	5640	31

Subgroup	Stations	Season	Start Date	End Date	Count	Average	Minimum	Maximum	Geomean
		Dry	5/12/1999	10/20/2003	51	357	1	2295	43
Turbidity (NTU); Geomean WQC: Wet = 5 NTU and Dry = 2 NTU									
1	6,8	Wet	11/5/2001	4/1/2002	15	191	10	2310	38
		Dry	7/20/1999	9/9/2002	12	705	6	3800	96
2	7,4	Wet	11/5/2001	4/1/2002	14	136	5	667	35
		Dry	5/5/2002	10/7/2002	11	683	3	4200	36
3	SW-5, SW-6, SW-11, SW-12, 5a	Wet	2/8/2002	4/7/2011	177	2246	10	41290	319
		Dry	5/6/2002	6/4/2011	48	196	12	987	103
5	1,3	Wet	3/15/1999	2/23/2004	42	498	2	4840	59
		Dry	5/12/1999	10/20/2003	42	262	2	1320	45
Total Phosphorus (µg/L); Geomean WQC: Wet = 50 µg/L and Dry = 30 µg/L									
1	6,8	Wet	11/5/2001	4/1/2002	16	100	5	1050	17
		Dry	7/20/1999	9/9/2002	13	894	8	2920	239
2	7,4	Wet	11/5/2001	4/1/2002	15	178	5	1070	51
		Dry	5/5/2002	10/7/2002	10	783	12	3500	191
3	SW-5, SW-6, SW-11, SW-12, 5a	Wet	2/8/2002	4/7/2011	230	3120	20	40000	774
		Dry	5/6/2002	6/4/2011	87	678	5	5200	333
5	1,3	Wet	3/15/1999	2/23/2004	63	489	5	5100	191
		Dry	5/12/1999	10/20/2003	46	655	94	3610	388

4.3.1. Review of Impaired Segments

Several waterbody-pollutant combinations for the Waikele watershed were included on the section 303(d) list of impaired waterbodies in 2002 (Table 2). An impaired waterbody remains on the 303(d) list until either a TMDL is developed, or until new data indicates that the waterbody is no longer impaired. The Waikele watershed was not reassessed for 303(d) listing purposes following the initial 2002 impairment listing, so the current impairment listings remain as they were in 2002.

Temporal and spatial analysis of data collected after the 2002 impairment listing demonstrate that impairments continue to occur throughout the watershed (Figures 13-22, Table 8). For this analysis, nitrite-nitrate, total nitrogen, total suspended solids, turbidity, and total phosphorus exceeded the geometric mean WQC to varying degrees in 35 of the 40 geometric means calculated. Although the impairments were widespread both geographically and among pollutant type, these results were not incorporated into the 303(d) listing process. Therefore, the impairments identified in the table are useful for targeting pollutant reduction practices, but the DOH will not require TMDL load reductions for pollutants not officially identified on the 303(d) list (total phosphorus, dry season TSS).

To view the sampling data by individual sampling station and supplement the table of exceedances, data were graphed over time and compared to the ‘Not to exceed (NTE) more than 10% of the time’ WQC (Figure 11 through Figure 20). For these graphs, the USACE data are represented by storm averages and daily averages were calculated for stations with more than one measurement on a particular day. The time series plots are shown on a normal scale (values exceeding the selected scale are presented in a text box on the plot) as well as a logarithmic scale. The normal scale demonstrates the typical magnitude of observations while the log scale is useful to illustrate details associated with measurements closer to the WQC (which varies by wet and dry season on the plots). Distinct drainages are represented in the graphs by like colors and they are presented in the legend from upstream to downstream.

There are no temporal trends observed in the time series graphs as measurements vary for each parameter (Figure 11 through Figure 20). Frequent exceedances are observed for all pollutants and at all stations in both the earlier sampling (through 2003) and the more recent monitoring study (2008-2011). It is useful to note that most of the more recent data were collected by autosamplers during storm events and these samples exceed the WQC most of the time (with the exception of nitrite-nitrate [Figure 14]). Nutrient exceedances are observed consistently at the most downstream stations (represented by pink symbols in Figure 12, Figure 14, and Figure 16) while the TSS and turbidity levels at these stations are above the WQC at least half of the time (Figure 18 and Figure 20, respectively).

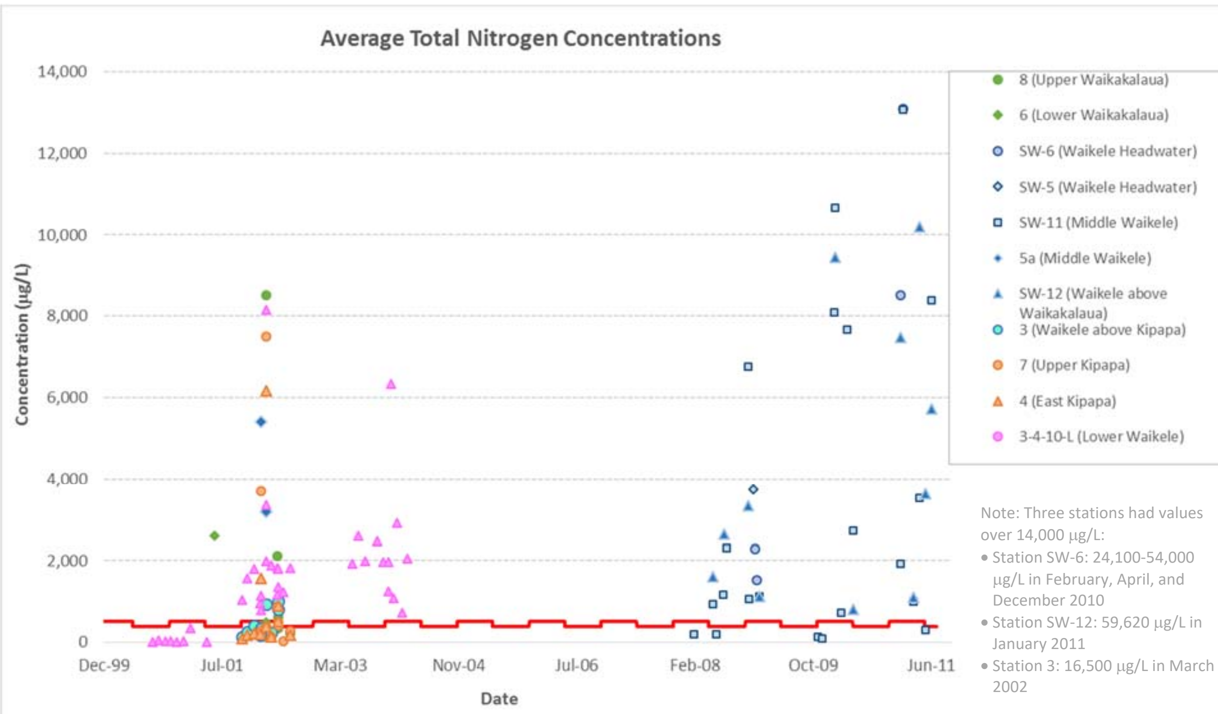


Figure 11. Average total nitrogen concentrations over time

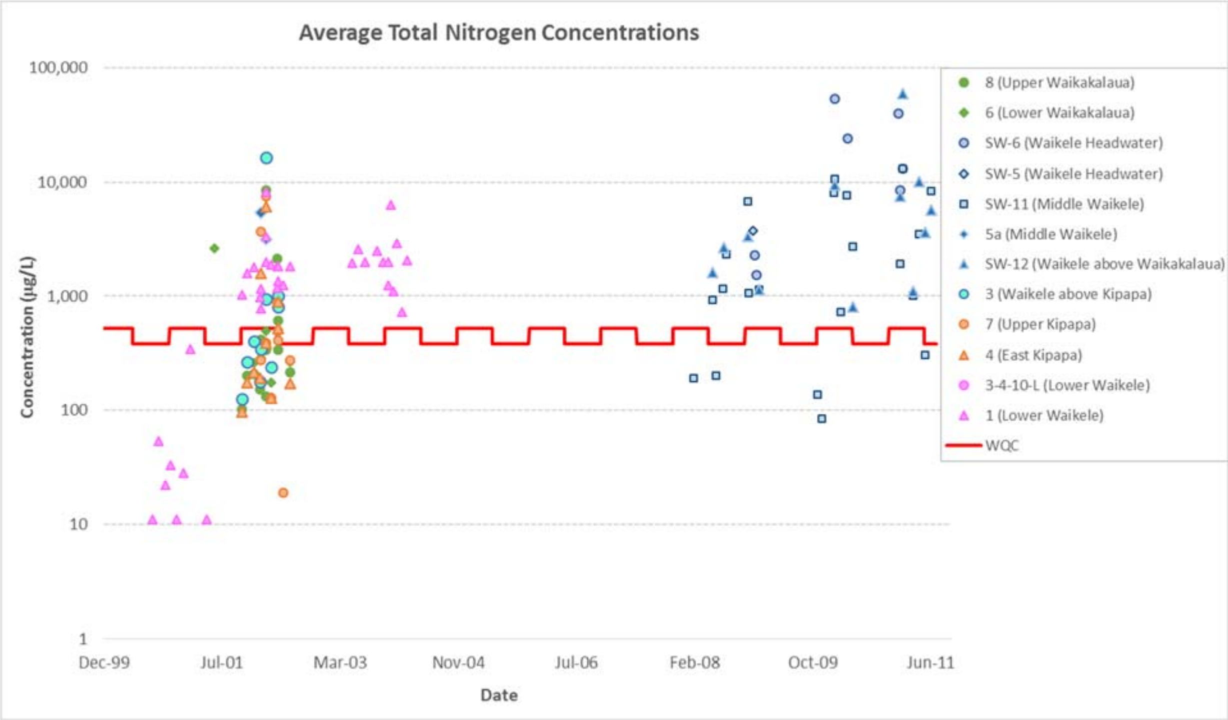


Figure 12. Average total nitrogen concentrations over time on a log scale

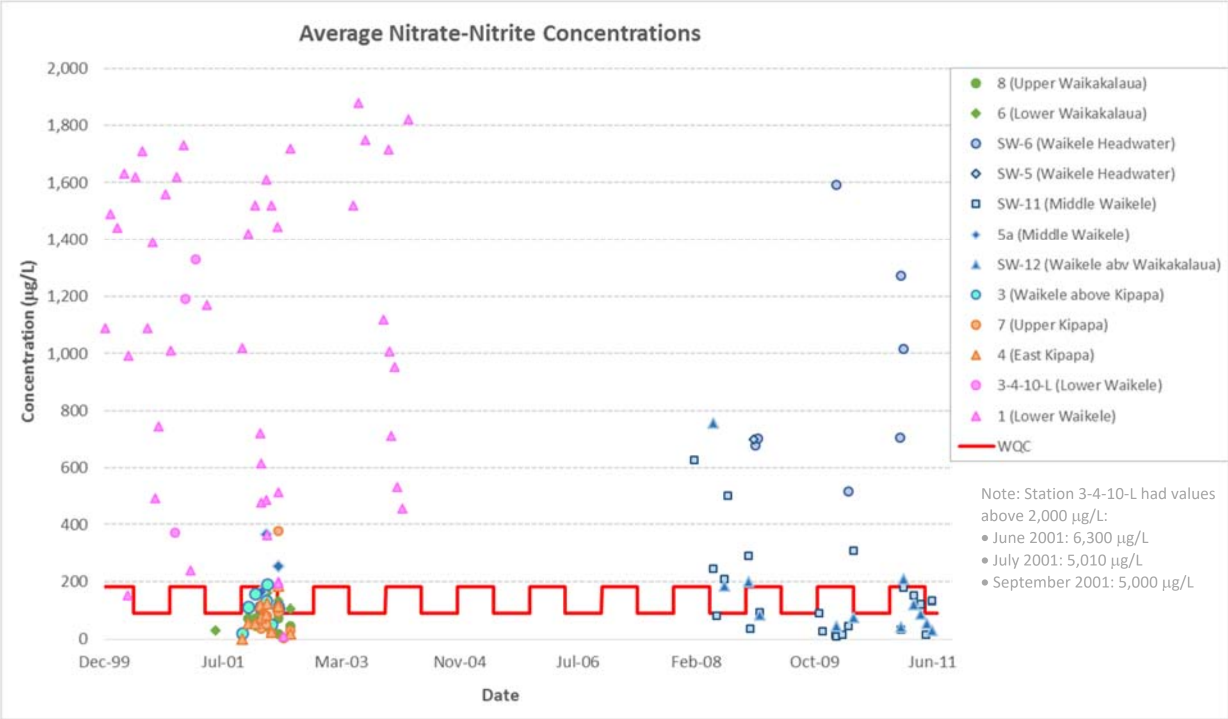


Figure 13. Average nitrite-nitrate concentrations over time

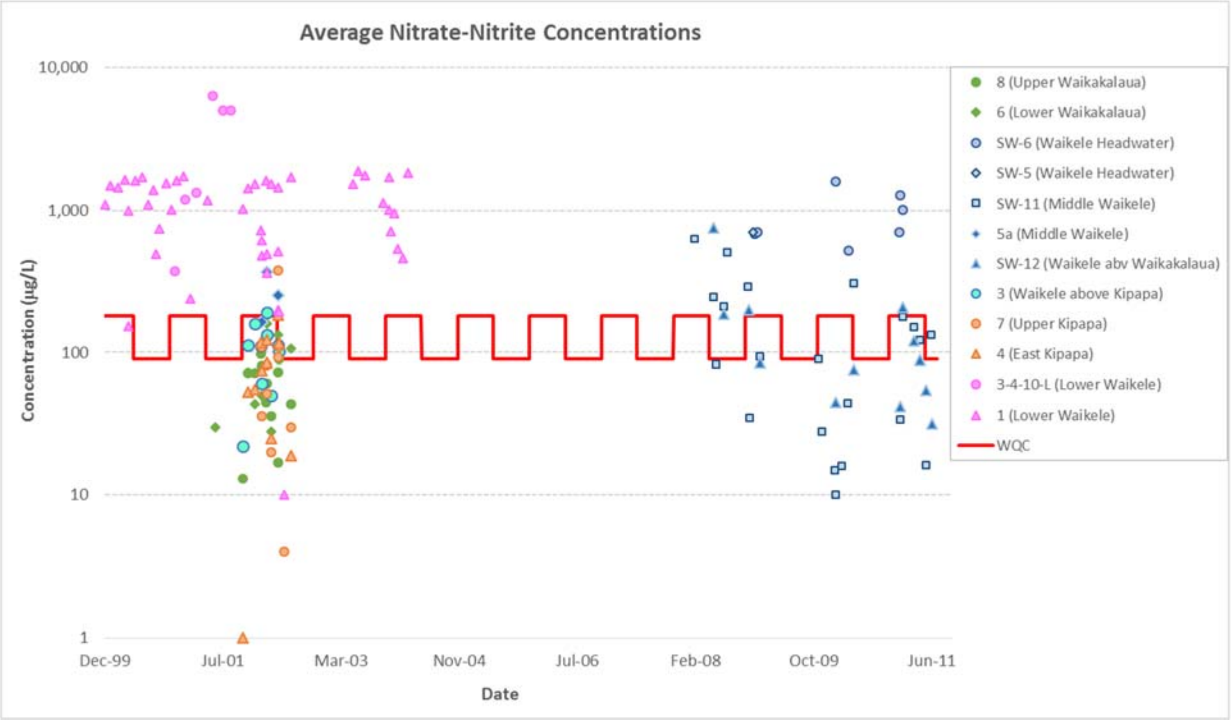


Figure 14. Average nitrite-nitrate concentrations over time on a log scale

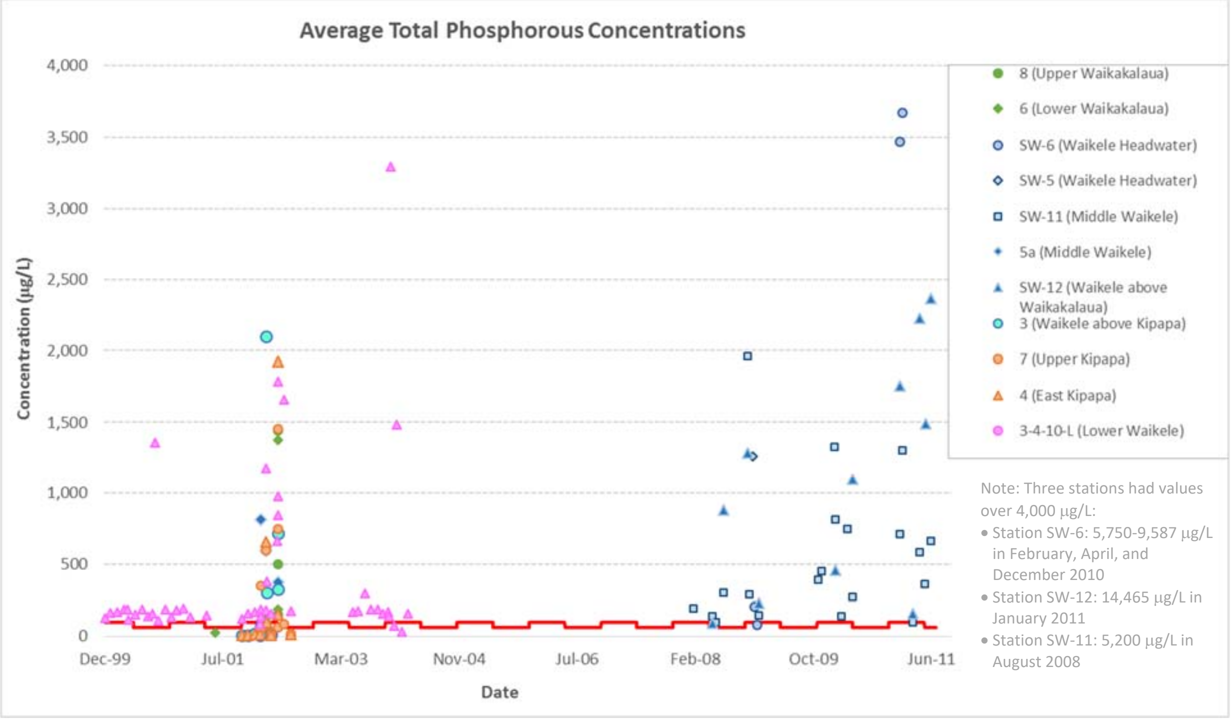


Figure 15. Average total phosphorus concentrations over time

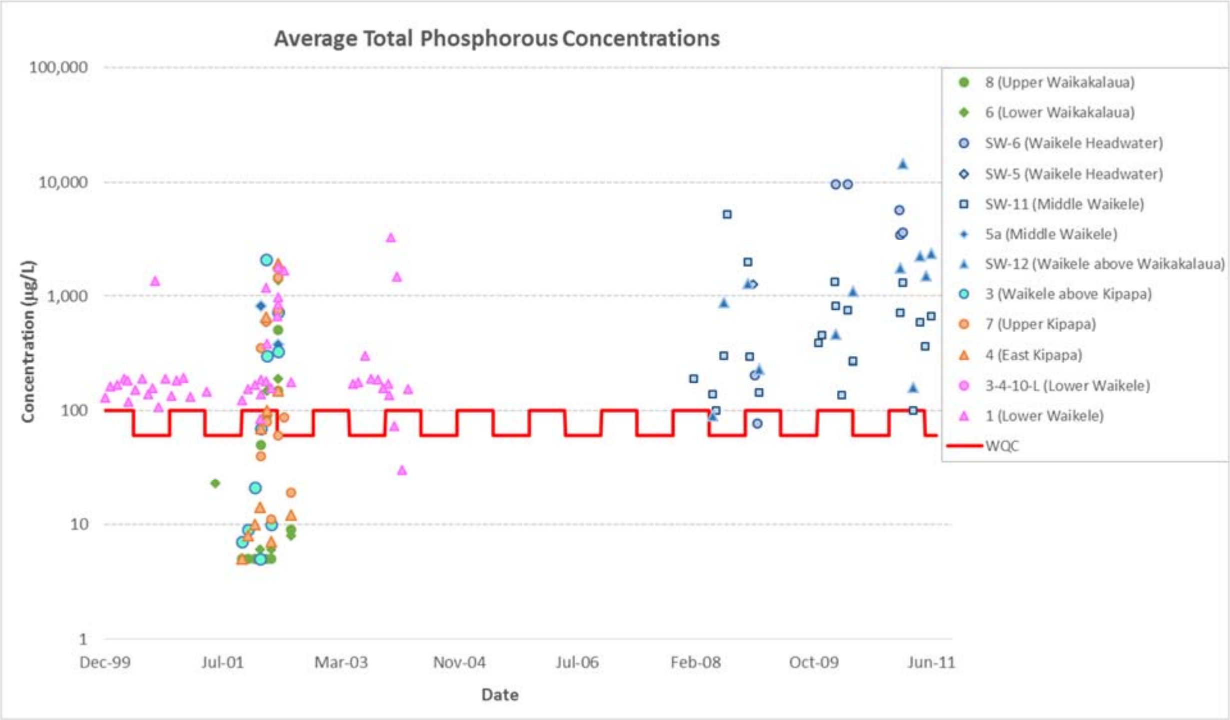


Figure 16. Average total phosphorus concentrations over time on a log scale

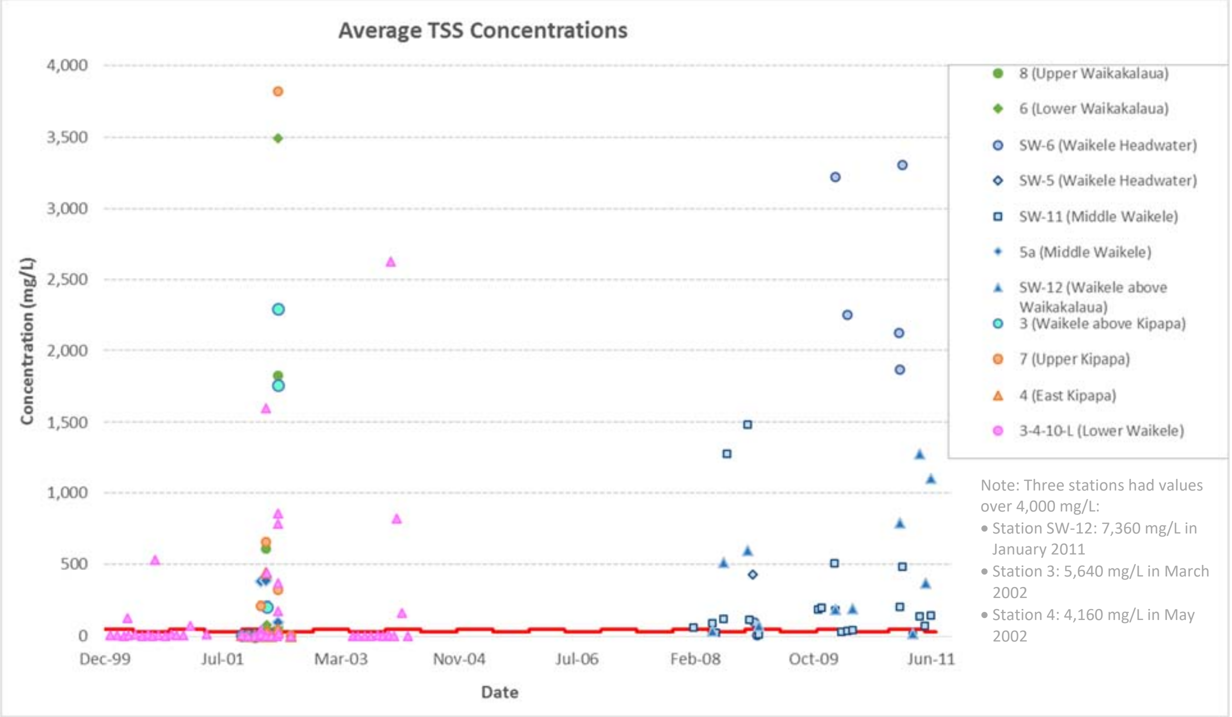


Figure 17. Average TSS concentrations over time

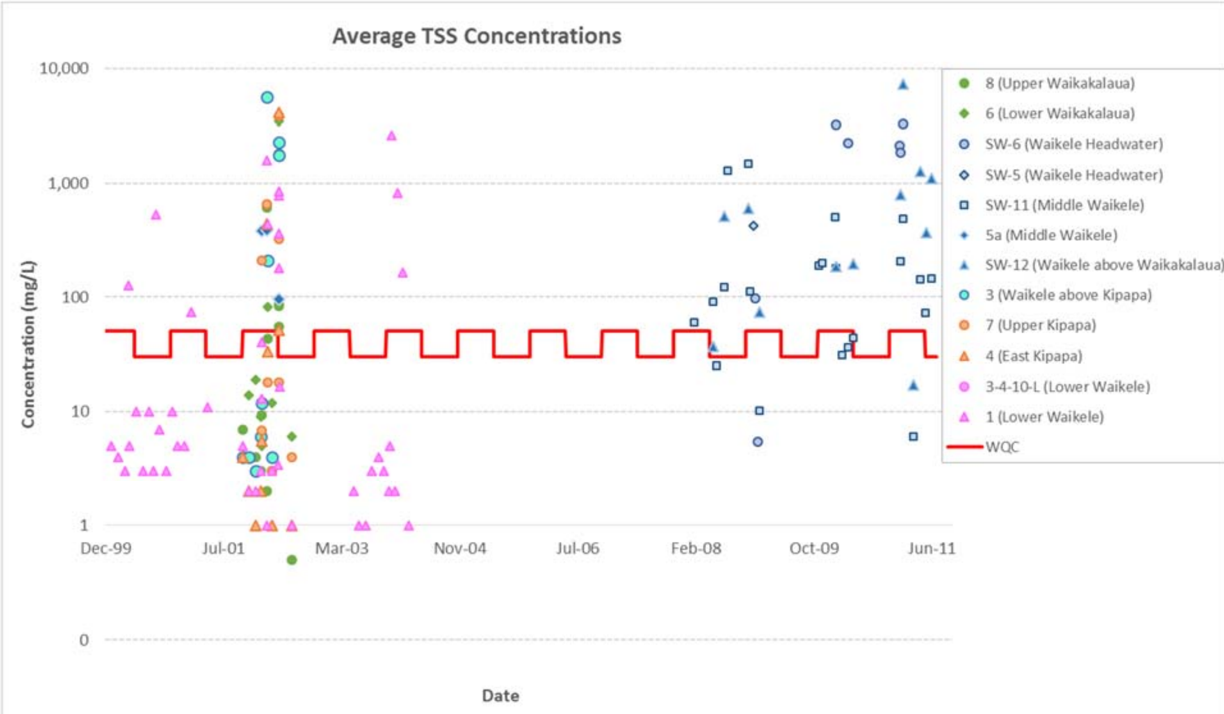


Figure 18. Average TSS concentrations over time on a log scale

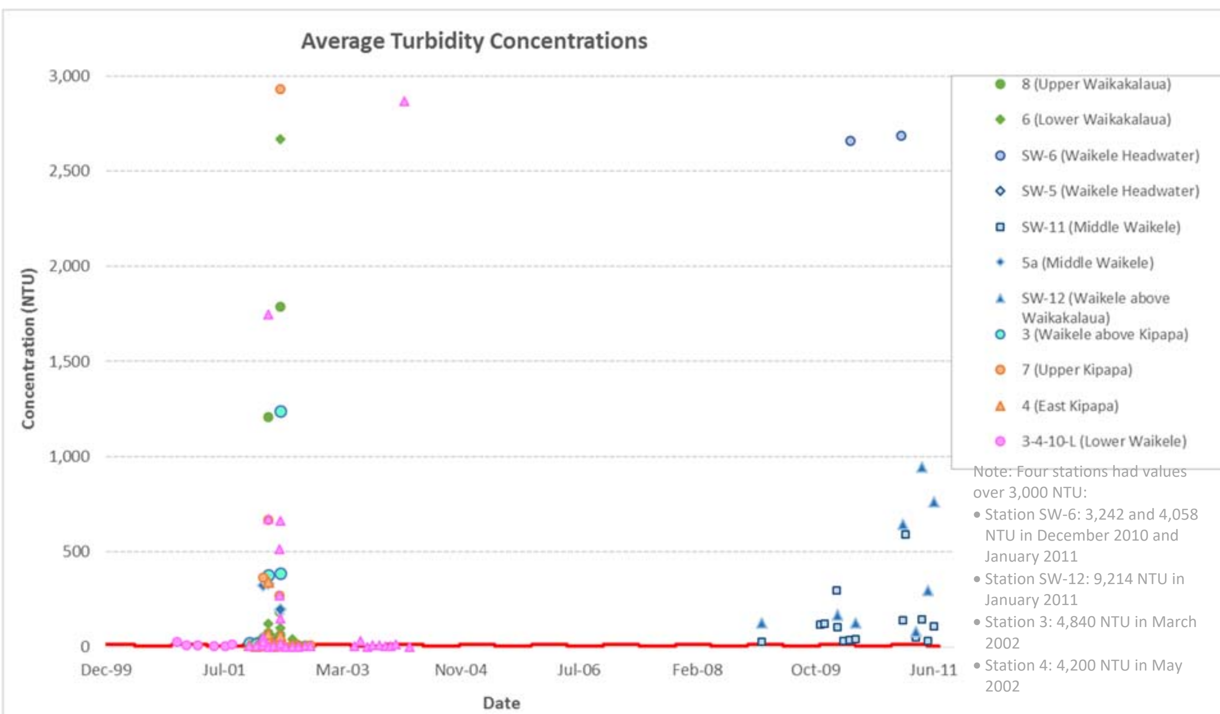


Figure 19. Average turbidity concentrations over time

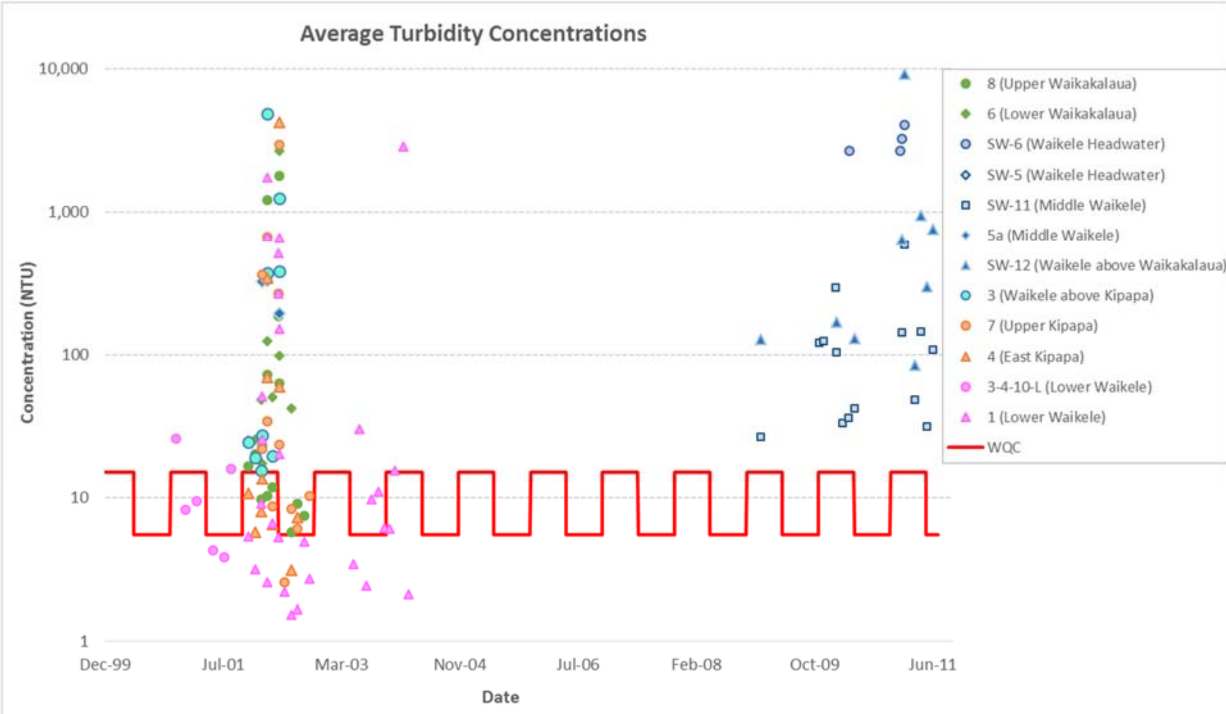


Figure 20. Average turbidity concentrations over time on a log scale

4.3.2. Trends and Relationships

Several trend analyses were conducted to obtain a better understanding of the conditions contributing to water quality problems. These include spatial and correlative analyses between parameters as well as an evaluation of the continuous SSC data with associated streamflow.

4.3.2.1. Correlative Analyses

To evaluate the relationships between water quality parameters, correlative analyses were performed. While these correlations are useful to understand conditions in the watershed and the connections between constituents that may be useful during implementation, they were not included in the loading calculations or allocations, which were based on model simulations (Appendices A through C).

Data analyses indicate that TSS and turbidity are strongly correlated in the Waikele watershed, with an R^2 value of 0.84 (Figure 21) based on 122 samples (collected by DOH and USACE); thus justifying the use of TSS as a surrogate for turbidity. This strong relationship is particularly evident at lower observed values (which are generally associated with lower flows) and become less predictable at higher values (which are generally associated with higher flows). Available nutrients and TSS data collected on concurrent days were evaluated and it was determined that total phosphorus concentrations have a strong relationship with TSS ($R^2 = 0.61$); however, total nitrogen and nitrite-nitrate did not have a strong correlation ($R^2 = 0.39$ and 0.02, respectively; Figure 22). Sub-hourly storm data collected by USACE were summarized into storm average concentrations for use in these analyses.

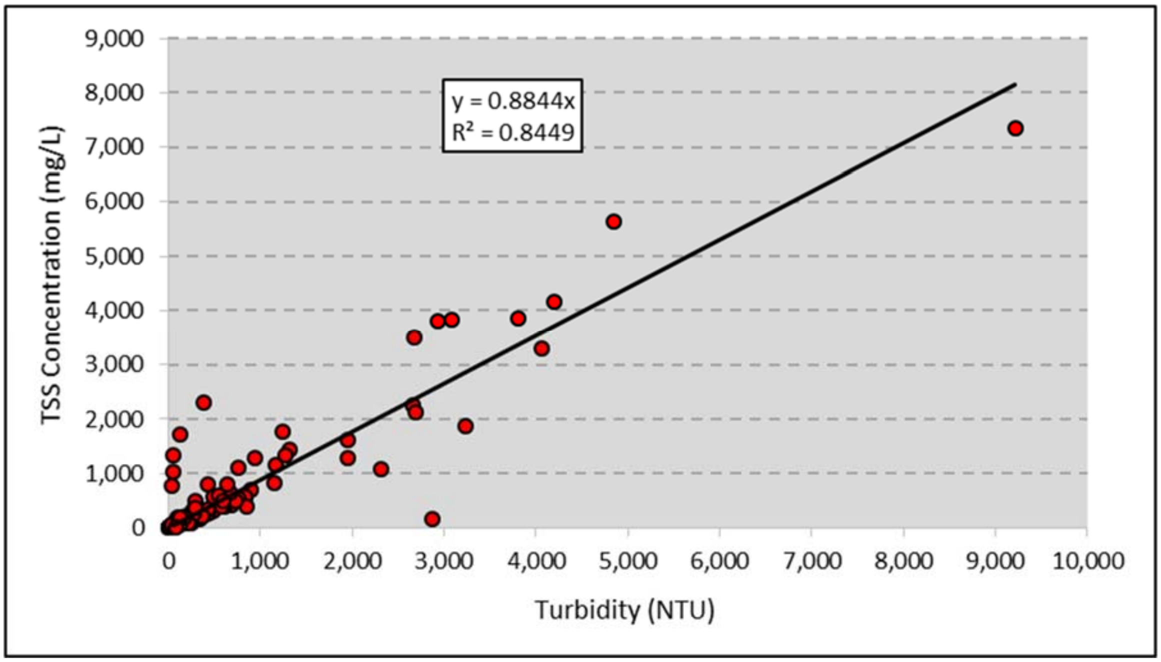
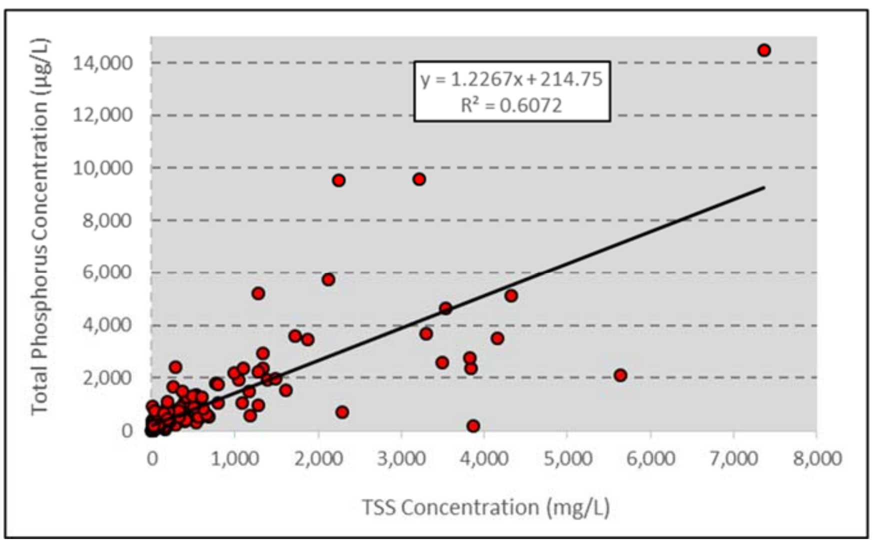


Figure 21. Turbidity and TSS relationship in the Waikele watershed



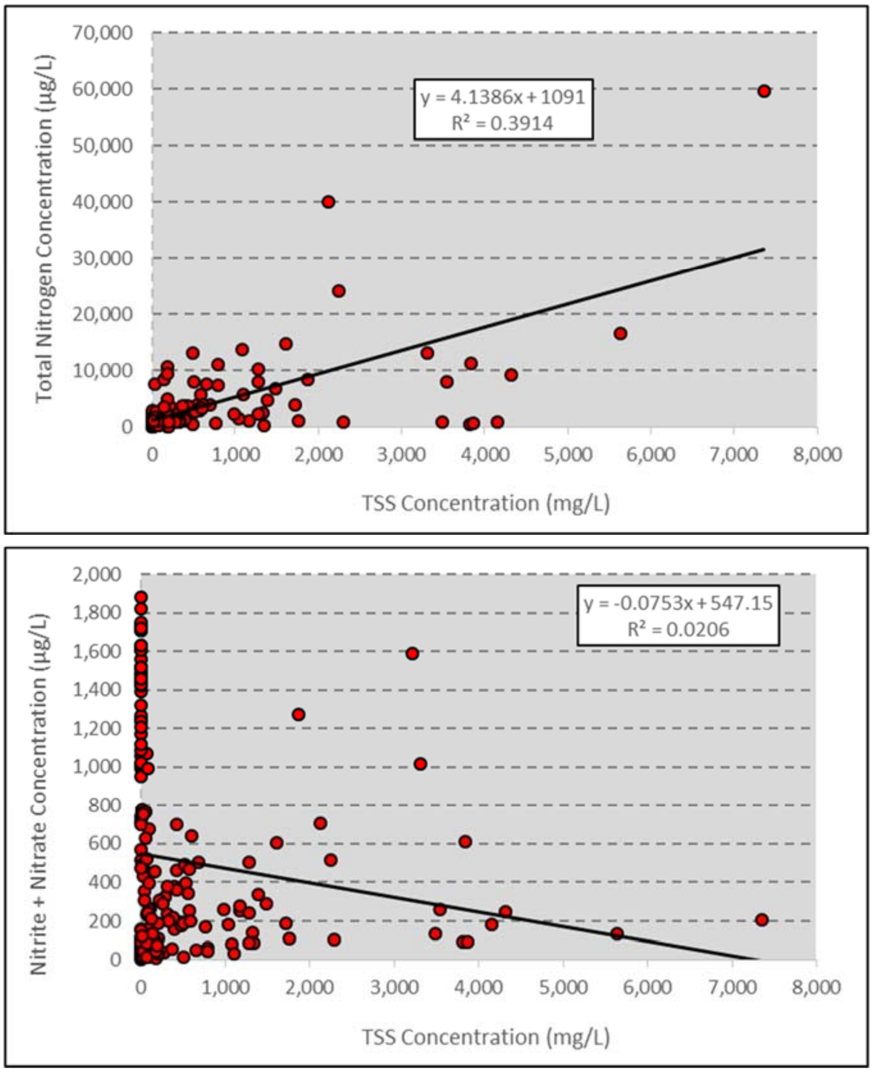


Figure 22. Relationships between sediment and nutrients

4.3.2.2. Spatial Trends

Spatial trends in the Waikele watershed were evaluated by HSPF subgroup by comparing their relative exceedance of geometric means (Figure 23). This value was calculated by normalizing the calculated geometric mean concentrations to the respective geometric mean water quality criteria for each parameter. The resulting value indicates the degree of exceedance relative to the water quality criteria, allowing for comparisons between pollutants. The red horizontal line represents the numeric water quality criteria (and is equal to 1). Each subgroup represented contains at 2 or more sample locations. The results show considerable variability between subgroups, seasons, and pollutants. General observations for each pollutant are listed and then discussed below.

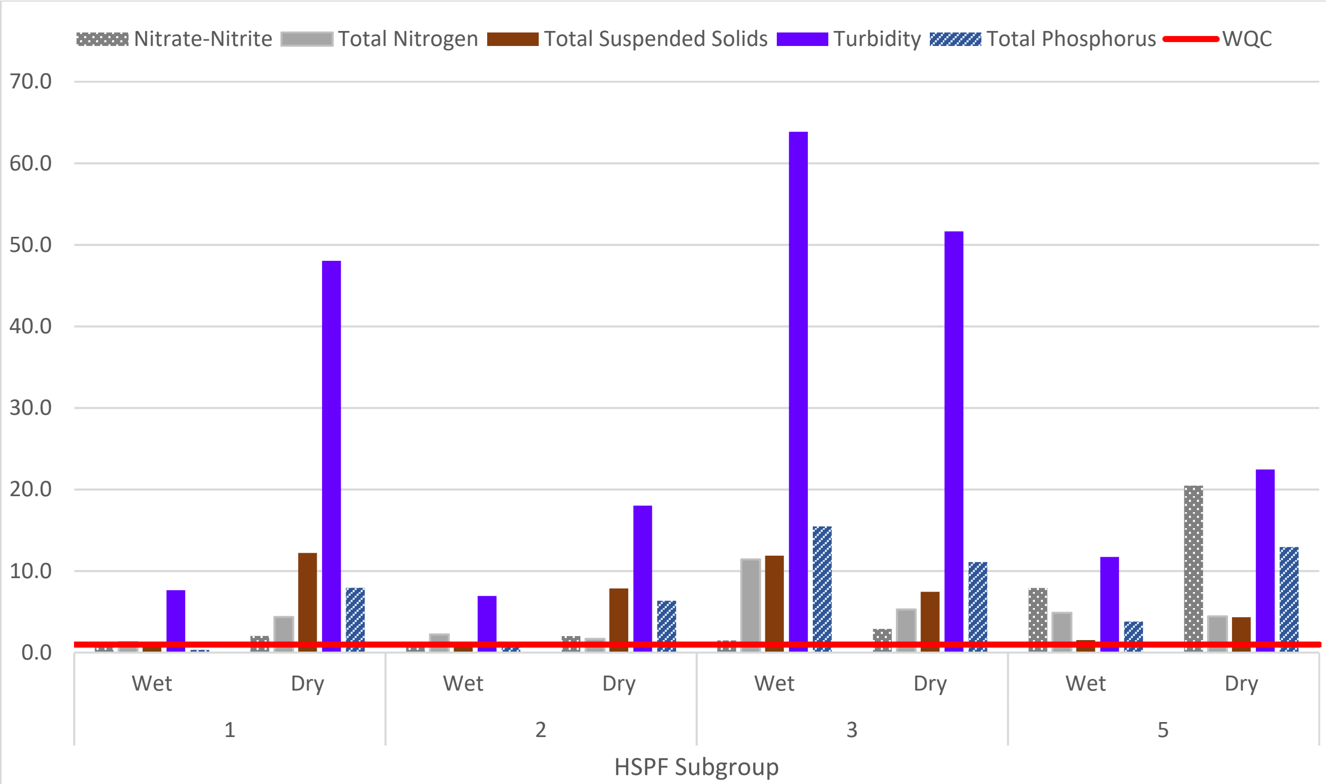


Figure 23. Relative exceedance of geometric means for the Waikele watershed

Nitrite-nitrate:

- HSPF subgroup 5 had the highest overall concentrations, where the dry season geometric mean was over 20 times the water quality criteria, and the wet season geometric mean concentration exceeded the criteria by a factor of 8.
- The lowest nitrite-nitrate concentrations for both wet and dry seasons were observed in subgroups 1and 2, which correspond to the two northernmost subwatersheds.
- Wet season: relative geometric mean exceedances ranged from 0.7 to 7.9
- Dry season: relative exceedance values ranged from 2.0 to 20.5.

Total Nitrogen:

- The highest relative exceedance values for both the wet and dry seasons occurred in HSPF subgroup 3.
- The lowest relative exceedance values for TN were observed in subgroups 1 and 2 during wet and dry seasons, respectively.
- Wet season: relative exceedance values ranged from 1.3-11.4.
- Dry season: relative exceedances of the geometric mean ranged from 1.7-5.3.

Total Suspended Solids:

- Subgroup 3 had the highest dry season geometric mean value, while subgroup 1 had the highest wet season value.
- Wet season: relative exceedance values ranged from 0.7- 12.2.
- Dry season: geometric mean values ranged from 4.3- 12.2.

Turbidity:
- Subgroup 3 had by far the highest exceedances relative to the water quality criteria for both wet and dry season among all of the pollutants.
- Subgroup 2 had the lowest relative exceedance values for both wet and dry season criteria.
- Wet season: relative geometric mean exceedances ranged from 7.0-63.8
- Dry season: relative exceedance values ranged from 18.0- 51.6.

Total Phosphorus:
- The highest concentrations of TP for wet season was in subgroup 3, and subgroup 5 for the dry season
- The wet season TP criteria were either at or below the WQS in subgroups 1 and 2.
- Wet season: geometric mean values ranged from 0.3- 15.5.
- Dry season: geometric mean values ranged from 6.4-12.9.

The highest turbidity exceedances for both wet and dry season occurred in subgroup 3, located in the upper Waikele portion of the watershed. Subgroup 3 is represented by stations SW-5, SW-6, SW-11, SW-12, and 5a and contains the headwaters of Waikele Stream. The highest exceedance of TSS WQC occurred in subgroup 1 during dry season, followed by subgroup 3.

The exceedance of WQC were spatially distributed among subgroups 3 and 5, the upper and lower Waikele subgroups, respectively. Subgroup 5 represented the largest relative exceedances of the nitrite-nitrate WQC for both the wet and dry season. The largest exceedances for total nitrogen were observed in subgroup 3 for wet and dry season. Total phosphorus exceedances were highest during dry season in subgroup 5, and wet season in subgroup 3.

The calculated geometric means were below the WQC in five instances (out of 40). Nitrite-nitrate and TSS were below the wet season WQC in subgroups 1 and 2. Total phosphorus was below the wet season geometric mean criteria in subgroup 1. Subgroups 1 and 2 represent the Waikakalua and Kipapa tributaries.

4.3.2.3. Monthly Analyses and Streamflow Correlations

To further understand the impact of stream flow on water quality in the Waikele watershed, a statistical comparison of flow versus SSC was performed. Specifically, flow data for the USGS gages were compared with the continuous SSC data at the same location. In addition, the SSC data were evaluated monthly to identify trends at each location. Figure 24 through Figure 31 and Table 9 through Table 12 present these findings.

The monthly distribution is presented at each station by a figure and table, followed by the flow-associated analyses. While the minimum and maximum values vary widely, the monthly analyses demonstrate a fairly narrow range in mean values throughout the year at all stations.

The flow-associated analyses illustrate the flow-weighted concentrations for all samples within a flow percentile and can be used to identify trends in pollutant levels associated with different flow regimes. As expected, these results show that the highest SSC concentrations occur with the highest flows. These findings can be used to identify station-specific minimum flow values that can be used to guide monitoring.

4.4. Biological Data

Hawaiian streams and their biota have been affected by urban development, stream diversions, and stream channelization. Flow diversions from Waikele Stream began prior to 1931 and ceased in 1989. In 1989, unintentional stream flow restoration occurred in Waikele Stream, related to the end of sugar cane cultivation and direct surface water diversions, as well as groundwater well pumping between 1994 and 1995. However, even with restored stream flow, surveys of Waikele Stream, conducted in 1993 and 1997 to 1998 from the Waikele Springs area downstream to the beginning of the tidal reach found that introduced fish remained abundant and native species appeared to have declined (Englund and Filbert 1999). For example, a reduction in water flow in Waikele Stream could decrease the freshwater lens (salinities ≤ 15 parts per thousand), which could reduce estuary habitat for ‘ama’ama and aholehole juveniles (Englund 1998). Reduced native species also suggests that water quality may be degraded as invasive species are often more tolerant to lower quality waters. These results indicate that although restoring hydrological conditions is an important first step in overall restoration of degraded aquatic ecosystems, flow restoration alone will not restore native aquatic species, especially in Oahu streams with naturally low discharge rates (Englund and Filbert 1999).

4.5. Soil Quality Data

USACE collected ten soil samples in their study area (in developed and undeveloped areas) and quantified their nutrient concentrations. These data were useful to understand the amount of nitrogen and phosphorus in soil that could contribute dissolved or particulate nutrient loads to Waikele Stream from those areas. The soil samples had average concentrations of nitrogen and phosphorus of 918 milligrams per kilogram (mg/kg) and 26 mg/kg, respectively. The nitrogen values were largely influenced by two stations in the upstream portion of the streambed that also had higher than average organic carbon levels (the average nitrogen concentration was 411 mg/kg with these stations removed). USACE found that contributions of nitrogen in the streams from erosion of soil nitrogen was small compared to other sources, while soil was a more significant source of phosphorus to the streams (2015).

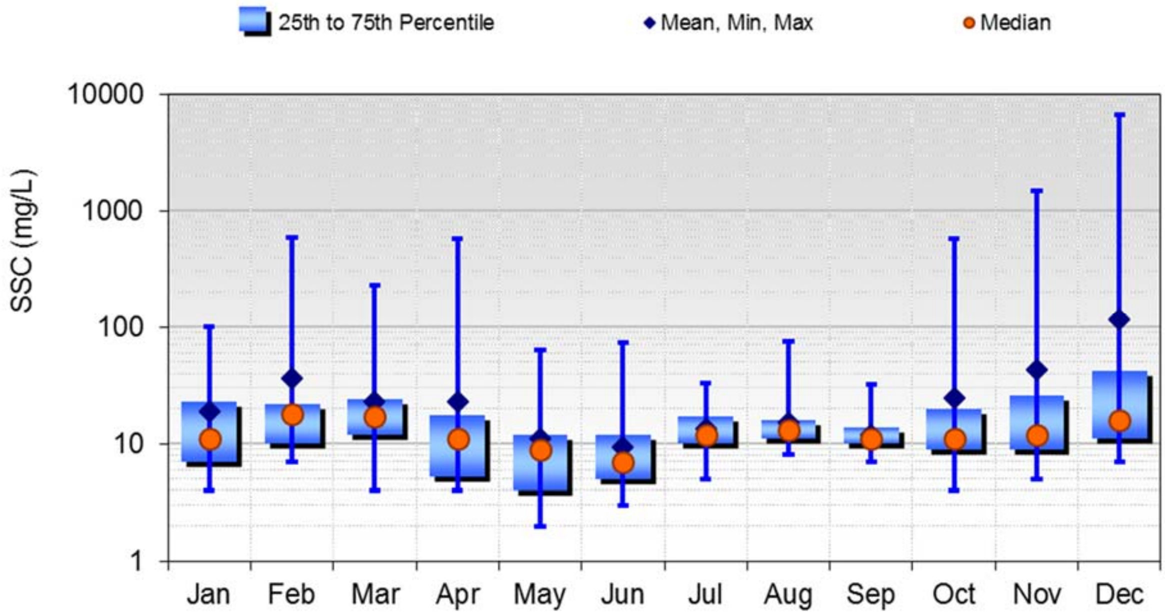


Figure 24. Monthly distribution of SSC data at Station 16213000

Table 9. Monthly summary statistics for SSC at station 16213000

Summary Statistics (Data: 10/1/2007 to 9/30/2010 in mg/L)							
Month	**Mean**	**Median**	**Min**	**Max**	**25th**	**75th**	**Number of Samples**
Jan	19	11	4	100	7	23	93
Feb	36	18	7	598	10	22	85
Mar	23	17	4	232	12	24	93
Apr	23	11	4	571	5	18	90
May	11	9	2	64	4	12	93
Jun	9	7	3	74	5	12	90
Jul	14	12	5	33	10	17	93
Aug	15	13	8	75	11	16	93
Sep	12	11	7	32	10	14	90
Oct	24	11	4	573	9	20	93
Nov	43	12	5	1490	9	26	90
Dec	117	16	7	6620	11	42	93
All Data	**29**	**12**	**2**	**6620**	**9**	**19**	**1096**

Flow-Associated Trend Assessment

Location: 16213000 (Waikele at Waipahu)
Data from: 10/1/2007 to 9/30/2010 (1096 Observations)

Flow Range	# Obs	Associated Flow			Pollutant Concentration		
Percentile	Count	Mean	Min	Max	Mean	Min	Max
0-10	110	12.5	9.4	13.0	10	3	22
10-20	109	14.1	14.0	15.0	9	3	23
20-30	110	15.0	15.0	15.0	10	2	23
30-40	109	15.7	15.0	16.0	13	5	40
40-50	110	16.0	16.0	16.0	11	3	29
50-60	109	17.2	16.0	18.0	14	2	43
60-70	110	19.4	18.0	21.0	11	4	31
70-80	109	24.5	21.0	28.0	16	4	50
80-90	110	36.3	28.0	47.0	25	4	50
90-100	109	121.2	47.0	1420.0	321	14	1490

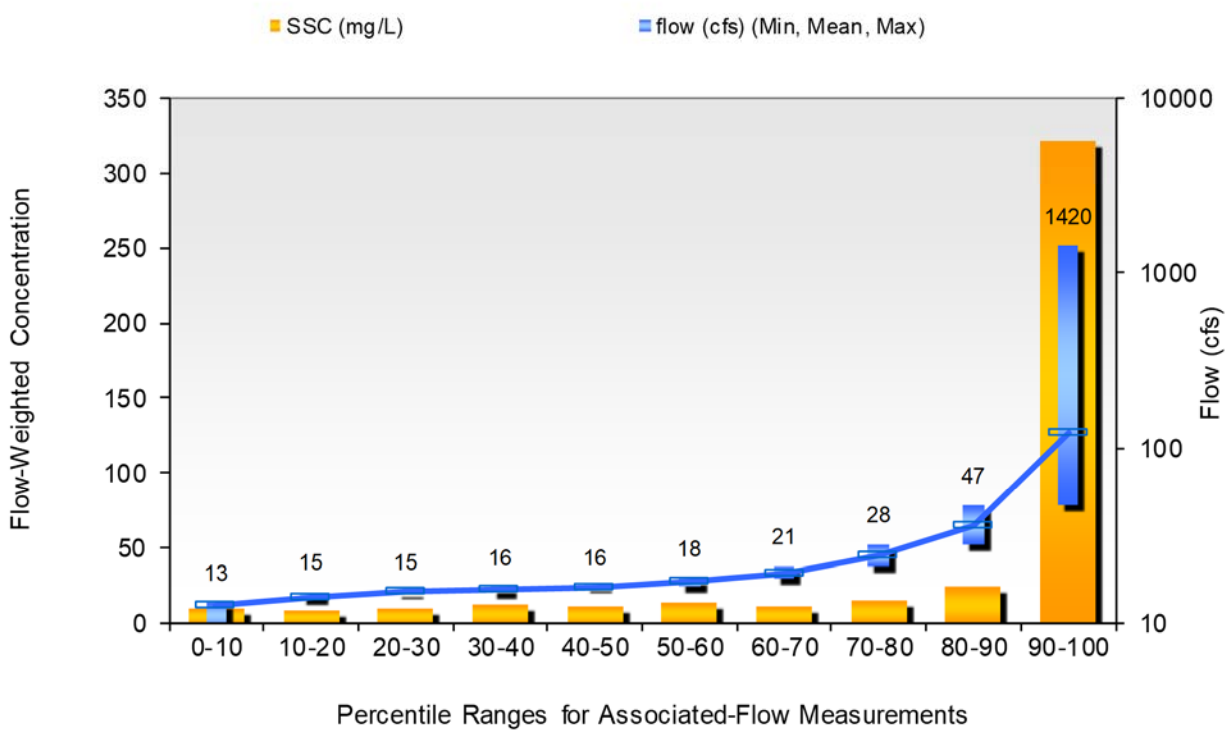


Figure 25. Flow-SSC relationships at station 16213000

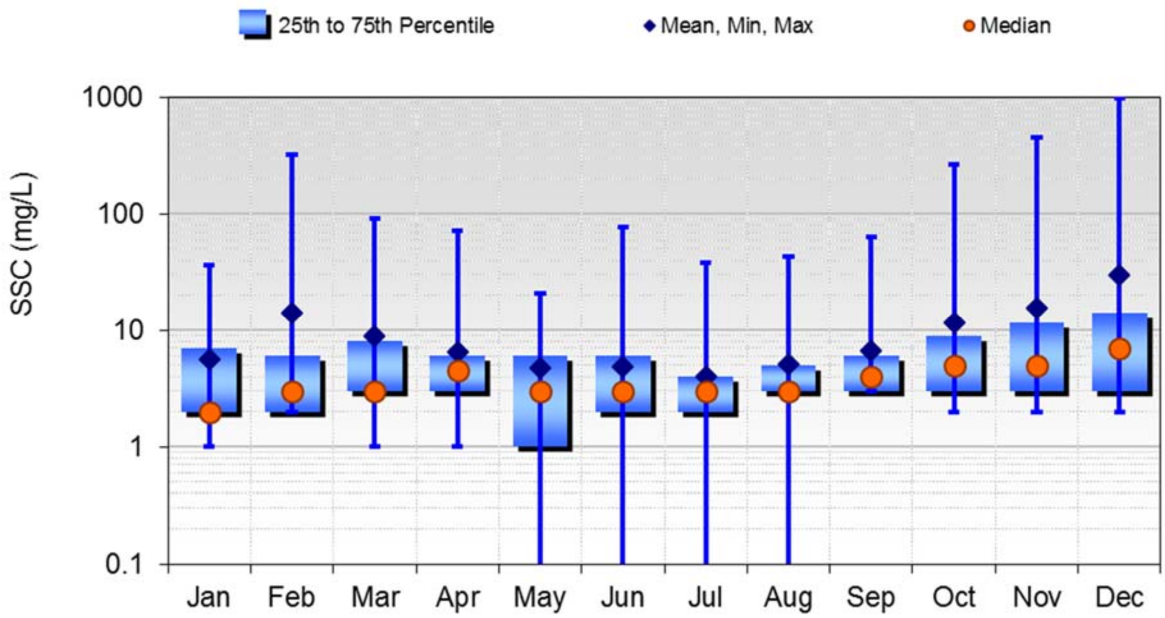


Figure 26. Monthly distribution of SSC data at station 16212800

Table 10. Monthly summary statistics for SSC at station 16212800

Summary Statistics (Data: 10/1/2007 to 9/30/2010 in mg/L)							
Month	**Mean**	**Median**	**Min**	**Max**	**25th**	**75th**	**Number of Samples**
Jan	6	2	1	36	2	7	93
Feb	14	3	2	320	2	6	85
Mar	9	3	1	91	3	8	93
Apr	6	5	1	71	3	6	90
May	5	3	0	21	1	6	93
Jun	5	3	0	78	2	6	90
Jul	4	3	0	38	2	4	93
Aug	5	3	0	43	3	5	93
Sep	7	4	3	64	3	6	90
Oct	12	5	2	267	3	9	93
Nov	15	5	2	455	3	12	90
Dec	30	7	2	994	3	14	93
All Data	**10**	**4**	**0**	**994**	**3**	**7**	**1096**

Location: 16212800 (Kipapa at Waipahu)

Flow Gage: flow (cfs)
Pollutant: SSC (mg/L)
Data from: 10/1/2007 to 9/30/2010 (1096 Observations)

Flow Range	# Obs	Associated Flow			Pollutant Concentration		
Percentile	Count	Mean	Min	Max	Mean	Min	Max
0-10	110	0.1	0.0	0.2	3	0	8
10-20	109	0.3	0.2	0.5	3	0	9
20-30	110	0.6	0.5	0.8	3	1	9
30-40	109	1.0	0.8	1.2	4	1	10
40-50	110	1.6	1.3	1.9	3	1	9
50-60	109	2.4	2.0	2.9	4	1	14
60-70	110	3.6	2.9	4.6	5	1	18
70-80	109	6.0	4.6	7.6	7	2	63
80-90	110	11.0	7.6	17.0	10	2	28
90-100	109	46.6	17.0	306.0	94	5	455

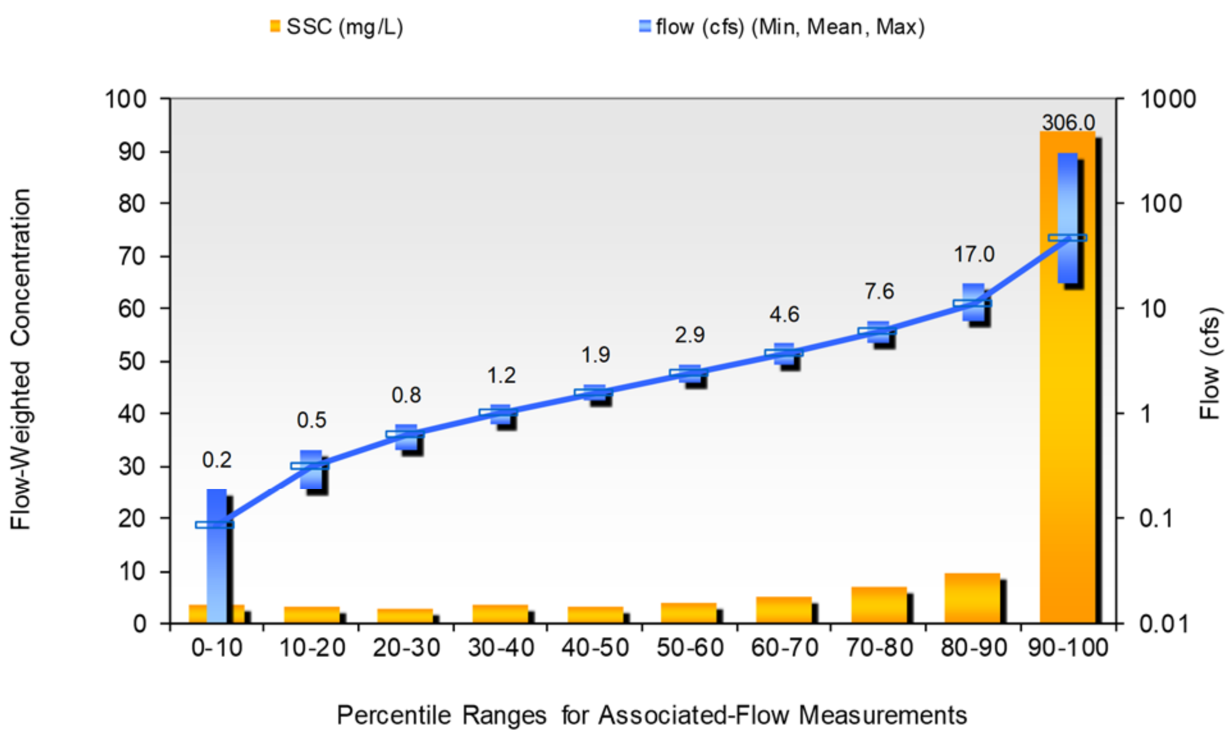


Figure 27. Flow-SSC relationships at station 16212800

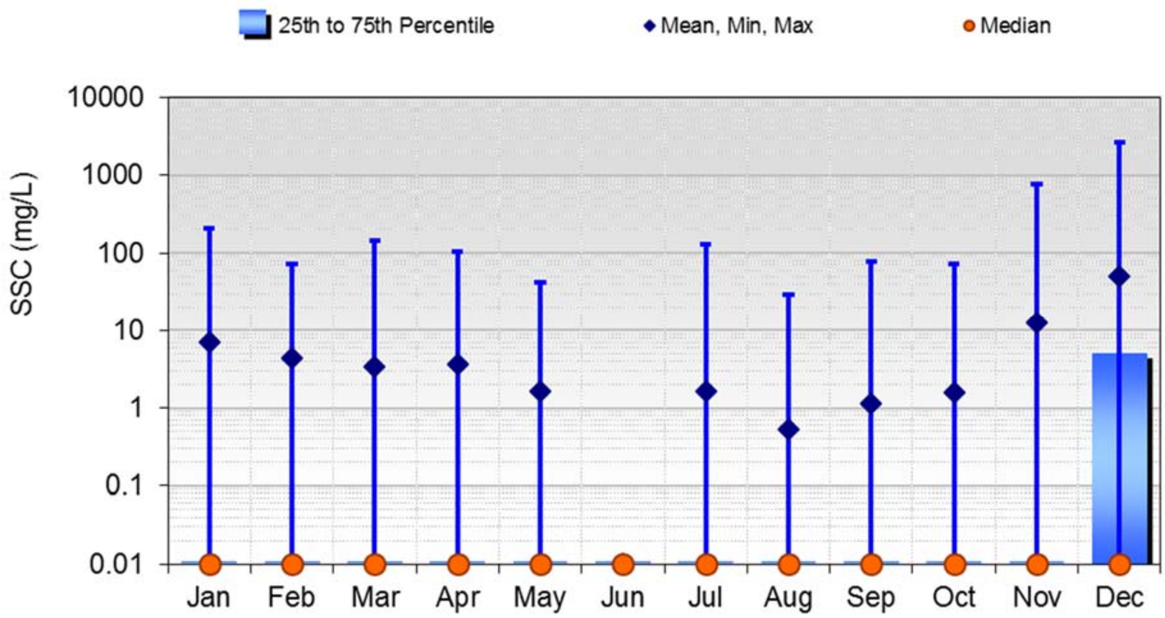


Figure 28. Monthly distribution of SSC data at station 16212601

Table 11. Monthly summary statistics for SSC at station 16212601

Summary Statistics (Data: 10/1/2007 to 9/30/2010 in mg/L)							
Month	**Mean**	**Median**	**Min**	**Max**	**25th**	**75th**	**Number of Samples**
Jan	7	0.01	0.01	205	0.01	0.01	93
Feb	4	0.01	0.01	73	0.01	0.01	85
Mar	3	0.01	0.01	142	0.01	0.01	93
Apr	4	0.01	0.01	105	0.01	0.01	90
May	2	0.01	0.01	42	0.01	0.01	93
Jun	0	0.01	0.01	0	0.01	0.01	90
Jul	2	0.01	0.01	130	0.01	0.01	93
Aug	1	0.01	0.01	29	0.01	0.01	93
Sep	1	0.01	0.01	78	0.01	0.01	90
Oct	2	0.01	0.01	71	0.01	0.01	93
Nov	13	0.01	0.01	772	0.01	0.01	90
Dec	50	0.01	0.01	2600	0.01	5.00	93
All Data	**7**	**0.01**	**0.01**	**2600**	**0.01**	**0.01**	**1096**

Location: 16212601 (Waikele at Wheeler)

Flow Gage: flow (cfs)
Pollutant: SSC (mg/L)
Data from: 10/1/2007 to 9/30/2010 (1096 Observations)

Flow Range	# Obs	Associated Flow			Pollutant Concentration		
Percentile	Count	Mean	Min	Max	Mean	Min	Max
0-10	110	0.0	0.0	0.0	0	0	0
10-20	109	0.0	0.0	0.0	0	0	0
20-30	110	0.0	0.0	0.0	0	0	0
30-40	109	0.0	0.0	0.0	0	0	0
40-50	110	0.0	0.0	0.0	0	0	0
50-60	109	0.0	0.0	0.0	0	0	0
60-70	110	0.0	0.0	0.0	0	0	0
70-80	109	0.0	0.0	0.0	0	0	6
80-90	110	0.0	0.0	0.2	2	0	6
90-100	109	4.9	0.2	80.0	240	1	772

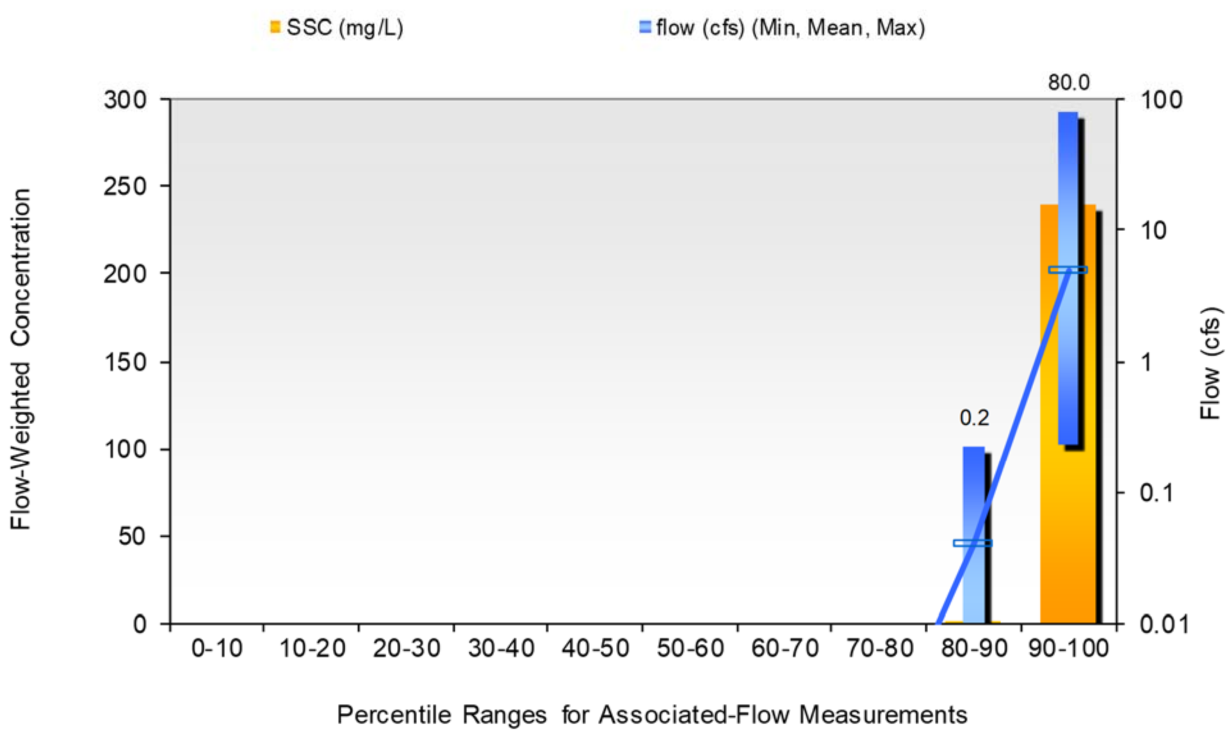


Figure 29. Flow-SSC relationships at station 16212601

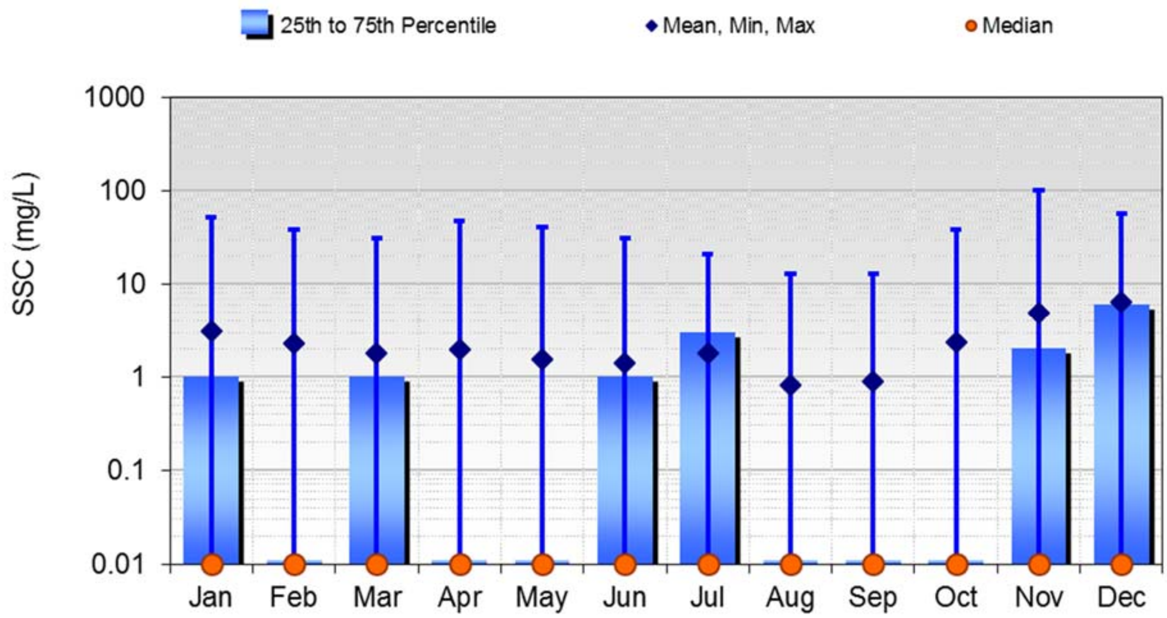


Figure 30. Monthly distribution of SSC data at Station 212604158012700

Table 12. Monthly summary statistics for SSC at station 212604158012700

Summary Statistics (Data: 10/1/2007 to 9/30/2010 in mg/L)							
Month	**Mean**	**Median**	**Min**	**Max**	**25th**	**75th**	**Number of Samples**
Jan	3	0.01	0.01	52	0.01	1.00	93
Feb	2	0.01	0.01	38	0.01	0.01	85
Mar	2	0.01	0.01	31	0.01	1.00	93
Apr	2	0.01	0.01	47	0.01	0.01	90
May	2	0.01	0.01	41	0.01	0.01	93
Jun	1	0.01	0.01	31	0.01	1.00	90
Jul	2	0.01	0.01	21	0.01	3.00	93
Aug	1	0.01	0.01	13	0.01	0.01	93
Sep	1	0.01	0.01	13	0.01	0.01	90
Oct	2	0.01	0.01	38	0.01	0.01	93
Nov	5	0.01	0.01	102	0.01	2.00	90
Dec	6	0.01	0.01	57	0.01	6.00	93
All Data	**2**	**0.01**	**0.01**	**102**	**0.01**	**1.00**	**1096**

Location: 212604158012700 (Mililani Storm Drain A)

Flow Gage: flow (cfs)
Pollutant: SSC (mg/L)
Data from: 10/1/2007 to 9/30/2010 (1096 Observations)

Flow Range	# Obs	Associated Flow			Pollutant Concentration		
Percentile	Count	Mean	Min	Max	Mean	Min	Max
0-10	110	0.0	0.0	0.0	0	0	0
10-20	109	0.0	0.0	0.0	0	0	0
20-30	110	0.0	0.0	0.0	0	0	1
30-40	109	0.0	0.0	0.0	0	0	4
40-50	110	0.0	0.0	0.0	0	0	1
50-60	110	0.0	0.0	0.0	0	0	1
60-70	109	0.0	0.0	0.0	0	0	8
70-80	109	0.0	0.0	0.1	1	0	6
80-90	110	0.1	0.1	0.3	4	0	18
90-100	109	0.9	0.3	5.3	28	2	102

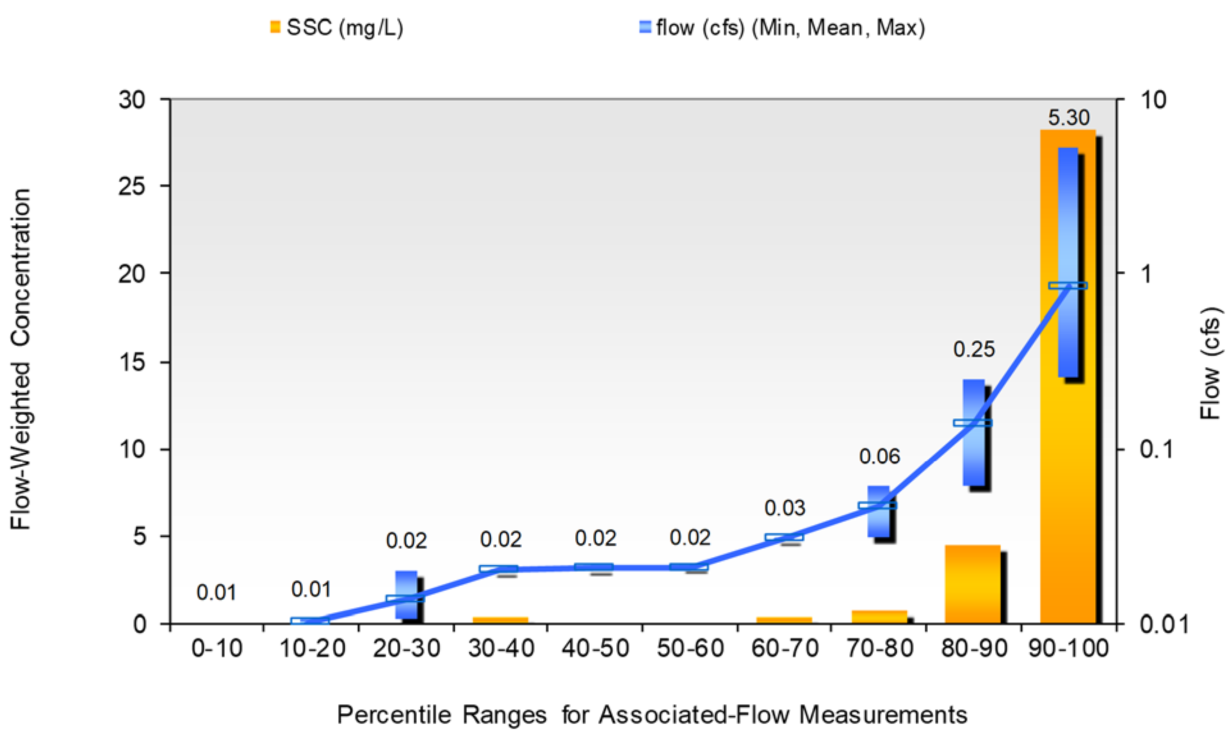


Figure 31. Flow-SSC relationships at station 212604158012700

5. Source Analysis

The purpose of the source analysis is to identify and quantify the sources of pollutants to the impaired waterbodies. Therefore, this section discusses the potential sources of sediment and nutrients to the Waikele watershed, including point and nonpoint sources. Point sources typically discharge at a specific location from pipes, outfalls, and conveyance channels from, for example, municipal wastewater treatment plants or municipal separate storm sewer systems (MS4s). Nonpoint sources, including groundwater, are diffuse sources that have multiple routes of entry into surface waters.

Multiple sources of sediment and nutrients associated with both natural and anthropogenic activities contribute to overall loads to the impaired waterbody during wet and dry weather periods. These are discussed in the point and nonpoint sources sections below. These sources can often be generally grouped and evaluated by land use. The Hawaii Land Use Law (HRS Chapter 205) separates land use into four districts: agriculture, conservation, rural, and urban. The island of Oahu, however, does not contain any land use designated as rural (DOH 2015). Figure 32 presents the land uses in the Waikele watershed (State Land Use Commission 2014), providing a useful context for evaluating point and nonpoint sources.

In-stream and watershed characteristic data were used to identify potential sources and establish the relationship between point and nonpoint source loadings and in-stream response. As discussed in Section 0, the relationship between loadings and in-stream conditions was investigated through the use of a watershed model (see also Appendices A and B). The results of the watershed model are summarized below to estimate the existing loads (Section 5.3).

5.1. Point Sources

NPDES permits allow point sources to discharge pollutants to a water of the United States. They are issued to industrial and municipal facilities, MS4s, and construction projects and receive a WLA in the TMDL. Point sources in the Waikele watershed are primarily associated with stormwater discharges from construction activities and industrial facilities as well as MS4s. These sources are generally located in the urban areas shown in Figure 32. Specific point sources are identified in Table 13 and discussed below. The MS4 areas, illustrated in Figure 33, represent a similar area to the urban land use shown in red in Figure 32.

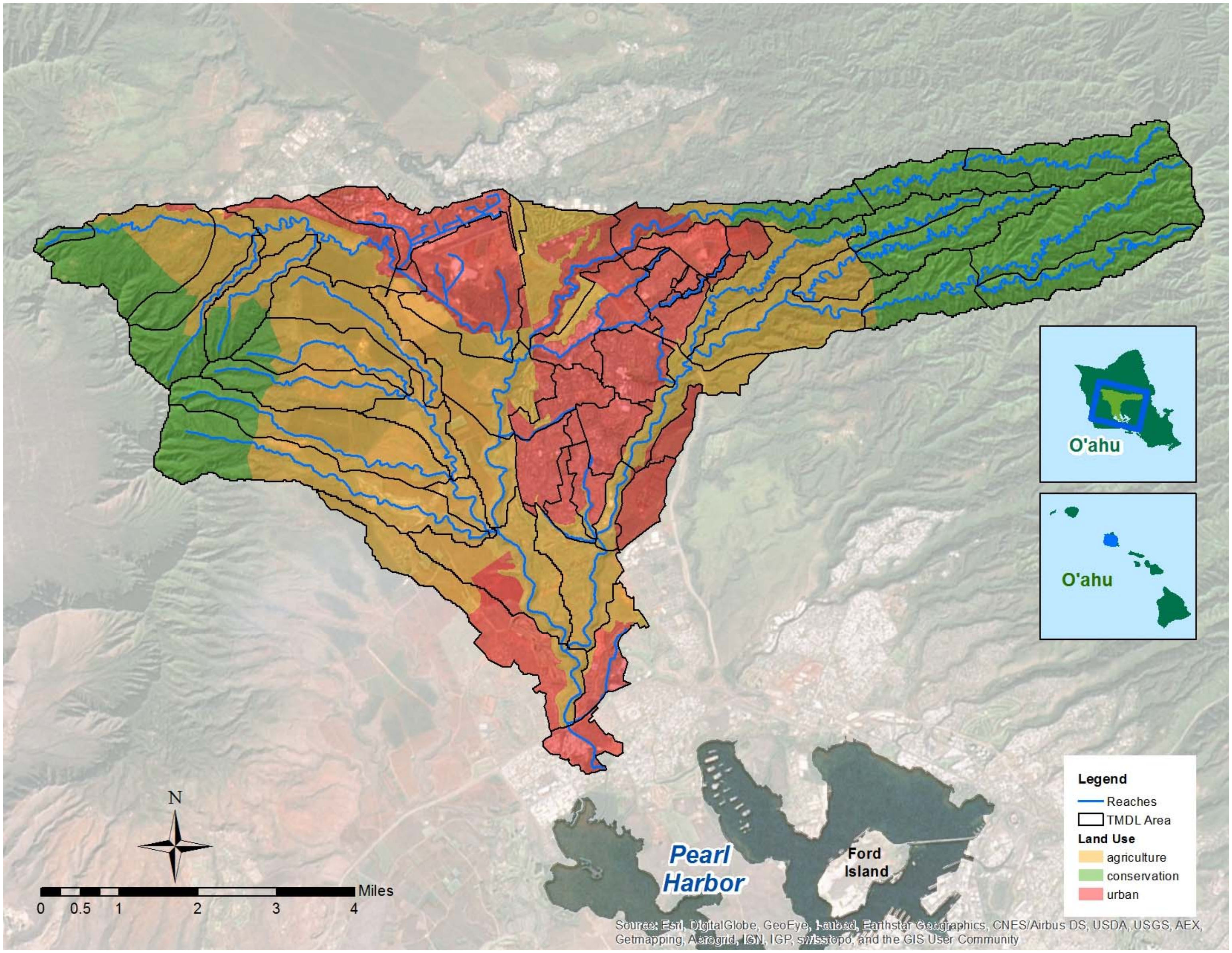


Figure 32. Waikele watershed land use (source: State Land Use Commission 2014)

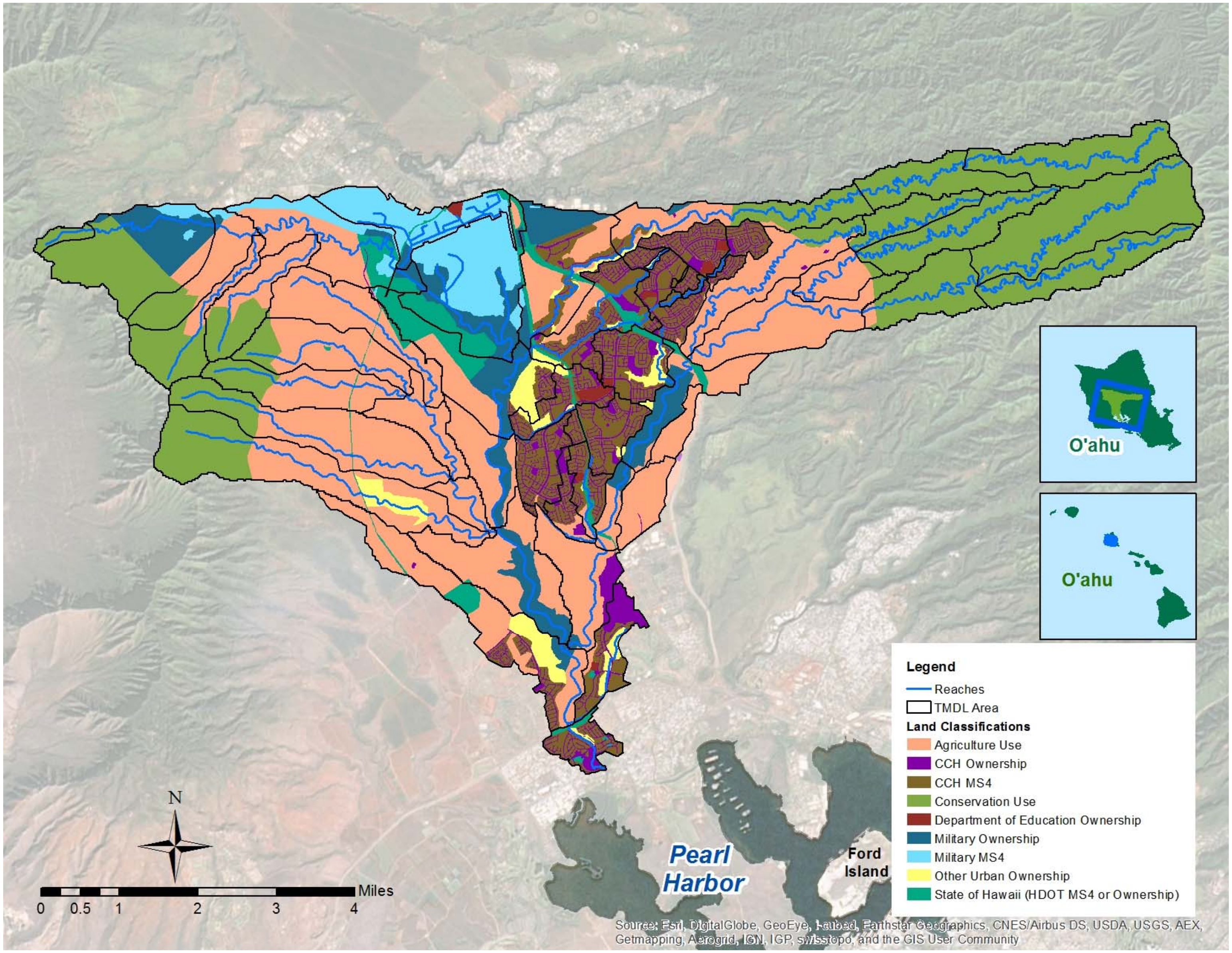


Figure 33. MS4 areas in the Waikele watershed

Table 13. Recent NPDES permits in the Waikele watershed

Permit Type	Permittee	Permit Number	Issued	Expires
Construction Stormwater General Permit	Various	HAR 11-55 Appendix C	12/06/2013	12/05/2018 (Pending approval)
General Permit*	900 Green Valley	HIR10E818	11/24/2015	12/05/18 (Extended)
General Permit*	Castle & Cooke Properties, Inc.	HIR10D794	12/9/2013	12/05/2018 (Extended)
General Permit*	U.S. Army Corps of Engineers	HIR10D964	2/27/2015	12/05/2018 (Extended)
Industrial Stormwater General Permit	Various	HAR 11-55 Appendix B	12/06/2013	12/05/2017
Individual Permit	Aqua Engineers (Schofield Barracks Wastewater Treatment Plant)	HI0110141	Renewal in Process	---
MS4 Permit	CCH	HIS000002	1/16/2015	1/15/2020
MS4 Permit	DOT-Highways	HIS000001	Renewal in Process	9/26/2018
MS4 Permit	U.S. Army Garrison Hawaii	HIS000090	Renewal in Process	---

*NPDES General permit authorizing discharges of storm water associated with construction activities (DOH 2013a). Permits are current as of February 2019.

5.1.1. MS4 Permits

The state has three MS4 permits in the watershed (Table 13 and Figure 33), consisting of both Phase I and Phase II permits. Phase I MS4s generally serve populations of 100,000 or greater. Phase II small MS4s are located in urbanized areas and are designated by the permitting authority to obtain NPDES permit coverage for their stormwater discharges.

There are two Phase I MS4s in the watershed, operated by the State of Hawaii Department of Transportation – Highways Division (DOT) and CCH (Table 13). The service area for the Hawaii DOT MS4 permit is represented by the consolidation of all DOT highway areas in the watershed (approximately 370 acres). The area associated with the CCH MS4 permit is the consolidation of all neighborhood parks, residential, commercial, industrial and municipal street areas in the watershed that drain to the MS4 system (approximately 4,800 acres).

The Phase II MS4 permitted facility in the watershed is the U.S. Army Garrison Hawaii (Table 13). The U.S. Army Garrison Hawaii permit service area includes Wheeler Army Air Field and the portion of Schofield Barracks that lies in the Waikele watershed (approximately 3700 acres). Other NPDES permits that reside within the U.S. Army Garrison Hawaii's area footprint include Hawaii Army National Guard, the Schofield Barracks Wastewater Treatment Plant, and the Schofield Generating Station.

Urban areas, represented by the MS4 permitted areas in the Waikele watershed, can increase stormflow in streams due to the amount of impervious surface cover found in developed areas. In impervious areas, sediment and nutrients build up over time to a maximum amount for each impervious land use type and is transported through runoff events. For the purposes of this report, it was assumed that all of the impervious area contained within the footprint of an MS4 area drains to the MS4. This increased stormflow can contribute to the erosion of banks, further increasing suspended sediment loads downstream. Northwest Hydraulic Consultant's (NHC) geomorphic assessment and the HSPF model both ranked urban land use areas as the lowest land use contributor to total fine sediment yield. Specifically, USGS data collected from 2008 to 2010 at the Mililani Storm Drain A at Mililani gage concluded that erosion from mature residential areas is not a very important source of sediment (NHC 2016 in Appendix A).

5.1.2. Construction Stormwater Permits

Stormwater from construction activities can carry sediment, chemicals, and debris into water bodies or storm sewer systems. Sediment is the primary pollutant generated during construction activities due to disturbance and exposure of soil during these projects (USEPA 2007). Stormwater discharges associated with construction activities are typically temporary sources that are expected to be controlled by shorter-term site-specific BMPs and standard general permit conditions. The bare earth land cover was used as an estimate of area in the watershed potentially subject to this general permit (approximately 59 acres), although it is important to note that other areas not categorized as bare earth could be under construction.

In the past decade, three general permits (regulated by Appendix C of HAR Chapter 11-55; DOH 2013a) and one individual permit were issued for stormwater discharges from construction activities in the watershed (Table 13).

5.1.1. Industrial Stormwater Permits

Similar to construction activities, industrial facilities can contribute pollutants into receiving waters or storm sewer systems. The NPDES general permit for stormwater discharges from industrial activities (regulated by Appendix B of HAR Chapter 11-55; DOH 2013b) applies to all areas except for discharges in or to Class 1 inland waters, Class AA marine waters, and areas with a no discharge policy in place. The industrial land use was used as an estimate of area in the watershed potentially subject to this general permit (approximately 675 acres).

Schofield Barracks Wastewater Treatment Plant (NPDES ID HI0110141) is an individual permittee authorized to discharge stormwater from industrial activities to Waikele Stream through its Outfall No. 002 (Table 13). This individual permit is currently in the process of renewal. This permit requires reporting of various pollutants annually, including sediment and nutrients (numeric discharge limitations are provided for oil and grease, fecal coliform, and pH; reporting requirements are provided for other pollutants with non-numeric discharge limits).

5.2. Nonpoint Sources

A nonpoint source is a source that discharges via sheet flow or natural discharges. These sources receive a LA in the TMDL. Nonpoint sources in the Waikele watershed include runoff from agricultural lands and conservation lands, as well as diffuse inputs from groundwater sources that may be under the influence of human activities (such as the leaching of fertilizers and wastewater). There are also some urban areas that fall outside of the MS4 boundary. Runoff from these areas was characterized as a nonpoint source because it does not reach the stream through the MS4.

Nonpoint pollutant sources were quantified with the watershed model by land cover type since loadings can be highly correlated with land-based activities. Wash-off of sediment and nutrients from various land covers during wet weather events is considered the primary mechanism for transport. After they build up on the land surface as the result of various land sources and associated management practices, many of the pollutants are washed off the surface during rainfall events. The amount of runoff and associated pollutant concentrations are therefore highly dependent on land-based activities. The methodology used for quantification of pollutant concentrations from various land cover types is discussed in Appendices A and B.

5.2.1. Agriculture

Agriculture contributes both sediment and nutrients to streams. Farming activities often involve applying nutrients such as nitrogen, phosphorus, and potassium via commercial fertilizers, manure, and sludge to crop fields. Planting and harvesting of crops contributes to sedimentation of agricultural soils in rivers, streams, and lakes. Disruption of soil though tillage and cultivation increases the susceptibility of the disrupted soil particles to be carried via overland flow into nearby surface waters (USEPA 2005). The sediment that is deposited in surface waters often carries excess nutrients such as phosphorus adsorbed to sediment particles. Excess nitrate that is not taken up by plants can also leach through the soil into the underlying groundwater (Section 5.2.4) (USEPA 2003a).

In the Waikele watershed, agriculture is predominantly located on the western edge of the Oahu Plain near the Waianae Gulches and Waikele Stream. Kipapa Stream also has small areas of agriculture along its eastern border. Historically, the Waikele watershed was heavily cultivated with sugarcane and pineapple crops; however, sugarcane production stopped in the 1990s and pineapple cultivation has declined in recent years (Izuka 2012). Sugarcane was grown in the lower elevations and pineapple was grown in the upper elevations. Much of the land formerly used by the sugarcane and pineapple industries currently lies fallow or is covered by grass and shrub. Some of the land has been converted to diversified agriculture, agricultural research, or urban use. Diversified agriculture, such as seed corn and truck crops, have the potential to deliver more sediment to streams than pineapple or sugar cane plantations on the same acreage due to more frequent tillage, soil exposure, and harvest associated with diversified crop operations compared to plantation crops (El-Swaify 2002 in Appendix A). Agricultural roads, which have lower infiltration and higher erosion than other agricultural uses, are also an important potential source of pollutants and act as a transport mechanism from agricultural lands to streams. As discussed in Appendices A and B, the agricultural land use category is the largest contributor of sediment, total phosphorus, nitrite-nitrate, and total nitrogen within the Waikele watershed.

5.2.2. Department of Education

The Department of Education (DOE) has been issued a waiver of their previous Phase II MS4 permit; therefore, they are included as a nonpoint source in this TMDL. The DOE area is the consolidation of all public-school facility properties in the watershed. A separate load allocation is provided for this source to guide implementation activities on DOE lands.

5.2.3. Natural Background

The upper elevations of the Waikele watershed, particularly in the Ko'olau Mountains in the eastern headwaters of the watershed, are forested conservation areas that are largely undeveloped (including the Oahu NWR). Other conservations lands include the Schofield Barracks Forest Preserve.

Sediment and nutrient loading from conservation lands are associated with both natural and anthropogenic activities. Specifically, the presence of wildlife in wetlands, grasslands, and forested areas is a potential source of nutrients through their waste (USEPA 2005; Schueler and Holland 2000). Wildlife is also a potential source of sediment (which may have nutrients sorbed to the particles) as they can disturb soil and destroy vegetation in forests. Invasive plants in conservation lands also contribute to sediment loading due to their shallow root systems, which fail to retain soil during rain events. Combined, these sources can cause unstable slopes, which increases the threat of erosion, especially in the areas with steep slopes as these are also subject to higher precipitation. During a USGS study of suspended sediment sources in the Waikele watershed from 2007-2010, agriculture contributed the most suspended sediment yield per square mile to streams, when compared to forested and urban land uses (Izuka 2012).

5.2.4. Groundwater

In Hawaii, groundwater occurs as either basal or high-level groundwater. Basal groundwater is groundwater floating on and displacing seawater, while high-level groundwater is impounded within compartments formed by impermeable dikes or on low-permeable layers. Also present in the Waikele area is caprock, a sedimentary sequence that acts as a barrier to the seaward flow of freshwater and causes the basal freshwater lens to be greater than in other areas. The basal groundwater in Waikele is primarily made up of the Pearl Harbor Aquifer Sector Area and a small portion of the Central Aquifer Sector Area. The Pearl Harbor Aquifer Sector Area provides the largest amount of potable water on Oahu (Oceanit 2007). The terminal reach of Waikele Stream is fed by a series of large basal springs that are collectively called Waikele Springs, influencing baseflow at the lower end of the reach (Englund and Filbert 1999).

Groundwater, which is influenced by several sources such as cesspools, agricultural areas, soil, and urban runoff, is also a potential source of nutrients to the Waikele watershed. Groundwater contributions are included within the loads and allocations associated with the other watershed sources as it was included in the watershed model (Appendices A and B) and is part of the total simulated load from a source area.

5.2.5. Other Urban

Some urban areas fall outside of the MS4 boundary and are therefore not classified as point sources as their loading does not reach a receiving water through the MS4. Similar to other urban uses, these areas can be sources of sediment and nutrients. In the Waikele watershed, this includes contributions from golf courses, such as Hawaii Country Club Golf Course, Mililani Golf Club, Royal Kunia Country Club, Waikele Country Club, and Leilehua Golf Course (the latter is owned by the military and is included in the military load allocation). There are also several riparian areas located in private trusts and other land holdings in the watershed. These are generally forested or open areas located within city limits and were also included in the CCH ownership classification, receiving a load allocation in the TMDL.

5.3. Watershed-wide Estimated Existing Loads

The model output was summarized to estimate the relative pollutant contributions by land use category for dry and wet seasons (Figure 34-39). These loadings represent the simulated existing conditions, which were calibrated to observed data collected throughout the watershed (Appendices A and B). Dry and wet season results for total nitrogen demonstrated similar relative contributions by land use (Figure 34 and 35). The combined agricultural uses (shown in shades of blue) account for over a third of the loading under both conditions. Urban uses, which are illustrated in shades of red, contributed a larger proportion in the wet season than dry, while conservation lands (in dark green) were a slightly larger contributor during the dry season.

Nitrite-nitrate contributions were also similar when comparing the dry and wet seasons (Figure 36 and Figure 37, respectively). As illustrated in the charts, dry and wet season agricultural and urban loadings were similar between the two seasons, but they made up a slightly larger portion of the total load during the dry season. Conservation contributions of nitrite-nitrate were higher during the wet season than in the dry season and open space consistently contributed approximately 25 percent of the loading.

Urban loading was responsible for about 10 percent of the sediment loading during both the dry and wet seasons (Figure 38 and Figure 39, respectively). Over 50 percent of the sediment loads during dry season were associated with conservation and open space (green shading in Figure 38 and Figure 39). This proportion dropped to one third during the wet season (Figure 38 and Figure 39), during which fallow lands and pineapple contributions nearly doubled when compared to the dry season for both pollutants. In sum, agricultural uses contributed over half of the wet season sediment loads (Figure 38 and Figure 39, respectively).

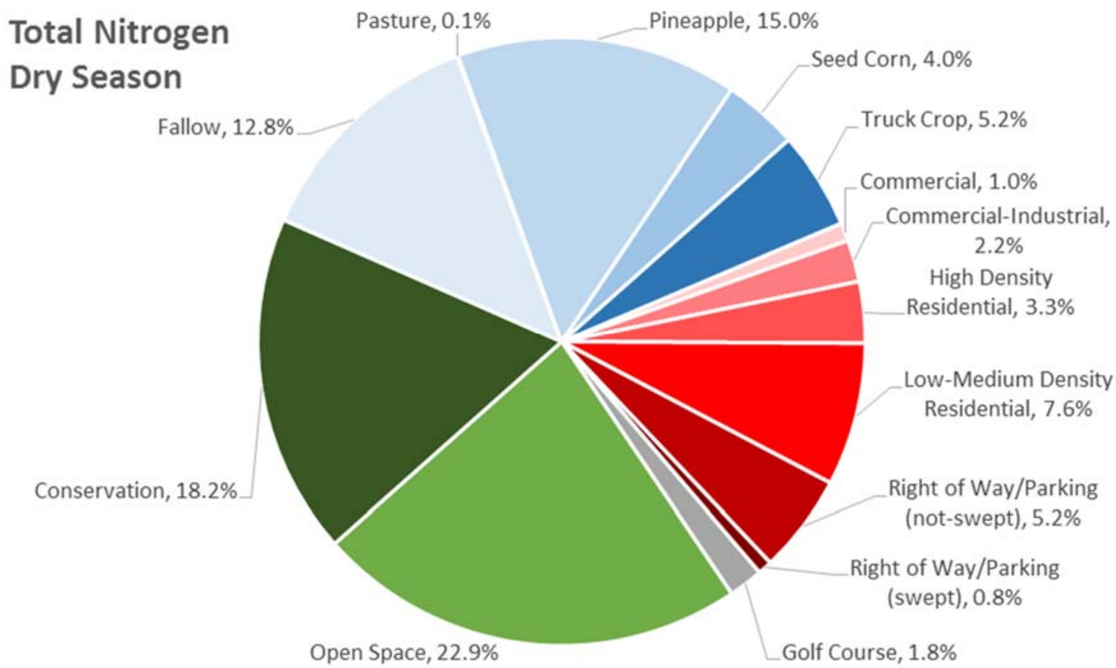


Figure 34. Dry season total nitrogen relative land use contributions

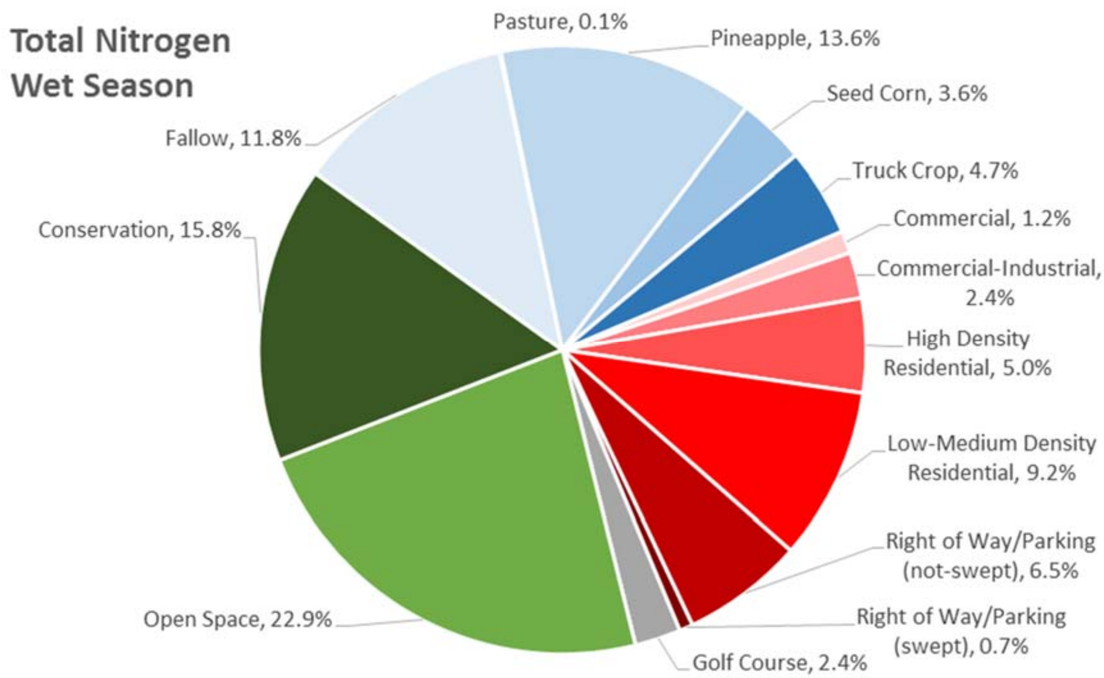


Figure 35.Wet season total nitrogen relative land use contributions

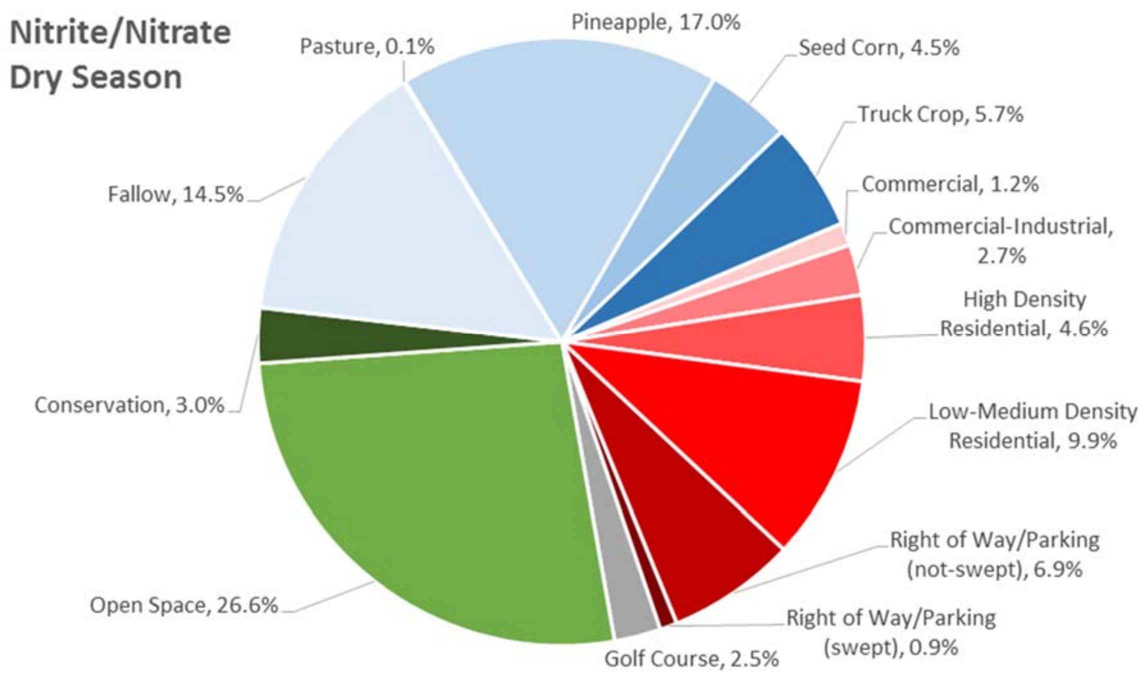


Figure 36. Dry season nitrite-nitrate relative land use contributions

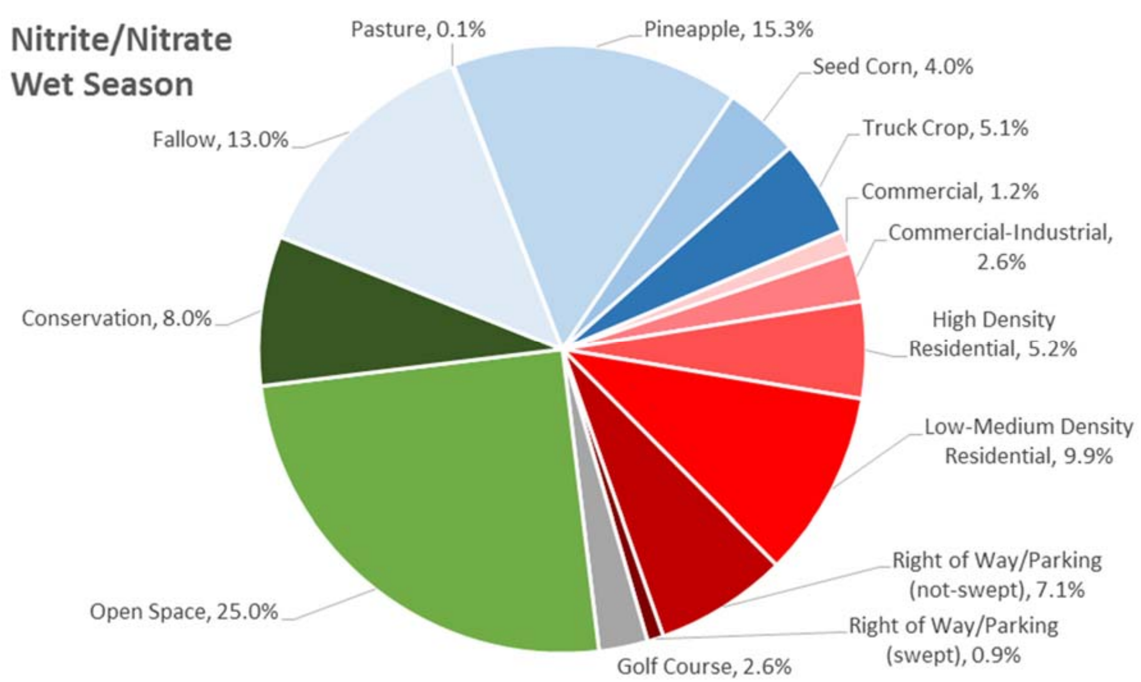


Figure 37. Wet season nitrite-nitrate relative land use contributions

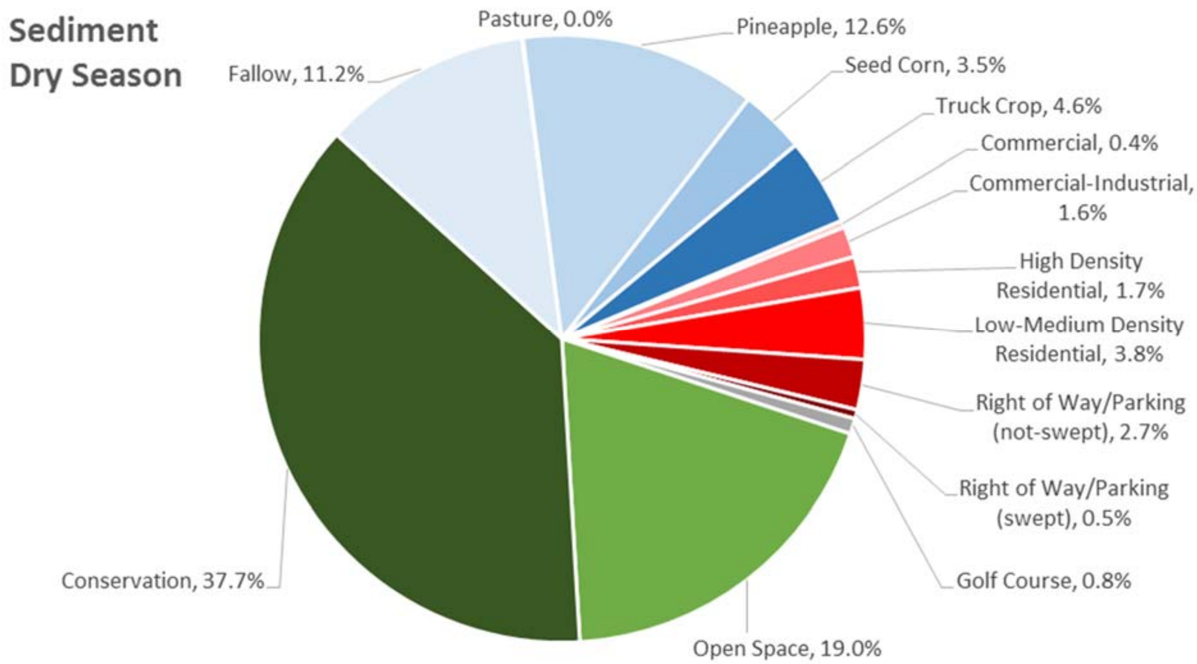


Figure 38. Dry season sediment relative land use contributions

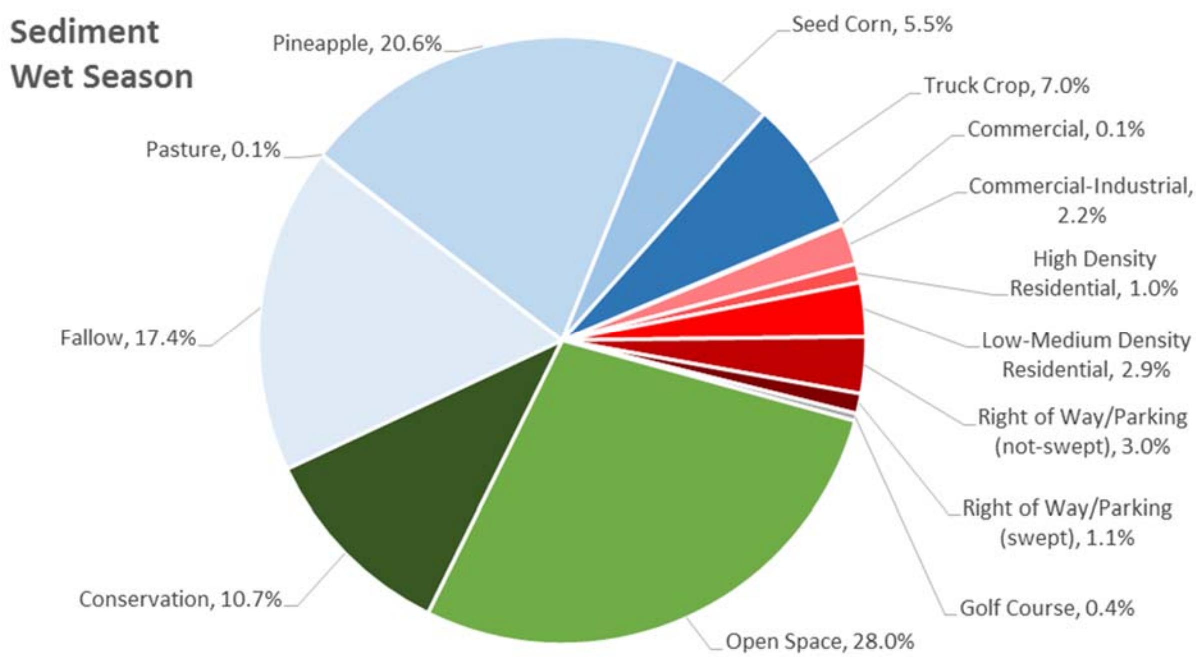


Figure 39. Wet season sediment relative land use contributions

5.4. Subgroup Estimated Existing Loads

Simulated loads were also summarized by modeled subgroup (Appendices A and B). The relative pollutant contributions by land use are presented for each subgroup (Tables 14-16). HSPF subgroups are described below in Table 17 and illustrated in Figure 40. These results show the same pattern as the watershed-wide dry and wet season contributions above (Section 5.3) but separate the contributions by subgroup categories. The values presented for subgroup 5 are not cumulative of all upstream loads; rather results are the pollutant contributions from the land within each subgroup.

Table 14. Nitrite-nitrate land use contributions by subgroup

Land Use	Subgroup					
	1	2	3	4	5	Total
Commercial	1.1%	0.7%	0.3%	0.0%	1.7%	**0.7%**
Commercial-Industrial	1.9%	2.0%	0.3%	1.0%	7.3%	**2.7%**
Conservation	44.9%	38.1%	27.4%	22.7%	0.0%	**25.6%**
Fallow	4.1%	3.0%	12.6%	20.8%	11.6%	**10.5%**
Golf Course	4.7%	0.0%	0.0%	2.7%	7.6%	**2.8%**
Right of Way/Parking (not-swept)	6.2%	6.7%	8.7%	0.4%	5.5%	**5.0%**
High Density Residential	5.5%	3.2%	19.2%	0.0%	2.9%	**4.1%**
Right of Way/Parking (swept)	1.3%	0.4%	0.3%	0.0%	0.4%	**0.4%**
Low-Medium Density Residential	9.4%	13.2%	0.0%	0.7%	10.3%	**7.7%**
Open Space	20.1%	23.1%	27.2%	14.9%	14.7%	**19.3%**
Pasture	0.0%	0.2%	0.0%	0.0%	0.0%	**0.1%**
Pineapple	0.0%	3.0%	3.8%	31.2%	17.4%	**13.2%**
Seed Corn	0.0%	0.0%	0.0%	4.4%	12.7%	**3.8%**
Truck Crop	0.8%	6.5%	0.1%	1.2%	7.7%	**4.2%**
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 15. Total nitrogen land use contributions by subgroup

Land Use	Subgroup					
	1	2	3	4	5	Total
Commercial	1.1%	0.7%	0.3%	0.0%	1.7%	**0.7%**
Commercial-Industrial	1.9%	2.0%	0.3%	1.0%	7.3%	**2.6%**
Conservation	44.9%	38.1%	27.4%	22.7%	0.0%	**27.2%**
Fallow	4.1%	3.0%	12.6%	20.8%	11.6%	**9.9%**
Golf Course	4.7%	0.0%	0.0%	2.7%	7.6%	**2.5%**
Right of Way/Parking (not-swept)	6.2%	6.7%	8.7%	0.4%	5.5%	**5.0%**
High Density Residential	5.5%	3.2%	19.2%	0.0%	2.9%	**3.9%**
Right of Way/Parking (swept)	1.3%	0.4%	0.3%	0.0%	0.4%	**0.4%**
Low-Medium Density Residential	9.4%	13.2%	0.0%	0.7%	10.3%	**8.1%**
Open Space	20.1%	23.1%	27.2%	14.9%	14.7%	**19.6%**
Pasture	0.0%	0.2%	0.0%	0.0%	0.0%	**0.1%**
Pineapple	0.0%	3.0%	3.8%	31.2%	17.4%	**12.4%**
Seed Corn	0.0%	0.0%	0.0%	4.4%	12.7%	**3.4%**
Truck Crop	0.8%	6.5%	0.1%	1.2%	7.7%	**4.3%**
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 16. Sediment land use contributions by subgroup

Land Use	Subgroup					
	1	2	3	4	5	Total
Commercial	1.1%	0.7%	0.3%	0.0%	1.7%	**0.7%**
Commercial-Industrial	1.9%	2.0%	0.3%	1.0%	7.3%	**2.7%**
Conservation	44.9%	38.1%	27.4%	22.7%	0.0%	**23.5%**
Fallow	4.1%	3.0%	12.6%	20.8%	11.6%	**12.2%**
Golf Course	4.7%	0.0%	0.0%	2.7%	7.6%	**2.9%**
Right of Way/Parking (not-swept)	6.2%	6.7%	8.7%	0.4%	5.5%	**4.1%**
High Density Residential	5.5%	3.2%	19.2%	0.0%	2.9%	**2.8%**
Right of Way/Parking (swept)	1.3%	0.4%	0.3%	0.0%	0.4%	**0.3%**
Low-Medium Density Residential	9.4%	13.2%	0.0%	0.7%	10.3%	**7.0%**
Open Space	20.1%	23.1%	27.2%	14.9%	14.7%	**18.2%**
Pasture	0.0%	0.2%	0.0%	0.0%	0.0%	**0.0%**
Pineapple	0.0%	3.0%	3.8%	31.2%	17.4%	**16.9%**
Seed Corn	0.0%	0.0%	0.0%	4.4%	12.7%	**4.5%**
Truck Crop	0.8%	6.5%	0.1%	1.2%	7.7%	**4.2%**
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Table 17. HSPF subgroup area

HSPF Subgroup	Estimated Area (acres)	Percent of Total Area	Estimated Agriculture Area (acres)	Estimated Urban Area (acres)	Estimated Conservation Area (acres)
1	3,690	13%	800	1,220	1,670
2	9,920	34%	3,120	3,000	3,800
3	5,790	20%	2,250	1,950	1,590
4	5,410	18%	4,180	0	1,230
5	4,600	16%	2,950	1,650	0
Total	29,410	**100%**	**13,300**	**7,820**	**8,290**

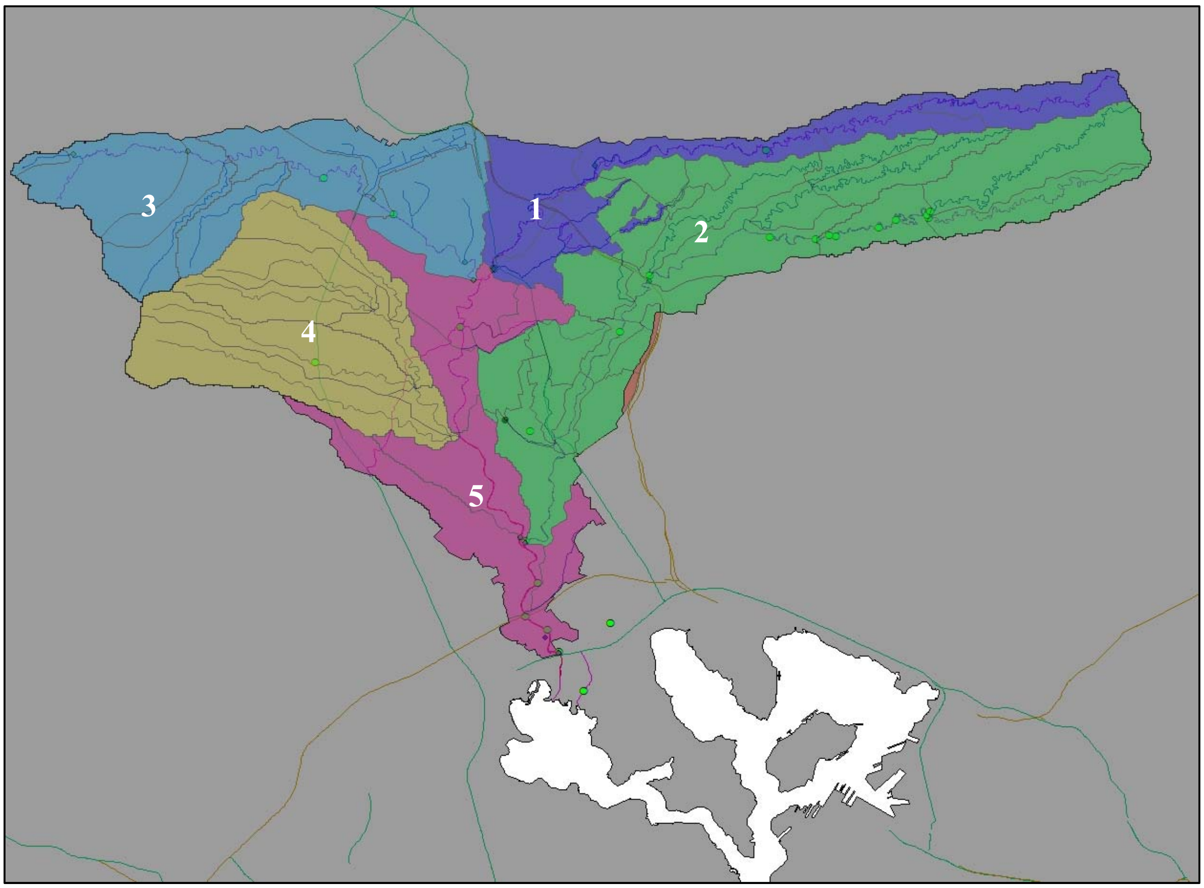


Figure 40. HSPF modeled subgroups

6. Linkage Analysis

The linkage analysis component of the TMDL establishes the relationship between nutrient and sediment loading and numeric targets and defines the total maximum daily load (TMDL) or loading capacity of receiving waters in order to determine the reductions required to attain the WQS (as expressed by the numeric targets) (USEPA 1999).

To support the TMDL objectives using available data, the development of a comprehensive watershed model was used to represent the Waikele watershed. A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes using land-based calculations as input.

TMDLs were calculated for each waterbody-pollutant combination described in Section 2 using watershed simulation model output. Attainment of the TMDL numeric targets will result in attainment of WQC. The percent reduction from the total existing load needed to attain WQC was also calculated for each pollutant.

The remainder of this section describes the model selection criteria, the selected model, and general model application. The model was used to calculate both existing loadings and the TMDLs (or loading capacities). The modeling approach and results are described in further detail in Appendices A and B.

6.1. Model Selection Criteria

In selecting an appropriate modeling approach for TMDL calculation, technical, regulatory, and user criteria were considered. Technical criteria include the physical system in question, including watershed characteristics and processes and the constituent(s) of interest. Regulatory criteria include WQC or procedural protocol. User criteria comprise the operational or economic constraints imposed by the end-user and include factors such as hardware/software compatibility and financial resources. The following discussion details the considerations in each of these categories. Based on these considerations, an appropriate model was chosen to simulate watershed conditions.

6.1.1. Technical Criteria

This section outlines key functions and processes that must be considered in the selection of an appropriate modeling strategy for the Waikele watershed. These technical criteria are divided into three main topics: physical domain, source contributions, and constituents. Consideration of each topic was critical in selecting the most appropriate modeling system to address the pollutant sources and the numeric targets associated with the impaired waters.

6.1.1.1. Physical Domain

Representation of the physical domain is perhaps the most important consideration in model selection. The physical domain is the focus of the modeling effort – typically described by either the receiving water itself or a combination of the contributing watershed and the receiving water. Selection of the appropriate modeling domain depends on the constituents of interest and the conditions under which the receiving water exhibits impairment. For a receiving water dominated by point source inputs that exhibit impairments under only low-flow conditions, a steady-state approach is typically used. This type of modeling approach focuses on only in-stream (receiving water) processes during a user-specified condition. For receiving waters affected additionally or solely by rainfall-driven flow and pollutant contributions, a dynamic approach is recommended.

Dynamic models consider time-variable nonpoint source contributions from a watershed surface or subsurface, or throughout the water column of a receiving water body. Some models consider monthly or seasonal variability, while others enable assessment of conditions immediately before, during, and after individual rainfall events. Dynamic models require a substantial amount of information regarding input parameters and data for calibration purposes. The Waikele watershed is dominated by rainfall-driven flow and pollutant contributions that deposit directly to tributaries and their receiving waters.

6.1.1.2. Source Contributions

Primary sources of pollution to a waterbody must be considered in the model selection process as well. Accurately representing contributions from permitted point sources and nonpoint source contributions from agricultural and natural areas is critical in properly representing the system and ultimately evaluating potential load reduction scenarios.

Data analysis of the available data indicates that the main sources of sediment and nutrients to the Waikele watershed are stormwater discharges from MS4s and construction, conservation areas, and runoff from agriculture. Watershed sources can be addressed through the model calibration and validation process and major source categories considered controllable for TMDL implementation purposes can be simulated by varying assumptions for management scenarios.

6.1.1.3. Constituents

Another important consideration in model selection and application is the constituent(s) to be assessed. Choice of state variables is a critical part of model application. The more state variables included, the more difficult the model is to apply and calibrate. However, if key state variables are omitted from the simulation, the model might not simulate all necessary aspects of the system and might produce unrealistic results. A delicate balance must be met between minimal constituent simulation and maximum applicability.

The focus of development of this study is on turbidity/sediment and nutrients (specifically, total nitrogen, and nitrite-nitrate). Turbidity cannot be directly simulated using most watershed models. A turbidity load cannot be calculated because its measurements are not mass-based. To overcome this limitation, a mass-based surrogate was used during model development. Sediment was considered a suitable surrogate for simulating turbidity. The bulk of available monitoring data were SSC; therefore, the model was calibrated to this constituent.

Nutrient cycling is complex and accurate estimation of nutrient loading relies on a host of interrelated factors. The relative impact of external nutrient loading to the waterbody must be represented by the modeling system.

6.1.2. Regulatory Criteria

A properly designed and applied model provides the source-response linkage component of the TMDL and enables accurate assessment of assimilative capacities and allocation distribution. A waterbody’s assimilative capacity is determined by assuming adherence to WQS. The HAR establishes, for all waters in the State, the beneficial uses for each waterbody to be protected, the WQC that protect those uses, and the water quality certification process in place to ensure standards are met. The modeling platform must enable direct comparison of model results to in-stream concentrations and allow for the analysis of the duration of those concentrations. For the watershed loading analyses and for future implementation activities, it is also important that the modeling platform enables examination of gross land cover loading as well as in-stream concentration.

6.1.3. User Criteria

User criteria are determined by the needs, expectations, and resources of DOH and USEPA. Modeling software must be compatible with existing personal-computer-based hardware platforms, and due to future use for planning and permitting decisions, should be well-documented, tested, and accepted. From a resource perspective, the level of effort required to develop, calibrate, and apply the model must be commensurate with available funding, without compromising the ability to meet technical criteria. In addition to these primary criteria, the required time-frame for model development, application, and completion is important.

6.2. Model Selection and Overview

Establishing the relationship between the in-stream water quality targets and source loading is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired source load reductions. The link can be established through a number of techniques, ranging from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions. The objective of this section is to present the approach taken to develop the linkage between sources and in-stream responses for TMDL development in the Waikele watershed.

In addition, to provide decision support for watershed management, the model may be used to simulate various scenarios and may require future modifications to address specific management and environmental factors. Such scenarios may result from the augmentation of input data to be collected in ensuing monitoring efforts, future implementation of various management strategies or BMPs, or adaptation and linkage to additional models developed in subsequent projects. Therefore, model flexibility is a key attribute for model selection.

The watershed model selected for the Waikele watershed TMDLs is HSPF. HSPF was selected for simulation of watershed processes, including hydrology and pollutant accumulation and wash-off, and to represent flow and water quality in the streams that drain to the mouth of the Waikele watershed.

HSPF can simulate hydrology and associated water quality processes on pervious and impervious land surfaces and in streams. In this way, nonpoint source loads of sediment and nutrients are generated that can be combined with imposed point sources within the HSPF system for watershed-scale management (Bicknell et al. 2001). HSPF integrates GIS, comprehensive data storage and management capabilities, and a dynamic watershed model into a convenient personal computer-based windows interface that dictates no software requirements.

The HSPF model is capable of predicting water quantity and quality from complex watersheds with variable land covers, elevations, and soils. Because it is largely physically based, the model requires specific input data, such as weather, soils, land cover, and topography. This offers the ability to apply the model in areas where observation data are sparse. The model can simulate sediment and nutrient contributions from specific source areas (e.g., subwatershed or land cover areas). This is important in terms of TMDL development and allocation analysis. Details regarding the theoretical structure of the HSPF model and its modules can be found in the HSPF User's Manual (Bicknell et al. 2001).

6.3. Model Application

A complete discussion of the HSPF model is provided in Appendices A and B. These documents describe model configuration, hydrologic calibration and validation, and water quality calibration for sediment and nutrients. The model was calibrated to observed hydrologic and water quality data to characterize existing conditions in the watershed.

6.3.1. Watershed Segmentation

The most downstream portion of the modeled watershed is coincident with Station 1 and the USGS gaging station 162130000 (Figure 7). The geographic location of each modeled subgroup area is illustrated in Figure 40 (note: subgroups are made up of several contributing subwatersheds in in the TMDL area) and Table 17 identifies the area associated with each subgroup along with the land use areas that make up each subgroup. The subgroups are determined based on significant drainage areas.

HSPF subgroup 2 contains Kipapa Stream, and is the largest subgroup in the TMDL area, making up 34 percent of the drainage area (approximately 9,900 acres). Land uses are evenly distributed in this subgroup. Subgroup 3 contains Upper Waikele Stream, and is the second largest drainage area with approximately 5,800 acres. Subgroup 1 is the smallest drainage and contains Waikakalaua Stream (nearly 3,700 acres).

6.3.2. Model Configuration, Calibration, and Results

A summary of the HSPF model configuration, calibration and results is provided below while details are presented in Appendices A and B. Appendix A contains details on model configuration and sediment calibration, while Appendix B describes the nutrient simulations.

6.3.2.1. Model Configuration

HSPF was used to represent the variability of point and nonpoint source contributions through dynamic representation of hydrology and land practices. Key components of the watershed modeling and configuration included watershed delineation, meteorological data, land use and cover representation, soils, topography, reach characteristics, hydrology representation, and pollutant representation. The HSPF model configuration represents the diversity of land management/land use, precipitation, land cover, soils and topography within watershed subbasins using pervious and impervious land segments. The model was run for each unit and runoff and pollutant contributions to each stream channel were based on the acreage of each pervious and impervious segment in each subbasin.

To evaluate pollutant sources contributing to the impaired waterbodies and to represent the spatial variability of these sources, the contributing drainage area was represented by a series of subbasins. The subbasins were distributed among five subgroup areas in the Waikele watershed as discussed in Section 6.3.1. The Waikele watershed was subdivided into 54 subbasins ranging in size from 8 to 1,500 acres. Each subbasin was delineated to a desired outlet location (established flow gaging stations and stormwater outfalls) based on topographic contours and the CCH stormwater GIS inventory. In addition to the hydrologic basin boundaries, the model was also divided into land classifications based on MS4 permits, land ownership, or land use designations. The ownership land classifications were applied to areas that do not drain to a stormwater system. The modeled subbasins and land classifications are shown above in Figure 33.

Existing land use in the HSPF model was based on CCH's current tax parcel data and included the following land uses:

- Commercial-industrial
- High density residential
- Low-medium residential
- Open space
- Golf courses
- Conservation
- Pasture
- Fallow
- Pineapple
- Seed corn
- Truck crop
- High pollution generating impervious surfaces, swept by Hawaii DOT
- High pollution generating impervious surfaces, swept by CCH
- High pollution generating impervious surfaces, not swept

The subbasins were also represented by different soil characteristics. Study area soils were characterized by using the NRCS's Soil Survey Geographic database (SSURGO) (see Section 4.1.4). There are dozens of soil types in the Waikele watershed, but for the purposes of modeling, the soils were grouped into the five categories of Waianae Mountain soil, Koolau Mountain soil, valley rock lands, steep silty-clays, and other silty-clay.

In addition to the representation of the watershed itself, meteorological data are used to drive the model. Precipitation data were discussed in Section 4.1.3. The HSPF model also required time-series data for potential evapotranspiration, air temperature, solar radiation, dew point temperature, average wind speed, and cloud cover. Most of these meteorological parameters used for the HSPF model were recorded at the Honolulu Airport (HNL), except for pan evaporation and cloud cover, which were recorded at the Honolulu Observatory and Wheeler Army Air Force base.

To accurately represent current conditions during the calibration period, the two primary actions currently implemented in the watershed to control sediment sources (permanent BMPs and street sweeping) were represented. Specifically, eighteen existing permanent BMPs were included in the model. Design calculations for theses BMPs were not available; therefore, the area treated by each BMP was estimated based on the area of the parcel(s) in which the BMP was located. The amount of sediment removed by each BMP was assigned to HSPF using the BMP module. The module allows the user to assign a pollutant removal efficiency to each BMP and that sediment load is then removed from the runoff generated in that area. In addition to the existing BMPs, Hawaii DOT performs street sweeping in the watershed. Street sweeping plans were not available, but it was assumed that all roadways owned by the state are swept once per month with a removal rate comparable to the Ala Wai I&M Plan (0.048 tons per acre) (Appendix A).

6.3.2.2. Model Calibration and Results

After the model was configured, model calibration was performed. Calibration is the process of adjusting model parameter values with the goal of achieving an acceptable level of agreement with observed data. Calibration of the HSPF model was performed in three sequential phases: hydrology, sediment, and nutrients. A simulation period of October 1997 through September 2011 (water years 1998-2011) was selected for HSPF model calibration. The calibration used a weight of evidence approach by considering a combination of qualitative and quantitative measures of calibration including

- Visual evaluation of graphical time-series or scatter plots of observed flow, loads or concentrations
- Tabulations of measured and predicted values
- Error statistics

Hydrology Calibration

The hydrology calibration of the Waikele watershed model was performed by setting an initial set of model soil parameters and modifying them to improve the match between simulated stream flow and observed stream flow at four primary calibration locations and four secondary locations. The primary locations include four USGS gages: Kipapa Stream at Wahiawa, Waikele Stream at Wheeler, Mililani Storm Drain A and Waikele Stream at Waipahu. The secondary locations include three USACE monitoring locations (SW-5, SW-6, SW-11 and SW-12) that have smaller sample sizes and less information available about the monitoring program. The locations of these stations are shown in Figure 7. Two different time scales were used to judge to quality of the Waikele Stream hydrology calibration: 1) matching the water balance of monthly average discharge over many water years and 2) matching individual event hydrographs at an hourly time scale. The monthly time scale comparison was used to inform adjustments to the balance between runoff, evaporation, infiltration and deep groundwater recharge. Evaluation of the hydrology results indicated that the model did a reasonable job of representing monthly mean flows at all four gages. The differences between modeled and observed flows are discussed in detail in section 4.2.2 of Appendix A.

After an acceptable monthly time-scale calibration was achieved, individual storm hydrograph comparisons were then used to inform adjustments to the fraction and timing of runoff that responds as surface or shallow groundwater flow. These adjustments control the magnitude and shape of individual storm hydrographs. Different approaches were used for calibration of single events for the USGS and USACE gaging stations based on the format of the observed data at each location. The USGS gages had continuous hourly and daily streamflow records, while the USACE gages had weekly interval and periodic instantaneous discharge measurements.

Modeled and observed daily and hourly time-step hydrographs were compared at the USGS gages for storm events between December 2003 and December 2008. The December 2008 event was by far the event of record in all gages in the basin except Kipapa at Wahiawa, where the event was large, but not to the same degree as central and western portions of the watershed. The model did a reasonably good job of tracking the storm hydrographs for these events at the Kipapa at Wahiawa and Waikele Stream at Waipahu sites (see Appendix A). Tracking at the Waikele Stream at Wheeler was fair, with the largest absolute error of the evaluated storms being the December 2008 storm (the simulated daily peak was 18% higher than observed peak). The match to observed hourly flows at Mililani Storm Drain A were fair for the few events that had both observed flow and local rainfall data (e.g., peak hour for November 2007 and December 2008 within 20%), but the higher degree of development and smaller size of this basin causes the flows in this reach to be very flashy and sensitive to small bursts of rainfall. As a result, the model under or over-estimates event peaks when recorded rainfall volumes do not correspond to observed storm system peaks in Mililani Storm Drain A (e.g. December 5, 2007).

Single event volume comparisons at USACE gages were also performed. Observed and simulated stream flows were compared at stations SW-5, SW-6, SW-11 and SW-12. The quality of the hydrology calibration at the USACE gages was relatively poor. Since the available quality assurance/quality control data for the USGS gages in the watershed were more substantial, the USGS flow data were used to inform the model calibration.

Sediment Calibration

After the model was calibrated for hydrology, water quality simulations were performed, beginning with sediment. Similar to hydrology, the model parameters controlling simulation of sediment production, delivery and transport were calibrated by setting an initial set of parameters and modifying those to improve the match between simulated and observed sediment concentration data. Daily average SSC concentrations at the same three USGS gages that were used in the hydrology calibration (Waikele at Wheeler and Waipahu and Kipapa at Wahiawa) were used for the comparison (Figure 7). The sediment calibration focused on 2007 to 2010.

For calibration of individual storm days, the simulated mean daily discharge was typically within approximately 30 percent of observed daily discharge, and simulated daily suspended sediment yields were similarly close to the USGS's observed suspended sediment yield. Of particular importance is the agreement between the model and observed sediment yield for the storm of December 11, 2008, the event of record, at all three gage sites (see Table 28 in Appendix A).

Comparisons of simulated and observed daily sediment load pollutographs at the Kipapa at Wahiawa, Waikele at Wheeler, and Waikele at Waipahu gage sites for storm events between November 2007 and December 2008 are provided in Figures C1-C10 in Appendix A. The figures show good agreement between simulated and observed daily sediment loads at all three gage sites during most storm periods shown; notable exceptions being the December 5, 2007 event at the Waikele at Wheeler site. The cause for mismatches between simulated and observed sediment loads can be partly attributed to poor rainfall data, mass-wasting, or other processes not explicitly included in the model. Another challenge with the Upper Waikele Stream region (i.e., upstream of the Waikakalaua confluence) is a relatively rapid change from pineapple agriculture to fallow and/or other land uses between the period 2005 and 2008. As part of the calibration process Google Earth imagery from late 2008 was reviewed and some pineapple areas were shifted to fallow.

Total sediment load data provided in the USACE (2015) report were also utilized for calibration of the HSPF model sediment parameters in the developed portions of Upper Waikele Stream. Total observed sediment loads were reported for seven events at stations SW-11 and SW-12. Observed sediment loads and the simulated HSPF sediment loads at stations SW-11 and SW-12 were compared. Some of the observed sediment loads reported by USACE (2015) for these locations conflicts with the observed USGS data for the same events; when data conflicts were identified, the USGS data was given greater weight during the calibration. The resulting comparisons of loads at these sites are discussed in detail in Appendix A.

Average annual suspended sediment for 2008 through 2010 at USGS gages were also used for calibration. The HSPF modeled sediment closely matched the USGS sediment (see Table 33 of Appendix A). Given the high degree of spatial variability in local rainfall data, changing land use, and dynamic hydrologic processes active in the mountainous regions of this watershed, the calibration was considered adequate for the objectives of this study.

Nutrient Calibration

The ability to achieve a good nutrient water quality calibration is dependent on the sediment calibration, and similarly, the sediment calibration was dependent on the hydrology calibration. Using an approach similar to that applied for the calibration of stream flow and sediment, the HSPF model parameters controlling simulation of nutrient production, delivery and transport were also calibrated by setting an initial set of parameters and modifying those to improve the match between simulated and observed data. The simulation period, October 1997 through September 2011, is identical to that used for the sediment calibration, however the period of observed data differs. The stations used for nutrient calibration are shown in Figure 7. USACE nutrient data from site SW-12 were excluded from this analysis because some questionable values need to be investigated further before application to the model.

Several related criteria were used to guide nutrient calibration including:

1. Match cumulative distribution function (CDF) curves of concentrations observed at eight DOH sites and three USACE sites.
2. Match dry season (May through October), wet season (November through April), and overall geometric mean concentrations observed at eight DOH sites and three USACE sites.
3. Match observed pollutographs of sequential samples collected at Station 1 between 1999 and 2001.
4. Match event mean concentrations from runoff on a land use basis as reported in literature for studies in Hawaii and the U.S. mainland.

The first comparison of the model's ability to match observed nutrient observations was the CDF curves. Simulated and observed concentration curves were developed by sampling the time-series of concentrations simulated for each monitoring location at the times corresponding to the available observed samples. CDF curves for the upper watershed stations illustrated that the model generally matches observed concentrations well in undeveloped conservation areas. Station 1, which is located at the most downstream reach in the model, reflects the cumulative nutrient loads from the watershed. This site has more observed samples than any other site, making it the most reliable observed CDF curve. The simulated curves at Station 1 match well with observed nutrient observations (with the exception of missing one observed sample at the highest point in the curve for total phosphorus).

Next, dry season (May through October) and wet season (November through April) and overall geometric mean concentrations observed at eight DOH sites and three USACE sites were compared. Tabulations of observed and simulated concentrations, expressed as geometric means, are provided in Table 4 through Table 6 in Appendix B. The values used to calculate these geometric means are identical to those used to generate the CDF curves discussed above.

During periods when frequent monitoring data were available, pollutograph plots were used to visualize and compare the timing and magnitude of simulated and observed pollutant concentrations. Station 1 is the only site within the study area that had data suitable for this comparison, and only a relatively short period between April 1999 and April 2004 was available at that location. The level of agreement between observed and simulated concentrations in these plots is good, which is expected given the quality of the match in the CDF plots discussed above and shown in Appendix B.

Finally, unlike some simple water-quality models that utilize a set of pollutant event mean concentrations as inputs, the HSPF model user must define parameters to represent pollutant loading behavior. The simulated load or concentration generated from each land use can then be queried and compared to expected concentrations of runoff based on monitoring of individual land uses or literature. This comparison is important as the spatial distribution of pollutant load generation has management implications.

The resulting stormwater pollutant concentration characterizations were tabulated along with the average seasonal simulated concentrations from the HSPF model in Table 8 through Table 10 in Appendix B. Simulated nutrient concentrations match the literature values by land use with varying levels of accuracy. However, the overall nutrient calibration results indicate that the model does a good job of predicting observed concentrations within the Waikele watershed.

7. TMDL Calculations and Allocations

This section discusses the methodology used for TMDL development and TMDL results in terms of loading capacities and required load reductions for the Waikele Stream segment listed on Hawaii's section 303(d) list due to nutrient and turbidity impairments (Table 2 and Figure 1) (DOH 2018). Waikele Stream was also identified as impaired for total phosphorus and TSS by various data analyses (Section 4.3), however because those impairments were not officially identified on the 303(d) list, they will not be addressed by this TMDL. Allocations, critical conditions, and reasonable assurance are also presented below.

7.1. TMDL and Loading Capacity Calculation

A TMDL represents the total amount of a pollutant that can be assimilated by a receiving waterbody while still achieving WQS – also called the *loading capacity*. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL's loading capacity must be established and thereby provide the foundation for establishing water quality-based controls. TMDLs can be expressed on a mass loading basis (e.g., kilograms of a pollutant per year [kg/yr]) or as a concentration in accordance with 40 CFR 130.2(l).

A TMDL for a given pollutant and waterbody is comprised of the sum of individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for both nonpoint sources and natural background loads, and a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is represented by the equation:

$$TMDL = \Sigma\ WLAs + \Sigma\ LAs + MOS$$

TMDLs were established using the methodology described below. These TMDLs identify and allocate to the sources that cause or contribute to the turbidity, sediment, and nutrient impairments. The WLA portion of this equation is the total loading assigned to point sources. The LA portion is the loading assigned to nonpoint sources. The MOS is the portion of loading reserved to account for any uncertainty in the data and computational methodology, as described in Section 7.1.4. An implicit MOS was used for this TMDL.

7.1.1. Methodology

To determine existing conditions and TMDLs for the nutrient, turbidity, and sediment impaired waterbodies, the HSPF watershed loading model was used. The HSPF model was calibrated for a fourteen- year period (water years 1998 to 2011) (Appendices A and B). These years covered a range of hydrologic conditions, including wet, dry, and average years. Because turbidity cannot be directly simulated using the watershed model (Section 6.1.1.3), sediment was simulated as a surrogate (Section 4.3.2.1). The model was calibrated to SSC, consistent with the majority of available data. The TMDL numeric targets for sediment are in TSS. TSS is generally lower than SSC due to the difference in the analytical methods (Glysson et al. 2000). In addition, a USGS study conducted in Hawaii, which compared SSC and TSS concentrations in paired samples demonstrated that SSC overestimates TSS by approximately 35% (Hill 1996); therefore, use of SSC in conjunction with a correction factor to estimate existing loads and TSS for loading capacity calculations was considered reasonable as it provides an implicit MOS (Section 7.1.4). Ultimately, achieving the sediment and nutrient TMDLs will contribute to meeting the turbidity WQS. Nutrient concentrations were simulated directly using the HSPF model. The simulated sediment and nutrient point and nonpoint source concentrations and loads represent the existing conditions in the TMDL.

TMDL tables with load-based allocations are presented in Tables 18-21 for total nitrogen, nitrite-nitrate, and sediment, respectively. These values can be readily incorporated into permits and are useful to assess compliance.

The modeling output was used to calculate existing pollutant loadings and to identify the reductions needed to meet the loading capacity and corresponding numeric targets. These reductions are provided for guidance and reference only, as compliance will be determined based on attainment of the allocations, not reductions. Reductions were calculated based on the modeled existing loadings of sediment and nutrients relative to their respective loading capacity (based on the applicable sediment and nutrient numeric targets):

$$\text{Percent Reduction} = \frac{(\text{Modeled Existing Concentration} - \text{Loading Capacity})}{(\text{Modeled Existing Concentration})} \times 100$$

The allowable loads were distributed as waste load and load allocations to sources within the watershed based on areas of land use ownership and the distribution of pollutant loadings among land use types. Since specific land use loading rates were not available for inclusion into this document, and land use and ownership are expected to change over time, it is appropriate to consider specific land use loading rates and/or refinement of land use areas to calculate permit limits and assess compliance. TMDL tables with load-based allocations are presented in Tables 18- 21 for total nitrogen, nitrite-nitrate, and sediment, respectively.

7.1.2. Waste Load Allocations

The WLA is the portion of the loading capacity allocated to point source discharges to the waterbody. Point sources in the Waikele watershed include NPDES permits for construction and industrial stormwater and MS4s. The MS4 permittees include CCH permit HIS000002, Hawaii DOT permit HIS000001, and U.S. Army Garrison Hawaii permit HIS000090 (Table 13). The WLA calculations for MS4s assumes that all of the impervious area contained within each MS4 footprint drains to the MS4.

NPDES permitted discharges from construction and industrial stormwater facilities were existing and continued throughout the sampling and flow modeling time period used in TMDL development. Both of these facilities were assigned a WLA of zero because construction stormwater permits are of short duration and are required to implement BMPs to minimize or eliminate runoff from the construction site, and the potential runoff from the industrial stormwater permits in the Waikele watershed (specifically Schofield Barracks WWTP industrial stormwater) are generally included within the U.S. Army Garrison's footprint. The modeled existing loads in the TMDL from these areas was distributed to other WLA and LA land owners. In the future, construction and industrial stormwater NPDES permits will be required to reduce pollutant discharges through application of BMPs and additional permit requirements, consistent with the requirements of the TMDLs. These conservative assumptions, 1) that existing loads from construction and industrial NPDES permits are assigned zero existing load, and, 2) that these loads will be reduced by future permit requirements, provide an additional layer of implicit MOS for the TMDLs. A separate WLA was also included as a reserve capacity for future permittees in the watershed.

7.1.3. Load Allocations

The LA is the portion of the loading capacity allocated to nonpoint source discharges to the waterbody. Nonpoint sources receiving load allocations in the Waikele watershed include agriculture, forested areas owned by the CCH, and U.S. Army Garrison Hawaii, natural background (conservation land), the Department of Education, and agricultural and lands owned by either the state or private entities that are not subject to an NPDES permit.

7.1.4. Margin of Safety

A MOS must be included in a TMDL to account for any uncertainty or lack of knowledge regarding the pollutant loads and the response of the receiving water. The MOS can be implicit (incorporated into the TMDL analysis through conservative assumptions) or explicit (expressed in the TMDL as a portion of the loadings) or a combination of both. The TMDLs for the Waikele watershed includes an implicit MOS that is based on the following conservative assumptions:

1. The TMDL numeric targets are a direct translation of the WQC and are applied at all locations within the watershed using the modeled flow at the mouth of the watershed. Therefore, the application of the numeric WQC throughout the watershed does not account for the waterbody's ability to assimilate pollutants (specifically nutrients) prior to reaching the station used to calculate the loading capacities.
2. The model was calibrated using a time series rainfall/streamflow dataset that includes an extreme wet weather event (December 2008) beyond a 100- yr. storm, resulting in uncertainty regarding the modeled loadings. The uncertainty is incorporated into the TMDL load calculations by assuming a 100- yr. return flow on the affected days. Nevertheless, because the data collected during the large storm event remains a source of uncertainty, it is still considered an implicit margin of safety.
3. The TMDL for sediment was calculated based on the TSS numeric target, while the existing loads were calculated as SSC loads. In paired samples, SSC loads are expected to be higher than TSS loads, sometimes by as much as 35% (Glysson et al. 2000, Hill 1996). This was considered when calculating TSS load reductions, however the discrepancy remains a source of uncertainty.

7.2. TMDL Results and Allocations

Load-based allocations are presented for individual sources. The dry and wet weather loading capacities and for total nitrogen, nitrite-nitrate, and sediment are presented in Tables 18-21. These tables also present the reductions necessary to meet the TMDLs (presented as percent reduction from the existing loading). The TMDL allocations were calculated using the most stringent of the three criteria (geometric mean, 10% and 2% NTE) that were in exceedance. TMDL compliance will be based on the GM criteria for TN, and the 10 percent wet season criteria for TSS. Due to the high variability in modeled nitrite-nitrate loadings (Appendix B), the allocations for nitrite-nitrate will be assumed to be met, provided that the TN allocations are met. The nitrite-nitrate loading table (Table 19) is included in this document to provide additional information to assist with meeting the TN TMDL targets, and the State will not require WLAs and LAs for this pollutant.

Total nitrogen reductions required to achieve the geometric mean WQS numeric criteria are 89 percent and 83 percent for the dry and wet seasons, respectively. These reductions decrease to 70 and 51 percent, respectively, to meet the dry and wet season 2 percent exceedance value TMDLs. Nitrite-nitrate existing concentrations are estimated to need dry and wet season reductions of 97 and 93 percent, respectively, to achieve the geometric mean loading targets. Model results indicated that for sediment, the existing conditions are currently meeting the geometric mean numeric target; however, reductions of over 95 percent were required to meet the 10 percent exceedance value TMDLs. These analyses suggest that sediment loads tend to achieve the numeric targets during baseline conditions and exceed during storm events.

The TMDL tables are supplemented by graphs that illustrate the annual dry and wet season allowable and existing geometric mean loads and concentrations (Figures 41-43). For the 10 percent not-to-exceed sediment TMDLs, flow and precipitation conditions associated with exceedances of the loading capacities were summarized. For all days exceeding their respective loading capacity, the average flow at the mouth of the watershed was calculated. Average daily precipitation was also determined for the exceedance days at each of the six precipitation zones included in the watershed modeling analysis. These average values provide insight into the watershed conditions contributing to storm-driven impairments and are summarized in Table 22. In general, higher average rainfall and flow values were observed on exceedance days. However, the percent reductions required to achieve the load-based 10 percent exceedance value TMDLs are over 80 percent, indicating that the loads of sediment during storm events are large (Table 22).

Table 18.Total nitrogen allocations and reductions to achieve TMDL numeric targets

TMDL Component	Geometric Mean TMDL Dry Season* Load (kgd)	Geometric Mean TMDL Wet Season* Load (kgd)	Modeled Existing Load Dry Season* Load (kgd)	Modeled Existing Load Wet Season* Load (kgd)
Loading Capacity	7.01	16.24	N/A	N/A
Wasteload Allocations				
City County of Honolulu MS4	0.38	1.13	3.72	6.96
U.S. Army Garrison Hawaii MS4	0.09	0.42	0.87	2.60
State of Hawaii DOT MS4	0.07	0.16	0.69	0.96
Construction Stormwater General and Individual Permits	0	0	0	0
Industrial Stormwater General and Individual Permits	0	0	0	0
Reserve WLA for Future Growth (5%)	0.35	0.81	—	—
Load Allocations				
City County of Honolulu	0.68	1.98	6.54	12.23
U.S. Army Garrison Hawaii	0.16	0.75	1.56	4.66
State of Hawaii DOT (and other)	0.39	0.87	3.82	5.36
State of Hawaii DOE MS4	0.05	0.15	0.53	0.94
Agriculture	3.62	7.52	35.04	46.40
Conservation Land	1.21	2.45	11.73	15.09
Total Existing Load			64.48	95.22
Load Reduction			57.47	78.98
Percent Reduction			89%	83%

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.
Acronyms: kgd = kilograms per day, N/A = not applicable; "—" = not explicitly modeled

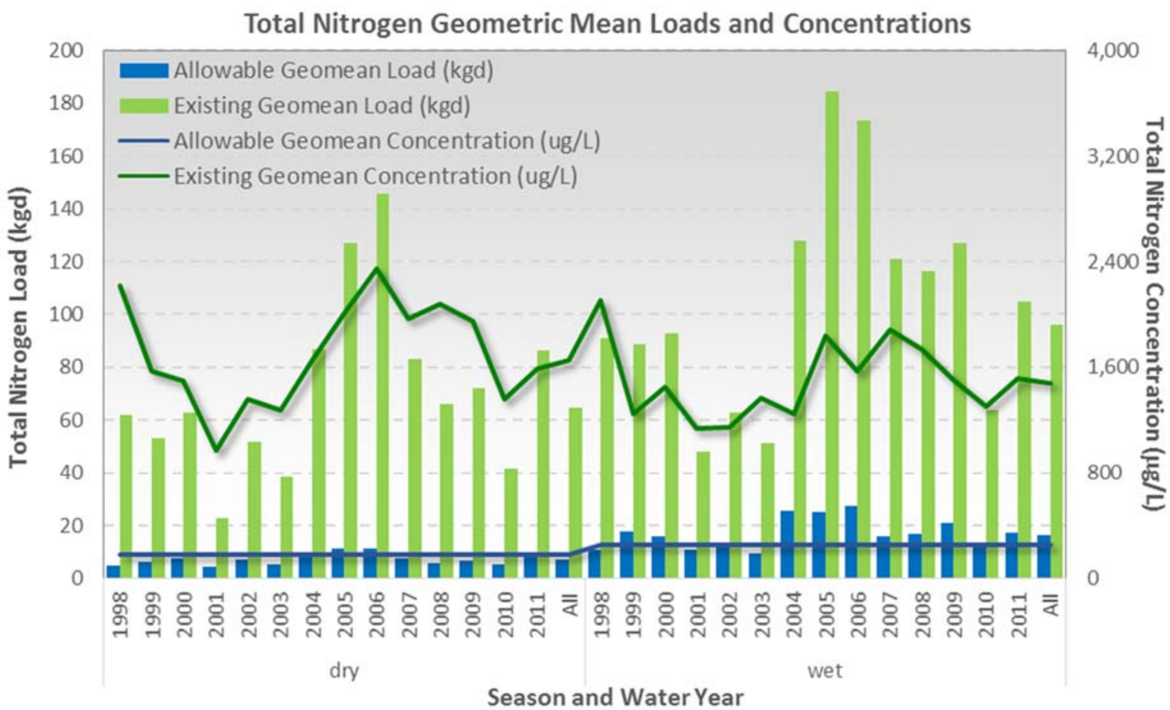


Figure 41. Total nitrogen annual TMDL and existing condition geometric mean loads and concentrations

Table 19. Nitrite-nitrate allocations and reductions required to achieve numeric targets

TMDL Component	Geometric Mean TMDL		Modeled Existing Load	
	Dry Season* Load (kgd)	Wet Season* Load (kgd)	Dry Season* Load (kgd)	Wet Season* Load (kgd)
Loading Capacity	1.17	4.55	N/A	N/A
Wasteload Allocations				
City County of Honolulu MS4	0.09	0.34	3.31	5.08
U.S. Army Garrison Hawaii MS4	0.02	0.12	0.88	1.72
State of Hawaii DOT MS4	0.01	0.05	0.55	0.78
Construction Stormwater General and Individual Permits	0	0	0	0
Industrial Stormwater General and Individual Permits	0	0	0	0
Reserve WLA for Future Growth (5%)	0.06	0.23	—	—
Load Allocations				
City County of Honolulu	0.15	0.60	5.82	8.92
U.S. Army Garrison Hawaii	0.04	0.21	1.58	3.07
State of Hawaii DOT (and other)	0.08	0.29	3.08	4.34
State of Hawaii DOE MS4	0.01	0.04	0.42	0.62
Agriculture	0.67	2.33	26.17	34.82
Conservation Land	0.03	0.35	1.28	5.16
Total Existing Load			43.09	64.52
Load Reduction			41.92	59.98
Percent Reduction			97%	93%

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.
Acronyms: kgd = kilograms per day, N/A = not applicable; "—" = not explicitly modeled

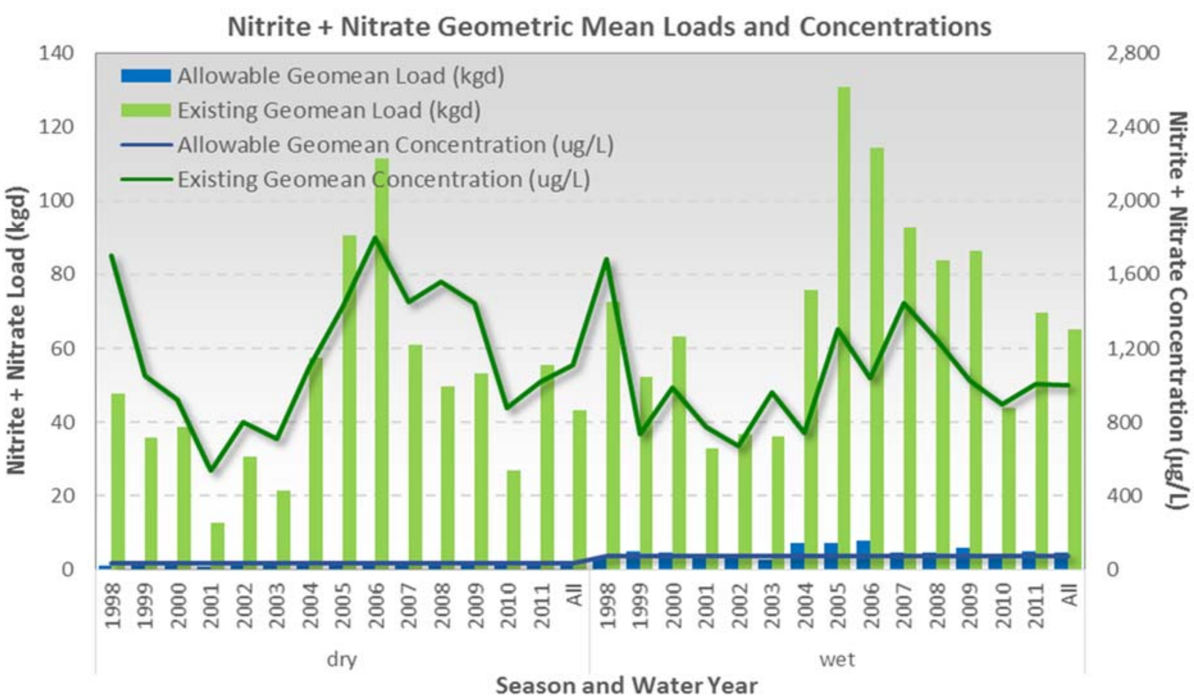


Figure 42. Nitrite-nitrate annual TMDL and existing condition geometric mean loads and concentrations

Table 20. Sediment allocations

TMDL Component	Geometric Mean TMDL		Modeled Existing Load	
	Dry Season* Load (kgd)	Wet Season* Load (kgd)	Dry Season* Load (kgd)	Wet Season* Load (kgd)
Loading Capacity	389.5	1,299.0	N/A	N/A
Wasteload Allocations				
City County of Honolulu MS4	9.2	12.7	1.7	2.2
U.S. Army Garrison Hawaii MS4	3.2	8.8	0.6	1.5
State of Hawaii DOT MS4	2.5	18.4	0.5	3.2
Construction Stormwater General and Individual Permits	0	0	0	0
Industrial Stormwater General and Individual Permits	0	0	0	0
Reserve WLA for Future Growth (5%)	19.5	65.0	—	—
Load Allocations				
City County of Honolulu	16.2	22.3	3.1	3.9
U.S. Army Garrison Hawaii	5.7	15.8	1.1	2.7
State of Hawaii DOT (and other)	14.0	102.7	2.6	17.8
State of Hawaii DOE MS4	1.06	1.3	0.2	0.2
Agriculture	178.4	919.1	33.7	159.6
Conservation Land	139.7	132.9	26.4	23.1
Total Existing Load			69.9	214.3
Load Reduction			N/A	N/A
Percent Reduction			N/A	N/A

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.
Acronyms: kgd = kilograms per day, N/A = not applicable; "—" = not explicitly modeled
Shaded loading values are intended for informational purposes only, and reductions are not required.

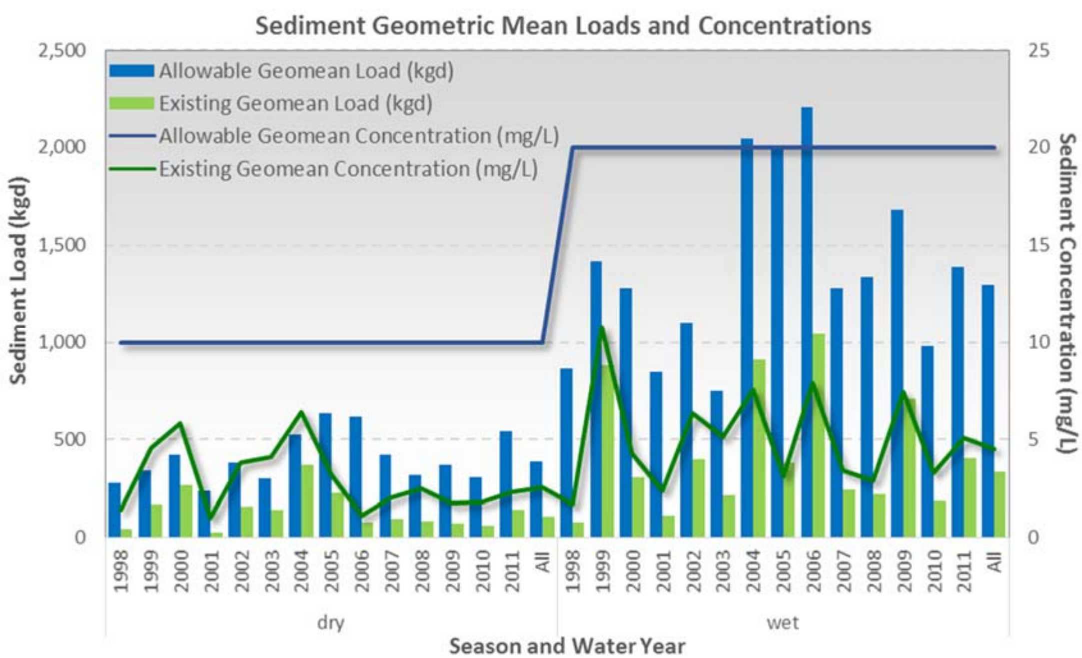


Figure 43. Sediment annual TMDL and existing condition geometric mean loads and concentrations

Table 21. 10% NTE Sediment TMDL allocations and reductions required to achieve TMDLs

TMDL Component	Geometric Mean TMDL Dry Season* Load (kgd)	Geometric Mean TMDL Wet Season* Load (kgd)	Modeled Existing Load Dry Season* Load (kgd)	Modeled Existing Load Wet Season* Load (kgd)
Loading Capacity	4,991.0	18,997.2	N/A	N/A
Wasteload Allocations				
City County of Honolulu MS4	117.8	185.8	2,349.1	3,686.8
U.S. Army Garrison Hawaii MS4	41.1	129.0	819.8	2,559.1
State of Hawaii DOT MS4	32.1	269.8	640.2	5,353.4
Construction Stormwater General and Individual Permits	0	0	0	0
Industrial Stormwater General and Individual Permits	0	0	0	0
Reserve WLA for Future Growth (5%)	249.6	949.9	—	—
Load Allocations				
City County of Honolulu	207.0	326.4	4,127.6	6,478.1
U.S. Army Garrison Hawaii	73.5	230.6	1,466.2	4,576.9
State of Hawaii DOT (and other)	178.8	1,502.5	3,565.5	29,815.2
State of Hawaii DOE MS4	13.6	19.4	272.0	385.8
Agriculture	2,286.7	13,440.9	45,600.7	266,723.2
Conservation Land	1,790.7	1,942.9	35,709.7	38,555.7
Total Existing Load			94,550.8	358,134.2
Load Reduction			89,559.8	339,137.0
Percent Reduction			95%	95%

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.
Acronyms: kgd = kilograms per day, N/A = not applicable; "—" = not explicitly modeled
Shaded loading values are intended for informational purposes only, and reductions are not required.

Table 22. Flow and precipitation conditions during exceedances of sediment TMDLs

Watershed Characteristic	Dry Season*	Wet Season*
Exceedances of 10 Percent Not-to-Exceed TMDL		
Exceedance Days (%)	17.6%	22.8%
Average Flow (cfs)	68.0	157.9
Average Zone 1 Precipitation (in)	1.19	1.60
Average Zone 2 Precipitation (in)	0.18	0.41
Average Zone 3 Precipitation (in)	0.12	0.28
Average Zone 4 Precipitation (in)	0.21	0.50
Average Zone 5 Precipitation (in)	0.47	0.70
Average Zone 6 Precipitation (in)	1.09	1.46

* Wet season is defined at November 1 through April 30 and dry season is May 1 through October 31.

7.3. *Critical Conditions and Seasonal Variation*

Seasonal variation and critical conditions associated with pollutant loadings, waterbody response, and impairment conditions can affect the development and expression of a TMDL. Therefore, TMDLs must be developed to ensure the waterbody will maintain WQS under all expected conditions. The intent of this requirement is to ensure protection of water quality in waterbodies during periods when they are most vulnerable. In the Waikele watershed, the critical conditions for nutrients, sediment, and turbidity impairments coincide with storm events. The Data Analysis section (Section 4.3) illustrates that such events can occur throughout the year.

A long-term continuous simulation determines when the pollutants are above the target endpoints; therefore, the watershed model was run for a fourteen- year period (water year 1998 to 2011). The entire simulation period was used for TMDL analyses to ensure that the WQC are attained during all conditions. Through simulation of multiple years, annual loads were estimated for all seasons and compared to the geometric mean numeric targets to determine necessary reductions (Figure 41 through 43). Model simulations of multiple years accounted for seasonal variations in rainfall, evaporation, and associated impacts on runoff and transport of sediment and nutrient loads to receiving waters. Additional information regarding the environmental conditions resulting in exceedances can be found in Appendix C.

7.4. *Reasonable Assurance*

USEPA requires that there is reasonable assurance that TMDLs can be implemented when the TMDL is a mixed source TMDL (USEPA 1991). A mixed source TMDL is a TMDL developed for waters that are impaired by both point and nonpoint sources. The WLA in a mixed source TMDL is based on the assumption that nonpoint source load reductions will occur. Reasonable assurance is necessary to determine that a TMDL's WLAs and LAs, in combination, are established at levels that provide a high degree of confidence that the goals outlined in the TMDL can be achieved.

WLAs will be enforced through the applicable NPDES permit conditions. For LAs, DOH may pursue implementation of the approved LAs through Hawaii's Nonpoint Source Management Plan (DOH 2015), Hawaii's Coastal Nonpoint Pollution Control Program Management Plan (State of Hawaii Department of Business, Economic Development, and Tourism) (State of Hawaii 1996), and the Clean Water State Revolving Fund Intended Use Plan, all of which serve the State Water Quality Standards (HAR §11-54) (DOH 2014). In addition, the development of watershed-based plans and TMDL Implementation Plans would provide specific measures for reducing loads in the Waikele watershed. If such plans address the nine elements required by USEPA guidance (USEPA 2003b) and incorporate the LA objectives, they will assist in the application for additional CWA §319(h) incremental funds for water quality improvement projects.

8. Implementation and Monitoring Recommendations

Implementing management measures in Waikele watershed is necessary to improve water quality to the point where the waterbodies can support their beneficial uses (including recreational uses, agricultural water supply, and native breeding stock). Additional monitoring is desired to verify TMDL assumptions and measure progress toward meeting WQS. This section presents recommendations for additional implementation and monitoring to assist in meeting the numeric targets and loading capacity for sediment, total nitrogen and nitrite-nitrate.

8.1. Implementation

The TMDL process provides a technical basis for activities that reduce pollutant loads, improve water quality, and repair the integrity of aquatic ecosystems. These activities are more likely to be funded by certain federal programs when they are supported by a detailed planning document such as a TMDL Implementation Plan or a Watershed Based Plan. The TMDL implementation framework presented below, along with Appendix C, provide information that can be used to design and implement appropriate BMPs to address WLAs and LAs.

TMDLs are living documents, and the information and assumptions used to develop TMDLs are expected to change over time. The loading calculations and distribution of WLAs and LAs for this TMDL were largely based on areas of land ownership and land use types. Therefore, information that either influences or further refines the land use and ownership characteristics (such as land use specific runoff rates or other applicable site-specific data) in the watershed may be considered in evaluating the WLAs and LAs identified in this document. Watershed specific or other relevant data that effect runoff rates or other model assumptions may be used for compliance purposes and is consistent with the methods used to develop the TMDL.

TMDL effectiveness should be initially be assessed at the base of the watershed (model subbasin 10) to promote consistency with how the loading capacities and TMDLs were calculated. Compliance with the WLAs and LAs will be demonstrated through the proper application of appropriate BMPs with specifications adequate to address the reductions and attain the allocations. Appropriate BMPs should be supported by quantitative analysis using actual or literature documentation of the estimated effectiveness of the activities targeted to reduce the pollutants of concern to demonstrate consistency with TMDL assumptions and development. Furthermore, implementation actions intended to comply with WLAs or LAs can be assessed either representatively or regionally (by HSPF subbasin).

8.1.1. Point Source Waste Load Allocation Implementation

Point sources in the Waikele watershed are predominantly associated with MS4s and construction and industrial stormwater activities in urban areas. WLAs for the Waikele watershed TMDLs will be implemented through the use of BMPs, compliance with NPDES permit conditions and by following the stormwater management plans associated with those permits (Table 13). It may be necessary to revise some of these permits to include effluent limitations consistent with the approved WLAs, as required by federal regulations at 40 CFR 122.44(d)(1). MS4 permittees are expected to comply with the WLAs through the issuance and compliance with NPDES permit limits. Updating the permit schedules, planning requirements, compliance information, and monitoring requirements, and making these updates more readily available for agency and public use, is an important ongoing implementation task.

The MS4 NPDES permits issued to the CCH, US Army Garrison Hawaii and State of Hawaii DOT require the respective permittees to develop WLA implementation and monitoring plans for at least one newly approved TMDL submittal per year, and to promptly begin implementing these plans. These WLA implementation plans shall identify specific BMPs or actions targeted to achieving the needed reductions of sediment and nutrients. The WLA monitoring plans shall specify the activity tracking necessary to demonstrate compliance with the WLAs assigned to the permittees. Similar conditions exist for non-MS4 permits (existing and new), requiring individual, site-specific implementation and monitoring plans sufficient to implement the specific WLAs, followed by specific action to reduce pollutant loading.

BMP activities and other relevant information not accurately accounted for during the time of model development should be considered when assessing compliance with the WLAs. Some BMPs that were occurring in the watershed during the time of model development were not included the model assumptions. Therefore, it is appropriate for permittees (specifically the State of Hawaii DOT and the U.S. Army Garrison), to include reductions from sweeping activities in the required Waikele Implementation and Monitoring Plan to be developed under the MS4 NPDES permits.

Additional information on point source stormwater management can be found on EPA's NPDES website and the following resources:

> Various. Site-specific Storm Water Management Program Plans for NPDES Phase 2 MS4 facilities (Oahu).
>
> U.S. Environmental Protection Agency, Office of Water. 2015. Measurable Goals Guidance for Phase II Small MS4s. https://www.epa.gov/sites/production/files/2015-11/documents/measurablegoals_0.pdf

8.1.2. Nonpoint Source Load Allocation Implementation

Hawaii's Nonpoint Source Management Plan 2015-2020 (DOH 2015) and Hawaii's Watershed Guidance (Hawaii Office of Planning 2010) establish a foundation for voluntary and regulatory approaches to improving and maintaining watershed health. Specific implementation measures for the Waikele watershed may be imported or adapted from a number of existing and pending planning documents, including:

> Hawai'i Department of Health, Clean Water Branch. 2010. Hawai'i's Management Measures for the Coastal Nonpoint Pollution Control Program. http://files.hawaii.gov/dbedt/op/czm/initiative/nonpoint/management_measure_update_2010.pdf
>
> National Oceanographic and Atmospheric Administration. 2006. Hawai'i Ocean Resources Management Plan. http://planning.hawaii.gov/wp-content/uploads/2013/01/ormp_2006.pdf
>
> State of Hawai'i Department of Transportation, Highways Division, Oahu District. 2015. Storm Water Management Program Plan. http://www.stormwaterhawaii.com/swmp_wp/wp-content/uploads/2014/10/SWMPP-Final_Combined_Compressed.pdf
>
> State of Hawai'i Department of Transportation, Highways Division. Storm Water Management Plans for NPDES Phase 1 MS4 permit (Oahu).

U.S. Environmental Protection Agency et al. 2004. Hawai'i's Local Action Strategy to Address Land-Based Pollution Threats to Coral Reefs. https://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/1189/Hawaii_LAS_2004.pdf

Various. Soil and Water Conservation Plans, Comprehensive Nutrient Management Plans, and other Farm Bill Program plans for agricultural lands, and other public and private planning initiatives (see Land ownership and Regulatory and management authority below).

By using these general approaches and specific measures, addressing the nine elements required by EPA guidance, and incorporating the LAs and load targets from the TMDLs, a detailed planning document can unlock the door to additional Clean Water Act §319(h) incremental funds for water quality improvement projects. Such projects may also qualify for construction funding from the DOH Clean Water State Revolving Fund Program. Questions of where to focus project activities and how to complete them can be addressed by viewing the watershed from various perspectives - such as waterbody classes and uses, land ownership, regulatory and management authority, land cover and degrading activities, and implementation tools. Other resources for this planning effort include:

U.S. Environmental Protection Agency, Office of Water. 2016. Community Solutions for Stormwater Management. https://www.epa.gov/sites/production/files/2016-10/documents/draftlongtermstormwaterguide_508.pdf

U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Control Branch. 2008. EPA Handbook for developing watershed plans to restore and protect our waters. https://www.epa.gov/sites/production/files/2015-09/documents/2008_04_18_nps_watershed_handbook_handbook-2.pdf , and other EPA publications at https://www.epa.gov/nscep

U.S. Environmental Protection Agency, Office of Water. 2005. National Management Measures to Control Nonpoint Sources Pollution from Urban Areas. https://www.epa.gov/sites/production/files/2015-09/documents/urban_guidance_0.pdf

Center for Watershed Protection. Various resources at www.cwp.org.

The implementation recommendations for Waikele focus on stormwater BMPs in agricultural areas and hillslopes and upland restoration due to the high contributions of these areas to sediment and nutrients to Waikele Stream. Similar to the WLAs, assessing compliance with the LAs on a regional basis is appropriate, as it is consistent with TMDL development. LAs for the Waikele watershed area may be implemented through a variety of approaches to polluted runoff and diffuse pollution control, including those described in Hawaii's Management Measures for the Coastal Nonpoint Pollution Control Program (DOH 2010) and DOT's Storm Water Permanent Best Management Practices Manual (Hawaii State DOT 2015).

Technical assistance for agricultural producers is available from various organizations, primarily the USDA NRCS and the University of Hawaii College of Tropical Agriculture and Human Resources. NRCS provides technical assistance with conservation planning, cost-sharing for plan implementation (Farm Bill programs), and related information (technical guides technical notes) (https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/econ/stateresources/?cid=stelprdb1044074).

Involvement with the Hawai'i Association of Watershed Partnerships and conducting public/landowner outreach is also recommended. There are currently two partnerships adjacent to the Waikele watershed, the Wai'anae Mountains watershed and the Ko'olau Mountains watershed partnership. The partnerships are voluntary alliances of public and private landowners that aid each other in developing and implementing watershed management strategies. Identifying, effectively engaging, and involving stakeholders through public outreach increases the effectiveness of implementation and watershed protection.

8.1.3. Best Management Practices

Stormwater BMPs include activities, procedures, or design projects that reduce the amount of stormwater runoff volume and pollutants entering storm systems and surface waters from both point and nonpoint sources. Selection of the appropriate BMP is site-specific and depends on the type of land use treated (impervious, agricultural, etc.), the size of the treated area, and the target pollutant. Common BMPs implemented to provide storm runoff water quality treatment for nutrients and sediment include bioretention basins, dry swales, infiltration trenches, and wetlands, which are described below.

- Bioretention Basin – Vegetated basin where runoff is directed and infiltrates through a filter bed of sand, organic matter, soil, and other media. Not practical in ultra-urban areas, can vary in space requirement, accepts heavily polluted runoff, can treat 5-acre maximum drainage area, and requires a medium amount of effort to maintain. Requires underdrain where there is inadequate infiltration capacity.

- Dry Swale – Vegetated open channel designed to capture and treat stormwater quality and quantity. Not practical in ultra-urban areas, can vary in space requirement, ideal for low density residential or small impervious areas, accepts heavily polluted runoff, can treat 5-acre maximum drainage area, and easy to maintain. Depth of swale limited by water table.

- Infiltration Trench – Provides stormwater recharge and water quality treatment. Can be practical in ultra-urban areas, has low space requirement, cannot accept heavily polluted runoff but can be designed to remove 80 percent of suspended solids, can treat 5-acre maximum drainage area, and requires high amount of effort to maintain. Limited by slope grade and surrounding clay content.

- Infiltration Basin – Provides stormwater recharge and water quality treatment, designed to retain and percolate stormwater for a given amount of time. Not practical in ultra-urban areas, can vary in space requirement, cannot accept heavily polluted runoff but can be designed to remove 80 percent of suspended solids, can treat 10-acre maximum drainage area, and required a medium amount of effort to maintain. Limited by slope grade and surrounding clay content.

- Wetlands (shallow, ponds, and extended detention) – Characterized by permanent pools with large surface areas with optional extended storage. Detention allows for settling of fine particles and pollutants. Not practical in ultra-urban areas, can vary in space requirement, accepts heavily polluted runoff, treats a 25-acre minimum drainage area, and requires a medium to high amount of effort to maintain. Limited by water balance and detention requirements.

Additional resources for BMP design criteria, pollutant removal efficiency, performance details, and planning include:

> Geosyntec Consultants and Wright Water Engineers. 2010. International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary: Nutrients. http://www.bmpdatabase.org/Docs/BMP%20Database%20Nutrients%20Paper%20December%202010%20Final.pdf
>
> State of Hawai'i Department of Transportation, Highways Division. 2015. Storm Water Permanent Best Management Practices Manual. http://www.stormwaterhawaii.com/swmp_wp/wp-content/uploads/2014/10/E.1_PBMP-Manual-April-2015.pdf
>
> U.S. Environmental Protection Agency, Office of Water. 1993. Guidance Manual for Developing Best Management Practices. https://www3.epa.gov/npdes/pubs/owm0274.pdf
>
> And the U.S. Environmental Protection Agency National Menu of Best Management Practices for Stormwater. https://www.epa.gov/npdes/national-menu-best-management-practices-bmps-stormwater#edu

8.2. Monitoring Recommendations

The water quality monitoring efforts conducted by the Hawaii DOH Clean Water Branch, STORET, and USACE between 1999 and 2011 have been significant in characterizing water quality conditions in the Waikele watershed. Continued monitoring of turbidity, TSS, SSC, ammonia, nitrite-nitrate, TN, and TP at the 10 USACE and DOH locations are recommended. Sustained collection of monitoring data at these locations, especially at DOH Station 1 at the mouth of the watershed, will provide continuous and consistent data for TMDL effectiveness, compliance assessment and trend analysis.

In addition to the existing monitoring infrastructure, increased monitoring and gaging throughout the watershed, especially on Waikele Stream, is recommended to help refine several areas of uncertainty within the model calibration. For example, the secondary locations used for the hydrology calibration of the Waikele watershed included four USACE monitoring locations (SW-5, SW-6, SW-11 and SW-12), which had smaller sample sizes and less information available about the monitoring program. Additional water quality and flow data will provide improved model performance since the ability to achieve a good nutrient water quality calibration is dependent on the sediment calibration, and similarly, the sediment calibration is dependent on the hydrology calibration.

Increased monitoring and gaging efforts within agricultural subbasins would also be useful to improve understanding of agricultural contributions and future analyses. Agricultural land use was the largest source of suspended sediment and the most likely source of high base flow nutrient concentrations in the watershed. Additional pollutant concentration data from these regions with known individual crop types will help refine loadings from those areas and allow for more accurate model results and focused management strategies.

Specific monitoring program details and framework may be imported or adapted from a number of existing and pending planning documents, including:

U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds. 2002. Consolidated Assessment and Listing Methodology. https://www.epa.gov/sites/production/files/2015-09/documents/consolidated_assessment_and_listing_methodology_calm.pdf.

Hawaii State Department of Transportation, Highways Division. 2017. Storm Water Annual Monitoring Plan 2017-2018. http://www.stormwaterhawaii.com/swmp_wp/wp-content/uploads/2014/09/2017-2018-Monitoring-Plan-Final.pdf

U.S. Geological Survey. 1998. National Water-Quality Assessment Program - Island of Oahu, Hawaii Fact Sheet. https://pubs.usgs.gov/fs/fs006-98/pdf/fs006-98.pdf

9. Public Participation

During the TMDL development process, DOH staff discussed the TMDLs with various interested parties and sources of information, including:

- City and County of Honolulu
- State of Hawaii Department of Health (Clean Water Branch, Wastewater Branch)
- U.S. Environmental Protection Agency
- U.S. Army Corps of Engineers
- State of Hawaii Department of Transportation Highways Division
- U.S. Army Garrison

A draft TMDL submittal was published for public review (with direct notice to interested parties and public notice) and opportunities to present and discuss the results was made available to the parties listed above. A coordinated response to public comments is included in the final edition of the TMDL technical report.

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