Appendix A: Nonpoint Source Existing Loads in the Waikele Watershed

In 2019, the U.S. Environmental Protection Agency (EPA) and Hawaii Department of Health (DOH) issued a total maximum daily load (TMDL) for the Waikele watershed in Oahu, Hawaii, to address turbidity and nutrient impairments (EPA and DOH, 2019). TMDL analyses included a watershed model that estimated existing and allowable loads by source and ownership. These results were initially used to divide the loads into wasteload and load allocations and required reductions in the draft TMDL. The separation between load and wasteload allocations was refined during the public review period in a post-processing step not captured in the input data used for the watershed model. The load allocations in the TMDL report are final; however, this post-processing required additional analyses to identify nonpoint source loads for reduction in the Waikele watershed implementation plan.

For the implementation plan, loading estimates were shifted from the geographic information system (GIS) layer documenting permitted and unpermitted areas by owner to a land use-based approach. In this new approach, land uses typically represented by permitted sources were associated with the TMDL wasteload allocations and the remaining land uses that generally have less infrastructure and no direct discharges were assigned as the nonpoint sources. These nonpoint source areas are the focus of the Waikele watershed implementation plan (see Table 6 of the implementation plan).

The distribution of these nonpoint source land uses by ownership category were applied to the seasonal existing loads from the watershed model and to the TMDL load allocations. Section 5 of the Waikele plan summarizes the nonpoint sources contributing to the existing loads, while Sections 6.2 and 8.1.2.2 present the estimated load reductions, which are the difference between the existing loads and the load allocations. This additional detail is useful to identify and prioritize management measures that will achieve the TMDL load allocations and, in conjunction with point source load reduction, will restore beneficial uses throughout the Waikele watershed.

References

U.S. Environmental Protection Agency (EPA) and Hawaii Department of Health (DOH). 2019. Turbidity, Sediment, and Nutrient Total Maximum Daily Loads for the Waikele Watershed. Oahu, Hawaii. Prepared by Tetra Tech, Inc.

Appendix B. STEPL Implementation for the Waikele Watershed

The Spreadsheet Tool for Estimating Pollutant Loads (STEPL) was utilized to estimate nutrient and sediment loads in the Waikele watershed based on watershed-specific land use input data. STEPL was then used to simulate a variety of locally applicable best management practice (BMP) scenarios to identify combinations of BMPs in application areas throughout the watershed capable of achieving load reductions outlined in the watershed plan and TMDL.

B.1. What is STEPL?

STEPL was developed to evaluate and understand watershed loading and load reductions. STEPL employs a set of simple algorithms contained within a spreadsheet-based model in Microsoft Excel to calculate nutrient and sediment loads from a variety of land use types and expected load reductions associated with implementation of various BMPs. Annual nutrient loadings are estimated within STEPL based on calculated runoff volumes and pollutant concentrations for the watershed of interest. Meanwhile, annual sediment loads are calculated based on the Universal Soil Loss Equation (USLE) and the sediment delivery ratio.

STEPL calculates loadings and load reductions at variable scales, ranging from sub-watershed areas (down to an individual field level) to multiple independent watersheds. The user can specify the size and characteristics of the desired area(s) for analysis. In addition, STEPL is capable of evaluating a diverse array of land use types (e.g., urban, cropland, forest).

Sections B.2 and B.3 below present the application of STEPL to calculate existing loads and load reductions in the Waikele Watershed. Section B.4 provides links to STEPL training and resource information.

B.2. STEPL Application to Estimate Existing Loads

Data Inputs via STEPL Worksheets

STEPL's Excel-based interface includes an 'Input' worksheet with a combination of required and optional tables where users can input data for the watershed(s) of interest (Table B-1). While some of these input tables specify *E. coli*, bacteria load estimates were not performed as part of this study.

A variety of data sources were used as inputs to STEPL to best represent the Waikele watershed. These were provided by the STEPL Input Data Server, Hawaii State Department of Health (HDOH), United States Environmental Protection Agency (USEPA), and the Hawaii Statewide GIS Program. The USEPA data are largely the information incorporated into the nutrients and sediment TMDL and its associated Hydrologic Simulation Program Fortran (HSPF) watershed model (Tetra Tech, 2019). The ten STEPL tables are described below, focusing on the input data to represent the Waikele watershed.

Table B-1. Required and optional input tables included in the STEPL Input worksheet.

STEPL Table Number	Description of Data
1	Watershed land use area and precipitation
2	Agricultural animals
3	Septic system and illegal direct wastewater discharge data
4	Universal Soil Loss Equation (USLE) parameters
5	Average soil hydrologic group
6	Reference runoff curve number
6a	Detailed urban reference runoff curve number
7	Nutrient concentration in runoff and *E. coli*
7a	Nutrient concentration in shallow groundwater and *E. coli*
8	Input or modify urban land use distribution
9	Input irrigation area and irrigation amount
10	Pastureland nutrient concentration in runoff and *E. coli*

Note: STEPL Tables 1-4 (unshaded) require user data inputs. Tables 5-10 (shaded in gray) are optional and can remain unmodified by the user if watershed-specific data are unavailable.

Watershed Land Use Area and Precipitation (STEPL Table 1)

When working with STEPL, the user is first prompted to select the state, county, and local weather station most closely associated with their watershed(s). For the Waikele watershed, selections were as follows: Hawaii (state), Honolulu (county), and Wahiawa Dam (local weather station). Based on the weather station selected, local precipitation data are populated in STEPL Table 1 for annual rainfall, rain days, and average rain per event. The user is then required to provide land use areas (acres) for the various land use types being evaluated. Land use areas were incorporated based on watershed-specific geospatial data used to develop the TMDL. However, land use types from the geospatial data had to first be binned (i.e., collapsing factor levels into broader land use categories) and subsequently re-classified to match land use types defined in STEPL (see Table B-2).

Table B-2. Crosswalk of binned land uses to pre-defined land use types in STEPL.

Binned Land Use	STEPL Land Use	Data Assumptions
Agriculture	Cropland	Pasture was binned within the Agriculture land use type in the Watershed Implementation Plan (WIP). Though Pastureland has its own designated land use in STEPL, it only encompasses approximately 16 acres. To be consistent with the WIP land uses, it was lumped in STEPL. Given the negligible acreage, pasture is unlikely to affect the results.
Conservation	Forest	None
Developed	Urban	None
Open Space	User Defined	None
Other (Bare Land, Water, Wetland)	Excluded	Land use types comprise less than 108 acres and do not fit into the other four binned land uses; given the relatively small area and low pollutant loading potential, they were excluded.

The values input into STEPL Table 1 for the Waikele watershed are shown below:

									Rain correction factors		
1. Input watershed land use area (ac) and precipitation (in)									0.884	0.453	
Watershed	Urban	Cropland	Pastureland	Forest	User Defined	Feedlots	Feedlot Percent Paved	Total	Annual Rainfall	Rain Days	Avg. Rain/Event
W1 - Waikakalaua	937	180	0	1655	913	0	0-24%	3685	38	100	0.748
W2 - Kipapa	2621	1263	0	3802	2305	0	0-24%	9991	38	100	0.748
W3 - Upper Waikele	1667	960	0	1590	1576	0	0-24%	5793	38	100	0.748
W4 - Waianae Range	118	3107	0	1226	955	0	0-24%	5406	38	100	0.748
W5 - Lower Waikele	1293	2274	0	0	1029	0	0-24%	4596	38	100	0.748
W6	0	0	0	0	0	0	0-24%	0	38	100	0.748
W7	0	0	0	0	0	0	0-24%	0	38	100	0.748
W8	0	0	0	0	0	0	0-24%	0	38	100	0.748
W9	0	0	0	0	0	0	0-24%	0	38	100	0.748
W10	0	0	0	0	0	0	0-24%	0	38	100	0.748

Agricultural Animals (STEPL Table 2)

The distribution of agricultural animals for each sub-watershed in Waikele was estimated by calculating the proportion of agricultural area contained within each subwatershed and multiplying by the total number of agricultural animals in the Waikele watershed (data acquired from the STEPL input data server). The distribution of agricultural animals by subwatershed is shown below (Table B-3).

Table B-3. Distribution of agricultural animals by subwatershed.

Sub-watershed	Percentage of Watershed-Wide Agricultural Area	Agricultural Animal Distribution by Sub-Watershed							
		Beef Cattle	Dairy Cattle	Swine	Sheep	Horse	Chicken	Turkey	Duck
Waikakalaua	5%	11	0	28	1	2	0	1	0
Kipapa	13%	80	0	193	7	14	0	7	0
Upper Waikele	17%	61	0	147	5	11	0	6	0
Waianae Range	57%	198	1	476	17	35	0	18	0
Lower Waikele	49%	145	1	348	13	26	0	13	0
W1 - Waikakalaua	**100**	**496**	**2**	**1192**	**43**	**88**	**0**	**45**	**0**

Note: Percentage of agricultural area in the Waikele watershed in each subwatershed and associated proportional distribution of agricultural animals to each subwatershed. Values are rounded and therefore show slight discrepancies in Watershed Total row. Totals are based on data from STEPL input data server and distributed among subwatersheds.

The values input into STEPL Table 2 for the Waikele watershed are shown below. Note that values input into STEPL were not rounded as in Table B-3 above:

2. Input agricultural animals										
Watershed	Beef Cattle	Dairy Cattle	Swine (Hog)	Sheep	Horse	Chicken	Turkey	Duck	# of months manure applied on Cropland	# of months manure applied on Pastureland
W1 - Waikakalaua	11.4960118	0.04635489	27.6275122	0.99663005	2.03961499	0	1.04298494	0	0	0
W2 - Kipapa	80.4863848	0.32454187	193.426957	6.9776503	14.2798425	0	7.30219217	0	0	0
W3 - Upper Waikele	61.1374235	0.24652187	146.927034	5.30022018	10.8469622	0	5.546742054	0	0	0
W4 - Waianae Range	197.99074	0.79834976	475.816455	17.1645198	35.1273893	0	17.96286954	0	0	0
W5 - Lower Waikele	144.88944	0.58423161	348.202041	12.5609797	25.706191	0	13.1452113	0	0	0
W6	0	0	0	0	0	0	0	0	0	0
W7	0	0	0	0	0	0	0	0	0	0
W8	0	0	0	0	0	0	0	0	0	0
W9	0	0	0	0	0	0	0	0	0	0
W10	0	0	0	0	0	0	0	0	0	0
Total	496	2	1192	43	88	0	45	0		

Septic System and Illegal Direct Wastewater Discharge Data (STEPL Table 3)

The distribution of septic tanks for each subwatershed in Waikele was estimated by multiplying the total number of septic tanks in the watershed (data acquired from the HDOH GIS layer for On-site Sewage Disposal Systems in Oahu) by each subwatershed's proportion of the total watershed area. The distribution of septic tanks is shown in Table B-4. Watershed-wide values of 'Population per Septic System' and 'Septic Failure Rate' were assigned to each subwatershed. *These data are also intended to account for the presence of cesspools and septic tanks in the watershed*.

Table B-4. Distribution of septic systems or cesspools by subwatershed.

Sub-watershed	Area (Acres)	Proportion of Total Watershed Area	Proportional Allocation of Septic Systems
Waikakalaua	3,685	0.13	26
Kipapa	9,991	0.34	50
Upper Waikele	5,793	0.20	0
Waianae Range	5,406	0.18	2
Lower Waikele	4,596	0.16	24
Watershed Total	29,471	1.00	102

Note: Distribution of septic systems to subwatersheds in the Waikele watershed based on each subwatershed's proportion of the total watershed area. Total septic system data was derived from the HDOH GIS layer for onsite sewage systems.

The values input into STEPL Table 3 for the Waikele watershed are shown below:

3. Input septic system and illegal direct wastewater discharge data					
Watershed	No. of Septic Systems	Population per Septic System	Septic Failure Rate, %	Wastewater Direct Discharge, # of People	Direct Discharge Reduction, %
W1- Waikakalaua	26	3	14	0	0
W2 - Kipapa	50	3	14	0	0
W3 - Upper Waikele	0	3	14	0	0
W4 - Waianae Range	2	3	14	0	0
W5 - Lower Waikele	24	3	14	0	0
W6	0	2.43	2	0	0
W7	0	2.43	2	0	0
W8	0	2.43	2	0	0
W9	0	2.43	2	0	0
W10	0	2.43	2	0	0

Universal Soil Loss Equation (USLE) parameters (STEPL Table 4)

USLE parameters were modified from default values provided by STEPL for Table 4. These values were refined where possible to best mimic HSPF existing load estimates, recognizing the distribution of land use, slopes, and other factors in each subwatershed, and ensuring that the final values were within known acceptable ranges and that the changes between subwatersheds and land uses were reasonable. Modified input values were incorporated into baseline existing load estimates.

Values input into STEPL Table 4 for the Waikele watershed are shown below:

4. Modify the Universal Soil Loss Equation (USLE) parameters										
Watershed	Cropland					Pastureland				
	R	K	LS	C	P	R	K	LS	C	P
W1- Waikakalaua	400.000	0.130	1.750	0.030	0.885	324.000	0.130	8.104	0.030	1.000
W2 - Kipapa	400.000	0.200	1.750	0.150	0.885	324.000	0.130	8.104	0.030	1.000
W3 - Upper Waikele	275.000	0.180	1.250	0.100	0.885	324.000	0.130	8.104	0.030	1.000
W4 - Waianae Range	300.000	0.250	1.750	0.250	0.885	324.000	0.130	8.104	0.030	1.000
W5 - Lower Waikele	250.000	0.325	1.000	0.400	0.885	324.000	0.130	8.104	0.030	1.000
W6	283.293	0.158	6.159	0.200	0.972	283.293	0.158	6.159	0.040	1.000
W7	283.293	0.158	6.159	0.200	0.972	283.293	0.158	6.159	0.040	1.000
W8	283.293	0.158	6.159	0.200	0.972	283.293	0.158	6.159	0.040	1.000
W9	283.293	0.158	6.159	0.200	0.972	283.293	0.158	6.159	0.040	1.000
W10	283.293	0.158	6.159	0.200	0.972	283.293	0.158	6.159	0.040	1.000

Forest					User Defined				
R	K	LS	C	P	R	K	LS	C	P
400.000	0.120	4.500	0.020	1.000	400.000	0.100	4.500	0.030	1.000
400.000	0.160	4.000	0.030	1.000	400.000	0.160	4.000	0.070	1.000
275.000	0.160	1.250	0.030	1.000	275.000	0.160	1.250	0.070	1.000
300.000	0.180	4.000	0.030	1.000	300.000	0.190	4.000	0.090	1.000
250.000	0.160	1.000	0.030	1.000	250.000	0.160	1.000	0.070	1.000
283.293	0.158	6.159	0.003	1.000	283.293	0.158	6.159	0.101	1.000
283.293	0.158	6.159	0.003	1.000	283.293	0.158	6.159	0.101	1.000
283.293	0.158	6.159	0.003	1.000	283.293	0.158	6.159	0.101	1.000
283.293	0.158	6.159	0.003	1.000	283.293	0.158	6.159	0.101	1.000
283.293	0.158	6.159	0.003	1.000	283.293	0.158	6.159	0.101	1.000

Average Soil Hydrologic Group (SHG) (STEPL Table 5)

Soil hydrologic group (SHG) geospatial data from the STATSGO database, which was incorporated into the TMDL (Tetra Tech, 2019), were used to populate STEPL Table 5. For each subwatershed, the total area encompassed by each SHG was summarized and represented as the percent of total area. Each subwatershed was then assigned a value for SHG corresponding to the SHG with the largest area within that subwatershed. A summary of soil hydrologic group area information is provided in Table B-5.

In addition, soil-associated nutrient concentrations are included in STEPL Table 5 for each subwatershed. These values were refined to best mimic HSPF nitrogen loadings. Default values for soil phosphorous provided by STEPL were not modified.

Table B-5. SHG areas by subwatershed.

Subwatershed	SHG	Area (acres)	SHG Percent of Sub-watershed Area
Waikakalaua	**B**	**2,061.16**	**55.93**
	C	20.99	0.57
	D	1,603.37	43.50
Kipapa	**B**	**5,908.17**	**59.45**
	C	534.12	5.37

Subwatershed	SHG	Area (acres)	SHG Percent of Sub-watershed Area
	D	3,495.40	35.17
Upper Waikele	A	0.02	0.00
	B	**4,019.68**	**65.71**
	C	1,947.37	31.84
	D	149.86	2.45
Waianae Range	B	**3,420.85**	**63.50**
	C	1,890.02	35.08
	D	76.72	1.42
Lower Waikele	A	16.00	0.36
	B	**3,822.69**	**86.14**
	C	165.91	3.74
	D	433.09	9.76

Note: Value in bold represents the dominant SHG in each subwatershed.

The values input into STEPL Table 5 for the Waikele watershed are shown below:

5. Select average soil hydrologic group (SHG), SHG A = highest infiltration and SHG D = lowest infiltration

Watershed	SHG A	SHG B	SHG C	SHG D	SHG Selected	Soil N conc.%	Soil P conc.%	Soil BOD conc.%	Soil E. coli conc. (#/100mg)
W1- Waikakalaua	○	◉	○	○	B	0.050	0.031	0.100	0.000
W2 - Kipapa	○	◉	○	○	B	0.050	0.031	0.100	0.000
W3 - Upper Waikele	○	◉	○	○	B	0.025	0.031	0.050	0.000
W4 - Waianae Range	○	◉	○	○	B	0.040	0.031	0.080	0.000
W5 - Lower Waikele	○	◉	○	○	B	0.030	0.031	0.060	0.000
W6	○	◉	○	○	B	0.080	0.031	0.160	0.000
W7	○	◉	○	○	B	0.080	0.031	0.160	0.000
W8	○	◉	○	○	B	0.080	0.031	0.160	0.000
W9	○	◉	○	○	B	0.080	0.031	0.160	0.000
W10	○	◉	○	○	B	0.080	0.031	0.160	0.000

Reference Runoff Curve Number (STEPL Table 6) and Detailed Urban Reference Runoff Curve Number (STEPL Table 6a)

STEPL provides default values for Tables 6 and 6a for all pre-defined land use types. To represent the Open Space user-defined land use type Open, runoff curve numbers were estimated from the U.S. Department of Agriculture's (USDA) Technical Release 55 (TR-55): Urban Hydrology for Small Watersheds (USDA-NRCS, 1986), assuming that the Open Space land is considered fair condition with grass covering 50 to 75 percent of the total area (Table B-6). The values for soil hydrologic group B for Open Space (STEPL Table 6) and soil hydrologic group B for urban areas (STEPL Table 6a) were modified slightly to better mimic HSPF existing loads.

Table B-6. Reference runoff curve numbers for Open Space.

Cover Description	Curve Numbers for Hydrologic Soil Group			
	A	B	C	D
Open Space (Fair Condition – Grass Cover 50 to 75%)	49	65	79	84

The values input into STEPL Tables 6 and 6a for the Waikele watershed are shown below:

6. Reference runoff curve number (may be modified)				
SHG	A	B	C	D
Urban	83	89	92	93
Cropland	67	78	85	89
Pastureland	49	69	79	84
Forest	39	60	73	79
User Defined	49	65	79	84

6a. Detailed urban reference runoff curve number (may be modified)				
Urban\SHG	A	B	C	D
Commercial	89	92	94	95
Industrial	81	91	91	93
Institutional	81	88	91	93
Transportatior	98	92	98	98
Multi-Family	77	79	90	92
Single-Family	57	77	81	86
Urban-Cultivat	67	78	85	89
Vacant-Develc	77	85	90	92
Open Space	49	69	79	84

Nutrient Concentration in Runoff and E. Coli (STEPL Table 7) and Nutrient Concentration in Shallow Groundwater and E. Coli (STEPL Table 7a)

Nutrient concentrations in runoff for both Forest and Open Space land use types were initially compiled for STEPL Table 7 using input information from the HSPF model (Tetra Tech, 2019; in particular, Appendix B: Waikele Stream HSPF Model Development Nutrient Calibration Report, Tables 8 and 10). Wet and dry season mean nutrient concentrations in runoff were averaged into a single nutrient concentration value for each land use type for use in STEPL Table 7. Nutrient concentration values for Open Space were calculated as the average of both 'Open Space' and 'Golf Course' values provided in HSPF model, as golf courses are nested within the Open Space land use type in the WIP. Nitrogen concentrations in runoff were subsequently modified to better mimic HSPF existing nitrogen loads in the watershed. Nutrient concentrations in runoff were calculated separately for both total nitrogen and total phosphorous (Table B-7).

Table B-7. Average nutrient concentrations in runoff from HSPF for Open Space and Forest lands.

Parameter	STEPL Land Use	WIP Land Use	Nutrient Concentration Wet (mg/L)	Nutrient Concentration Dry (mg/L)	Average Nutrient Concentration (mg/L)
TN	User Defined (Open Space)	Open Space	1.6	2.01	2.655
		Golf Course	5.15	1.86	
TP	User Defined (Open Space)	Open Space	0.28	0.7	0.545
		Golf Course	0.64	0.56	
TN	Forest	Conservation	0.72	1.81	1.265
TP	Forest	Conservation	0.11	1.19	0.65

Similarly, values were identified to represent nutrient concentrations in shallow groundwater using inputs to the HSPF model (Tetra Tech, 2019; Appendix B, Table 3). Groundwater nutrient concentrations were calculated for four different STEPL land use types (i.e., User Defined – Open Space, Cropland, Forest, and Pastureland) and three different nutrient parameters: Ammonia (NH_3), Nitrate plus Nitrite ($NO_3 + NO_2$), and Total Phosphorous (TP). Two STEPL land use types (User Defined – Open Space and Cropland) were calculated as the average of two contributing land use types represented in the HSPF model. Further, the Ammonia and Nitrate plus Nitrite values were summed for each land use type to represent Total Nitrogen for input into STEPL Table 7a. Several values were ultimately modified during existing load calculations. Table B-8 presents the full suite of watershed-specific shallow groundwater concentrations which were used as starting points and slightly modified in STEPL Table 7a to best match the HSPF loading calculations.

Table B-8. Nutrient concentrations in shallow groundwater by land use from HSPF.

Param	STEPL Land Use	HSPF Land Use 1	HSPF Land Use 2	Average Concentration (mg/L)	Total Nitrogen Concentration (if applicable; mg/L)
NH_3	User Defined (Open Space)	Grass Urban	Golf Course	**0.09**	**2.04**
NO_3+NO_2	User Defined (Open Space)	Grass Urban	Golf Course	**1.95**	
TP	User Defined (Open Space)	Grass Urban	Golf Course	**0.12625**	**--**
NH_3	Cropland	Ag. High Runoff	Seed Corn	**0.115**	**31.615**
NO_3+NO_2	Cropland	Ag. High Runoff	Seed Corn	**31.5**	
TP	Cropland	Ag. High Runoff	Seed Corn	**0.4575**	**--**
NH_3	Forest	Forest or Scrub-Shrub	--	**0.345**	**0.48**
NO_3+NO_2	Forest	Forest or Scrub-Shrub	--	**0.135**	
TP	Forest	Forest or Scrub-Shrub	--	**0.067**	**--**
NH_3	Pastureland	Pasture	--	**0.045**	**31.545**
NO_3+NO_2	Pastureland	Pasture	--	**31.5**	
TP	Pastureland	Pasture	--	**0.392**	**--**

The values input into STEPL Tables 7 and 7a in for the Waikele watershed are shown below:

7. Nutrient concentration in runoff (mg/l) and E. coli (MPN/100ml)				
Land use	**N**	**P**	**BOD**	**E. coli**
1. L-Cropland	**1**	**0.3**	**4**	0
1a. w/ manure	8.1	2	12.3	0
2. M-Cropland	**2**	**0.4**	**6.1**	0
2a. w/ manure	12.2	3	18.5	0
3. H-Cropland	**3**	**0.5**	**9.2**	0
3a. w/ manure	18.3	4	24.6	0
4. Pastureland (see Table 10 for default values with manure)				
5. Forest	**1.265**	**0.65**	**0.5**	0
6. User Defined	**1**	**0.545**	**13**	0

7a. Nutrient concentration in shallow groundwater (mg/l) and E. coli (MPN/100ml)(may be modified)				
Landuse	**N**	**P**	**BOD**	**E. coli**
Urban	1	0.063	0	0
Cropland	10	0.4575	0	0
Pastureland			0	0
Forest	0.48	0.067	0	0
Feedlot	6	0.07	0	0
User-Defined	1	0.12625	0	0

Input or Modify Urban Land Use Distribution (STEPL Table 8)

Total urban area (acres) was incorporated into STEPL Table 8 using geospatial data used for TMDL development. HSPF model values for urban land use distribution were input into STEPL for Table 8 and incorporated into baseline existing load estimates.

8. Input or modify urban land use distribution											
Watershed	**Urban Area**	**Commer-cial %**	**Industrial %**	**Institu-tional %**	**Transport-ation %**	**Multi-Family %**	**Single-Family %**	**Urban-Cultivated %**	**Vacant (developed) %**	**Open Space %**	**Total % Area**
W1- Waikakalaua	937	4	7	0	30	22	37	0	0	0	100
W2 - Kipapa	2621	3	7	0	27	12	50	0	0	0	100
W3 - Upper Waikele	1667	1	1	0	31	67	0	0	0	0	100
W4 - Waianae Range	118	0	48	0	19	0	33	0	0	0	100
W5 - Lower Waikele	1293	6	26	0	21	10	37	0	0	0	100
W6	0	15	10	10	10	10	30	5	5	5	100
W7	0	15	10	10	10	10	30	5	5	5	100
W8	0	15	10	10	10	10	30	5	5	5	100
W9	0	15	10	10	10	10	30	5	5	5	100
W10	0	15	10	10	10	10	30	5	5	5	100

Input Irrigation Area and Irrigation Amount (STEPL Table 9)

Total cropland area (acres) was estimated by combining several agricultural areas and used as input to STEPL Table 9 based on the TMDL geospatial data. In addition, the remaining fields in STEPL Table 9 were not modified but could be if local information becomes available.

9. Input irrigation area (ac) and irrigation amount (in)					
Watershed	Total Cropland (ac)	Cropland: Acres Irrigated	Depth (in) per Irrigation - Before	Depth (in) per Irrigation - After	Irrigation Frequency (#/Year)
W1- Waikakalaua	180	0	0	0	0
W2 - Kipapa	1263	0	0	0	0
W3 - Upper Waikele	960	0	0	0	0
W4 - Waianae Range	3107	0	0	0	0
W5 - Lower Waikele	2274	0	0	0	0
W6	0	0	0	0	0
W7	0	0	0	0	0
W8	0	0	0	0	0
W9	0	0	0	0	0
W10	0	0	0	0	0

Pastureland Nutrient Concentration in Runoff and E. Coli (STEPL Table 10)

Pastureland was not included as a unique land use in this application of STEPL; therefore, this STEPL table is unnecessary.

Existing Load Estimate Results

Using the information input above, STEPL estimated nutrient and sediment loads in the watershed. The STEPL output consists of both tabular and graphical summaries of load estimates. Tabular STEPL results for existing loads estimated in the Waikele watershed are provided in Table B-9.

Table B-9. Total loads in the Waikele watershed prior to BMP implementation.

Watershed	N Load (no BMP) *lb/year*	P Load (no BMP) *lb/year*	BOD Load (no BMP) *lb/year*	Sediment Load (no BMP) *t/year*
W1 - Waikakalaua	11,671.4	4,278.6	40,757.3	1,663.2
W2 - Kipapa	46,251.4	20,482.4	141,186.3	11,826.3
W3 - Upper Waikele	16,136.4	5,856.7	66,119.5	1,938.1
W4 - Waianae Range	30,905.5	20,438.3	81,025.9	14,387.0
W5 - Lower Waikele	23,026.6	13,290.3	78,561.6	8,527.1
Totals	127,991.4	64,346.3	407,650.7	38,341.7

To best mimic the HSPF model results, the STEPL results were continually compared with both subwatershed and land use loads. The final subwatershed comparisons are shown in Table B-10 and Table B-11 for total nitrogen and sediment, respectively. The sediment results in particular were extremely close between the two estimates (the average of the ratio of HSPF:STEPL results was 1.03, where a ratio of 1 represents a perfect match; Table B-11). The total nitrogen results were also close for all subwatersheds other than the Upper Waikele, where STEPL overestimated the load compared to the HSPF model (Table B-10). However, when fine-tuning the parameters within acceptable ranges and considering the land use distributions, we achieved an overall balance for land use loads for total nitrogen and could not make any additional revisions without compromising the loads calculated in other subwatersheds (Table B-12). The land use estimates for sediment were similar except for urban lands; however, there are very few parameters in STEPL the influence urban loads, so they could not be modified further without negatively influencing loads for other land uses (Table B-13).

Table B-10. Comparison of HSPF and STEPL total nitrogen loads by subwatershed.

Watershed	HSPF Nitrogen Load (lb/year)	STEPL Nitrogen Load (lb/year)	HSPF/STEPL
W1 - Waikakalaua	12,342	11,671	1.06
W2 - Kipapa	46,189	46,251	1.00
W3 - Upper Waikele	9,694	16,136	0.60
W4 - Waianae Range	29,860	30,906	0.97
W5 - Lower Waikele	21,734	23,027	0.94

Average ratio = 0.86

Table B-11. Comparison of HSPF and STEPL sediment loads by subwatershed.

Watershed	HSPF Sediment Load (t/year)	STEPL Sediment Load (t/year)	HSPF/STEPL
W1 - Waikakalaua	1,773	1,663	1.07
W2 - Kipapa	11,951	11,826	1.01
W3 - Upper Waikele	1,983	1,938	1.02
W4 - Waianae Range	15,147	14,387	1.05
W5 - Lower Waikele	8,765	8,527	1.03

Average ratio = 1.03

Table B-12. Comparison of HSPF and STEPL total nitrogen loads by land use.

Land Use Category	HSPF Nitrogen Load (lb/year)	STEPL Nitrogen Load (lb/year)	HSPF/STEPL
Urban	29,065	39,886	0.73
Cropland	45,030	46,146	0.98
Forest	19,975	18,818	1.06
User Defined (Open Space)	25,748	22,594	1.14

Average ratio = 0.98

Table B-13. Comparison of HSPF and STEPL sediment loads by land use.

Land Use Category	HSPF Sediment Load (t/year)	STEPL Sediment Load (t/year)	HSPF/STEPL
Urban	3,488	951	3.67
Cropland	21,826	22,544	0.97
Forest	5,416	5,724	0.95
User Defined (Open Space)	8,889	9,123	0.97

Average ratio = 1.64

B.3. Load Reduction Calculations Using STEPL

A variety of BMPs can be applied with STEPL to estimate load reductions in each subwatershed. The user can choose to apply a single BMP to a specified land use or apply multiple BMPs in the following manner:

Locating and Modifying the STEPL BMPList Worksheet

Each BMP included in STEPL is characterized by pre-defined nutrient and sediment reduction efficiencies that are listed in the hidden 'BMPList' tab in the STEPL program. STEPL defines a list of allowable BMPs for each land use type while also allowing the user to add BMPs to the list of allowable options for a given land use type. Nutrient and sediment reduction efficiencies must be provided by the user for all BMPs added to the allowable list for a given land use.

To reveal the 'BMPList' tab in the workbook, perform the following steps:

- In the STEPL workbook, select the 'Add-ins' option from the options bar.
- Select the 'STEPL' dropdown from the 'Menu Commands' section.
- Select the 'Hide/Unhide Other STEPL Sheets' option from the dropdown menu.
- A multitude of tabs will appear at the bottom of the workbook. Select the 'BMPList' tab to view defined BMPs for each land use category in STEPL.

Application of Individual, Non-Interacting BMPs in STEPL

The processes by which BMPs are applied in STEPL differ depending on the land use type to which the BMP is applied. BMPs applied to cropland, feedlot, forest, pasture, and/or the user-defined land use type are all completed by using the BMP tables provided in the 'BMPs' tab, whereas BMPs applied to the urban land use type are applied by selecting the 'Urban BMP Tool' button located at the top of the 'BMPs' tab.

Non-Urban BMPs

- In the 'BMPs' tab, a single BMP is selected from the dropdown menu corresponding to a specific land use type and subwatershed.
- The 'BMPs' tab contains BMP application tables for the following land use categories: cropland, feedlot, forest, pasture, and a user-defined land use ('open space' in the Waikele STEPL workbook).
- The user defines the percent area applied for the BMP. STEPL automatically multiplies this value by the total area (in acres) of the specified land use type within the designated subwatershed. It should be noted that the percent area applied refers to the proportion of acreage treated by the BMP rather than the acreage occupied by the BMP itself once installed.
- STEPL provides summary results including load reductions achieved by the BMP application in the 'Total Load' tab.

Urban BMPs

- In the 'BMPs' spreadsheet, the Urban BMP Tool button is selected to reveal the hidden 'Urban' spreadsheet. Within the Urban BMP Tool user interface, the following BMP application details are specified by the user:
    - The BMP designated for application
    - The subwatershed within which the BMP is to be applied
    - The urban land use sub-category within which the BMP is to be applied
    - The total acreage to which the BMP is to be applied within the selected urban land use sub-category. The distribution of urban acreage across sub-categories is specified by the user in Table 8 within the 'Inputs' spreadsheet

For the Waikele watershed, urban BMP application scenarios were created in independent STEPL workbooks corresponding to individual model runs; each model run contained identical input data. Model runs proceeded according to the following steps:

- Each workbook designated a single BMP for application to each of the five Waikele subwatersheds.
- The BMP was applied to a single land use category.
- To standardize load reduction estimates produced by STEPL, all BMPs were applied to 20% of the total area within each of the designated subwatersheds. For urban BMP applications, acreage was distributed evenly (i.e., 10% of the total urban area each) to the two largest urban land use sub-categories within each watershed.

Application of Multiple, Non-Interacting BMPs in STEPL

For cropland and pastureland land use types, STEPL allows the user to apply multiple BMPs to independent treatment areas within a specified watershed (i.e., the BMPs are acting in parallel rather than in series) to calculate total pollutant load reduction estimates for a watershed or subwatershed. For other land use types (e.g., Forest, User Defined), the user can simulate the application of multiple, non-interacting BMPs in STEPL using the 'BMP Calculator' tool (see 'Application of Multiple Interacting BMPs in STEPL' section below). To calculate load reduction estimates for multiple, non-interacting BMP application scenarios for cropland and pastureland land use types:

- The user first selects the 'Calculate Combined BMP Efficiency' button from the 'BMPs' spreadsheet to open the hidden 'CombinedBMPEfficiency' spreadsheet.
- The user then specifies the land use type (i.e., cropland or pastureland) to which the BMPs will be applied in row 2.
- In row 2, the user also specifies the total treated land use acreage. Note that entering the entire watershed or subwatershed acreage in this field is allowable, even if the BMPs selected only treat a fraction of that total area. This is because in the user can select '0 No BMP' in the 'Treatment' table in the tab as one of the BMPs selected as part of the combined BMP application within STEPL; the user can then input the total acreage outside of the treatment areas of the other applied BMPs as the acreage.
- Once the land use type and total acreage applied fields in row 2 have been updated, the user should select the 'Update BMP List' button near the top of the tab to ensure the BMPs in the 'Treatment' table match those available for the specified land use.
- The user then specifies the BMPs that will be applied in parallel in the provided table along with the acreage each BMP will treat. The acreages for the specified individual BMPs must sum to the total treated land use acreage provided in row 2.
- Combined load reduction efficiencies for all pollutants will be calculated in row 25. The user is required to copy these efficiencies into Table 7 in the 'BMPs' tab for the appropriate land use type and subwatershed.
- The user can then select the 'Combined BMPs-Calculated' option from the BMP table dropdown menu in the appropriate land use type table in the 'BMPs' worksheet tab.

It should be noted that because the 'Combined BMP Efficiency' tool is utilized for BMPs acting on independent treatment areas, the load reduction estimates generated by the tool are identical to those generated if the user were to apply the same BMPs individually in the same watershed to the same treatment area in the 'BMPs' tab. The table below summarizes the load reduction efficiencies for the following scenarios: (1) the 'Combined BMP Efficiency' tool was used to apply two BMPs to two independent cropland areas within a watershed, each treating 20% of the total cropland area, and (2) the same two BMPs were applied to equivalent areas of cropland in the same subwatershed individually without using the 'Combined BMP Efficiency' tool. Load reduction efficiencies from the two BMPs were

summed manually. Both scenarios result in identical load reduction efficiencies for nitrogen and sediment.

Table B-14. Example Comparison of Multiple, Non-Interacting BMP Application Scenarios in STEPL

Scenario	Watershed Acreage	Acreage per BMP	Load Reduction Efficiencies
BMPs applied individually in 'BMPs' tab	2274	454.80	Nitrogen = 0.068 + 0.107 = **0.1741** Sediment = 0.101 + 0.13 = **0.2366**
BMPs applied using the 'Combined BMP Efficiency' tool	2274	454.80	Nitrogen = **0.174** Sediment = **0.237**

Application of Multiple Interacting BMPs in STEPL

Applying multiple, interacting BMPs in STEPL to calculate combined pollutant removal efficiencies can be accomplished using the 'BMP Calculator' tool:

- From the 'Add-ins' section of the options bar, select the 'BMP Calculator' tool from the 'STEPL' dropdown menu to open the application.
- In the application window, BMPs can be added by selecting the 'Add a New BMP' button (blue and white button in the second options ribbon).
- Each box added to the window corresponds to an individual BMP.
- The user can open and edit the BMP parameters by double-clicking on a box. The user should edit the following options in the 'Set BMP Parameter Values' editing window:
    - BMP type dropdown window – a list of BMPs the user can choose from
    - Total Pollutant Load – The total acreage the BMP will effectively treat within the available land use type acreage in the subwatershed
- To interconnect BMPs that will be applied in series, the user can left click on the first BMP to be applied and drag an arrow to the adjacent box representing the second BMP in the series. This process can be repeated if more than two BMPs are part of the anticipated BMP application scenario.
- If there is some portion of the watershed that will not be treated by any of the BMPs in the series, the user should add an additional box to the window. The user should then drag an arrow from the final BMP in the series to the newly added box. Finally, the user should select '0 - no BMP' under the dropdown window and enter the total acreage within the subwatershed-land use area that will not be treated by any of the BMPs in the series.
- To calculate the pollutant removal efficiencies, the user can then select the 'Calculate the combined coefficient(s)' button (immediately to the right of the 'Add a New BMP' button). Pollutant removal efficiency coefficients will appear in blue text in the window.
- The user can copy the coefficients into Table 7 of the 'BMPs' worksheet in the section corresponding to the appropriate land use type and subwatershed.

Using the 'BMP Calculator' tool to apply multiple BMPs in series within a watershed typically leads to an increase in the pollutant removal efficiencies and, as a result, the total load reductions achieved relative to the application of the same BMPs in parallel. Tables B-15 and B-16 below provide a summary of load

reductions achieved by two example multi-BMP application scenarios (i.e., scenarios for both Cropland and Forest STEPL land uses). Both scenarios compare load reductions achieved when two BMPs are applied in parallel (i.e., no interaction) versus in series (i.e., interaction between BMPs). In Scenario (1), two BMPs – Grass Buffer and Filter Strip – were applied to 909.6 acres of cropland (454.8 acres per BMP) in the Lower Waikele subwatershed. In Scenario (2), two BMPs – Critical Area Planting and Livestock Exclusion Fencing – were applied to 1520.8 acres of forest land (760.4 acres per BMP). Nitrogen and sediment load reductions achieved were higher when BMPs were applied in series relative to when BMPs were applied in parallel (see Table B-17 below).

Table B-15. Cropland Example Comparison of Multiple, Interacting BMP Application Scenarios

Scenario	BMPs	Subwatershed	Land Use	Acreage Applied per BMP	Nitrogen Load Reduction (lbs/yr)	Sediment Load Reduction (t/yr)
(1) No BMP Interaction	1. Filter Strip-Agricultural 2. Grass Buffer (minimum 35 feet wide)	Lower Waikele	Cropland	454.8*	2900.5	1887.9
(2) BMPs Applied in Series					4214.3	2673.0

*** Figure represents 20% of available cropland area in the Lower Waikele subwatershed.**

Table B-16. Forest Example Comparison of Multiple, Interacting BMP Application Scenarios

Scenario	BMPs	Subwatershed	Land Use	Acreage Applied per BMP	Nitrogen Load Reduction (lbs/yr)	Sediment Load Reduction (t/yr)
(1) No BMP Interaction	1. Critical Area Planting 2. Livestock Exclusion Fencing	Kipapa	Forest	760.4*	1764.0	740.9
(2) BMPs Applied in Series					2731.4	1111.4

*** Figure represents 20% of available cropland area in the Lower Waikele subwatershed.**

Table B-17 Change in Load Reduction Efficiencies in Example BMP Application Scenarios when BMPs are Applied in Series Relative to in Parallel

Scenario	Δ Nitrogen Load Reduction Interacting BMP Scenario Relative to Non-interacting BMP Scenario	Δ Sediment Load Reduction Interacting BMP Scenario Relative to Non-interacting BMP Scenario
Cropland	+45%	+42%
Forest	+35%	+33%

Finally, it should be noted that while the 'BMP Calculator' tool is designed to implement multiple, interacting BMP application scenarios, it can also be used to implement single BMP application scenarios and multiple, non-interacting BMP application scenarios in STEPL.

Load Reduction Estimate Results

Load reduction tables and graphs are provided from the STEPL BMP scenario results. They are presented as loads reduced, total loads after BMP implementation, and unit area reductions after BMP implementation. Briefly, unit area load reductions were calculated as follows:

- One or more BMPs were applied to each of the specified land uses in STEPL in the 'BMPs' tab by choosing from a drop-down menu in sections corresponding to each land use type. Note that BMP applications for Urban land use areas were done using the Urban BMP Tool, which is located in the 'BMPs' tab.
- The '% area applied' parameter in the 'BMPs' tab was specified as 20% for all BMP application scenarios to facilitate calculations of unit area load reductions later in the analysis. STEPL multiplies the user-specified '% area applied' by the total area of a specified land use within the specified subwatershed of application to calculate the number of acres to which the designated BMP is applied.
- STEPL calculated the nutrient and sediment load reductions achieved by the application of the specified BMP(s) for each subwatershed.
- Unit area reductions were then calculated for each subwatershed by dividing the load reduction value by the total area to which the specified BMP or BMPs were applied.

B.4. Additional Information

The USEPA offers a variety of additional resources for users to gain a better understanding of STEPL, including:

- A general overview of STEPL's capabilities, software requirements, and download requirements (link)
- STEPL's input data server that allows the user to download watershed specific data for many of the required input tables (link)
- A video tutorial for STEPL's latest release (version 4.4b; link)

B.5. References

Tetra Tech. 2019. Turbidity, Sediment, and Nutrient Total Maximum Daily Loads for the Waikele Watershed Oahu, Hawaii. Prepared for USEPA Region 9 and Hawaii Department of Health. Available at https://health.hawaii.gov/cwb/files/2019/06/Waikele-TMDL-2019.pdf.

United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). 1986. Urban Hydrology for Small Watersheds. Technical Release 55 (TR-55). Available at https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf.

Appendix C: Financial and Technical Assistance Resources

NOTE: DOH has compiled the program details below for informational purposes. This appendix is not intended to be a comprehensive list of technical or financial assistance. Additionally, the information in this appendix largely duplicates relevant details from each program's website and DOH believes the information is correct as of the publication of this plan; interested parties should contact the programs directly to ensure that eligibility and other requirements remain the same.

Financial and Technical Assistance Programs

Agricultural Conservation Easement Program (ACEP)

- **Agency:** USDA NRCS
- **Type:** Financial and technical assistance
- **Target Land Use:** Agricultural
- **Summary:** ACEP helps landowners, land trusts, and other entities protect, restore, and enhance wetlands, grasslands, and working farms and ranches through conservation easements.
- **Eligibility/Requirements:**
    - Agricultural Land Easements include cropland, rangeland, grassland, pastureland and nonindustrial private forest land.
    - Wetland Reserve Easements include farmed or converted wetlands that have been previously altered for agricultural production that can be successfully and cost-effectively restored.
- **Grant size/Funding:**
    - Agricultural Land Easement: NRCS may contribute up to 50 percent of the fair market value of the agricultural land easement. Where NRCS determines that grasslands of special environmental significance will be protected, NRCS may contribute up to 75 percent of the fair market value of the agricultural land easement.
    - Wetland Reserve Easement: NRCS pays all costs associated with recording the easement in the local land records office, including recording fees, charges for abstracts, survey and appraisal fees, and title insurance.
- **Application process/cycle:**
    - Agricultural Land Easement: Eligible partners may submit proposals to the NRCS state office.
    - Wetland Reserve Easement: Landowners may apply at any time at the local USDA Service Center.
- **Applicable BMPs:** See Eligibility/Requirements
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/acep/

Agricultural Management Assistance (AMA) Program

- **Agency:** USDA NRCS
- **Type:** Financial and technical assistance
- **Target Land Use:** Agricultural
- **Summary:** NRCS helps producers develop an AMA plan of operations and construct or improve water management structures or irrigation structures, plant trees for windbreaks or to improve water quality, and mitigate risk through production diversification or resource conservation practices, including soil erosion control, integrated pest management, or transition to organic farming. Contracts are for a minimum of one year after completion of the last practice, but not more than 10 years. Participants are expected to maintain cost-shared practices for the life of the practice.
- **Eligibility/Requirements:**
    - Producers must:
        - Be engaged in livestock or agricultural production.
        - Have an interest in the farming operation associated with the land being offered for AMA enrollment.
        - Have control of the land for the term of the proposed contract.
        - Be in compliance with the provisions for protecting the interests of tenants and sharecroppers, including the provisions for sharing AMA payments on a fair and equitable basis.
        - Be within appropriate payment limitation requirements.
    - Land eligibility:
        - Land on which agricultural commodities or livestock are produced, such as cropland, hayland, pastureland, rangeland, and grassland.
        - Land used for subsistence purposes, private non-industrial forestland, or other land on which agricultural products, livestock, or forest-related goods are produced.
        - Land on which risk may be mitigated through operation diversification or change in resource conservation practices.
- **Grant size/Funding:**
    - Financial assistance up to 75 percent of the cost of installing conservation practices.
    - Total payments shall not exceed $50,000 per participant for any fiscal year.
- **Application process/cycle:** Applications may be obtained and filed at any time with your local USDA Service Center or a conservation district office. Applications may also be accepted by cooperating conservation partners approved or designated by NRCS.
- **Applicable BMPs:** NRCS conservation practice standards identified in the AMA Plan of Operations (APO).
- **Website**: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/ama/

CWA Section 319 Nonpoint Source Management Program

- **Agency:** EPA / DOH
- **Type:** Grant
- **Target Land Use:** All

- **Summary:** Projects implement a component of an existing watershed management plan, TMDL, or other work/action plan to address water quality issues.
- **Eligibility/Requirements:**
    - NPS control projects including one or more of the following:
        - Agricultural BMPs
        - Streambank and riparian restoration
        - Feral ungulate management
        - Invasive species control
        - Stormwater runoff BMPs
- **Grant size/Funding:** Grant appropriation for the State of Hawaii (approximate annual amounts from Hawaii NPS Management Plan 2021-2025)
    - Watershed Project Funds: $600,000
    - NPS Program Funds: $600,000
    - At a minimum, grant recipients must provide 25% matching funds or in-kind contributions from non-federal sources.
- **Application process/cycle:** DOH issues RFP on an annual basis.
    - Project selection is based on several criteria, including measurable water quality improvement outcomes, cost effectiveness, and stakeholder support. Requests for proposals will be conducted in July of each year.
- **Applicable BMPs:**
    - Watershed Project Funds:
        - NPS pollution control projects
        - Education and outreach
        - Water quality monitoring
        - Technical assistance for BMP prioritization and implementation
    - Nonpoint Source Program Funds:
        - Watershed-based plan development
        - National Water Quality Initiative water quality monitoring
        - All activities approved for Watershed Project Funding
- **Website:** https://www.epa.gov/nps/319-grant-current-guidance
- **Hawaii Nonpoint Source Management Plan 2021 – 2025:** https://health.hawaii.gov/cwb/files/2021/02/2021-02-12-NPS-Plan-Public-Comment-Draft.pdf

Clean Water State Revolving Fund (CWSRF)

- **Agency:** DOH
- **Type:** Financial assistance
- **Target Land Use:** All
- **Summary:** The Clean Water SRF (CWSRF) Program provides low interest loans to county and state agencies to construct point source and nonpoint source water pollution control projects. Eligible nonpoint source projects include watershed planning/assessment or implementation of projects needed to restore NPS impaired waters and cesspool replacement with septic tanks.
- **Eligibility/Requirements:**

    - CWSRF project funding is available for public facilities and systems owned by a state or county government agency. Projects eligible for funding must be listed on the current Project Priority List (Appendix B – Hawai'i – Project Priority List for SFY 2022). All projects scheduled for CWSRF funding will be reviewed for consistency with appropriate plans developed under Sections 208, 303(e), and 319 of the Act.
    - The Hawaii CWSRF Program provides loan funding for the construction of MS4 projects.
- **Grant size/Funding:**
    - Loans are issued for 100% of allowable project costs, assuming availability of funds.
    - Projects are assessed an interest rate and an administrative fee (also known as a loan fee).
    - Each loan is subject to a simple interest total loan rate which consists of the interest rate and loan fee.
    - The maximum loan repayment period will be based on the useful life of the project or 30 years, whichever is less. Repayments shall be made at least semi-annually.
- **Application process/cycle:** Annual. See the SRF Applicant Manual (Revised March 2017).
- **Applicable BMPs:**
    - Eligible Projects:
        - Watershed planning/assessment or implementation of projects needed to restore NPS impaired waters.
        - Cesspool replacement with septic tanks, aerobic units, constructed wetlands, or treatment plants.
        - Equipment purchase of street sweepers, catch basin vacuum vehicles, and sediment traps and basins.
        - Capping and closure of municipal solid waste landfills, landfill reclamation, landfill leachate collection, storage and treatment, and landfill gas collection and control systems.
        - Brownfield projects involving site assessments, underground storage tank removal and disposal, contaminated soil or sediment removal and disposal, capping wells, soil remediation, controlling stormwater runoff, and monitoring groundwater and surface water for contaminants.
        - Water quality projects involving leachate and stormwater management at municipal solid waste transfer stations.
        - Stormwater management projects.
- **Website:** https://health.hawaii.gov/wastewater/home/cwsrf/

Conservation Stewardship Program (CSP)

- **Agency:** USDA NRCS
- **Type:** Financial and technical assistance
- **Target Land Use:** Agricultural
- **Summary:** CSP helps agricultural producers maintain and improve existing conservation systems and adopt additional conservation practices.
- **Eligibility/Requirements:**

- Applicants may include individuals, legal entities, or joint operations. All CSP applications must meet the following requirements:
    - Be the operator, owner, or other tenant of an agricultural operation in the FSA farm records management system.
    - Have effective control of the land and include all eligible land in their entire operation in their contract.
    - Comply with highly erodible land and wetland conservation provisions and comply with Adjusted Gross Income provisions.
    - Comply with provisions for protecting the interests of tenants and sharecroppers, including the provisions for sharing payments on a fair and equitable basis.
- Land eligibility: CSP is available to all producers, regardless of operation size or type of crops produced. Eligible lands include private agricultural lands (crop, pasture, and rangeland), nonindustrial private forest land (NIPF), associated agricultural land, and farmstead. Public land associated with the land uses described above is eligible, if under the effective control of the applicant, and if a working component of the producer's agricultural or NIPF operation.
- Each conservation stewardship contract with a person or legal entity will be limited to $200,000 over the term of the initial contract period. Contracts with joint operations (FSA business type 2 or 3) may have a contract limit of up to $400,000 over the term of the initial contract period. Contracts are valid for five years, with the opportunity to compete for a contract renewal if the initial contract is successfully fulfilled and if the participant agrees to achieve additional conservation objectives.

- **Grant size/Funding:** Unknown
- **Application process/cycle:** NRCS accepts applications at any time throughout the year. NRCS sets specific deadlines for ranking and funding opportunities.
- **Applicable BMPs:**
    - Conservation activities include conservation practices, enhancements, and enhancement bundles.
        - Conservation practices must meet the criteria in the conservation practice standards and specifications available in the NRCS Field Office Technical Guide Pacific Islands Area (FOTG).
        - Enhancements are a conservation activity used to treat natural resource concerns and improve producer conservation performance. Enhancement adoption results in environmental benefits that are equal to or greater than the performance level for the planning criteria identified for a given resource concern.
        - Enhancement bundles are specific enhancements whose installation as a group produce conservation performance improvement and address resource concerns in a more comprehensive and cost-effective manner.
    - The five targeted resource concerns for Ag Land selected for the Pacific Islands Area (PIA) are:
        - Sheet and rill erosion
        - Organic matter depletion

        - Pathogens and chemicals from manure, biosolids, or compost applications transported to surface water
        - Plant productivity and health
        - Inadequate livestock water quantity, quality and distribution
    - The five targeted resource concerns for Non-Industrial Private Forest (NIPF) for PIA are:
        - Organic matter depletion
        - Sediment transported to surface water
        - Plant structure and composition
        - Plant pest pressure
        - Terrestrial habitat for wildlife and invertebrates
- **Websites:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/ ; https://www.nrcs.usda.gov/wps/portal/nrcs/main/pia/programs/financial/csp/#

Drinking Water State Revolving Fund (DWSRF)

- **Agency:** DOH
- **Type:** Financial assistance
- **Target Land Use:** All
- **Summary:** Up to 15% of the DWSRF Capitalization Grant is set-aside to support Local Assistance and Other State Programs, which includes source water protection-related activities. These activities include development of source water protection plans and strategies, as well as implementation of protection activities including outreach and educational programs.
- **Eligibility/Requirements:**
    - Eligible systems:
        - Existing privately-owned and publicly-owned community water systems and non-profit non-community water systems, including systems utilizing point of entry or residential central treatment.
        - New community water systems that represent cost-effective solutions to existing public health problems with serious risks caused by: unsafe drinking water provided by individual wells or surface water sources, with the scope of the service area limited to the specific geographic area affected by contamination; or technical, managerial, and financial difficulties that consolidation into a new regional community water system can address, with the scope of the service area limited to that of the systems involved.
- **Grant size/Funding:** Unknown
- **Application process/cycle:** Annual cycle
- **Applicable BMPs:** Eligible projects include development of source water protection plans and strategies, as well as implementing protection activities including outreach and educational programs.
- **Website:** https://health.hawaii.gov/sdwb/drinking-water-state-revolving-fund/

Environmental Quality Incentives Program (EQIP)

- **Agency:** USDA NRCS
- **Type:** Financial and technical assistance

- **Target Land Use:** Agricultural, Conservation
- **Summary:** EQIP provides financial and technical assistance to agricultural producers to address natural resource concerns with goals such as improving water and air quality, conserving ground and surface water, and increasing soil health to reduce soil erosion and sedimentation.
- **Eligibility/Requirements:**
    - Applications for conservation practices and systems that will result in greater environmental benefits for national, state, and/or local natural resource priorities will receive a higher score and higher priority to receive an offer for a financial assistance contract.
    - Historically Underserved Farmers or Ranchers may be eligible for advance payments.
    - Eligible land includes:
        - Cropland and hayland
        - Rangeland
        - Pastureland
        - Non-industrial private forestland
        - Other farm or ranch lands
        - Environmentally sensitive areas
    - Eligible applicants(s) include:
        - Agricultural producers
        - Owners of non-industrial private forestland
        - Indian Tribes
        - Those with an interest in the agricultural or forestry operations
        - Water management entities
- **Grant size/Funding:** Unknown
- **Application process/cycle:** Applications for EQIP financial assistance are accepted throughout the year. Specific deadlines are set for ranking and funding opportunities within each state.
- **Applicable BMPs:**
    - Popular practices include:
        - Cover crops (CP 340)
        - Forest stand improvement (CP 666)
        - Prescribed grazing (CP 528)
        - Irrigation (CP 441)
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

Farm Service Agency (FSA) Loan Programs

- **Agency:** USDA FSA
- **Award Type:** Financial assistance – Loan
- **Target Land Use:** Agricultural
- **Summary:** The FSA offers loans to help farmers and ranchers get the financing they need to start, expand, or maintain a family farm. Farm Ownership Loans can be used to purchase or expand a farm or ranch. This loan can help with paying closing costs, constructing or improving buildings on the farm, or to help conserve and protect soil and water resources.
- **Eligibility/Requirements:**

    - Be a family farmer
    - Have a satisfactory credit history
    - Be a citizen of the United States; a U.S. non- citizen national or a qualified alien under federal immigration law
    - Be unable to obtain credit elsewhere at reasonable rates and terms to meet actual needs
    - Have the legal capacity to incur the obligations of the loan
    - Not have outstanding unpaid judgments obtained by the U.S. in any court, excluding judgments filed in U.S. Tax Courts
    - Not be delinquent on a federal debt
    - Must not have provided FSA with false or misleading documents or statements in the past
    - Not have been convicted under federal or state laws of planting, cultivating, growing, producing, harvesting, or storing a controlled substance within the last 5 crop years
    - Not have received debt forgiveness from FSA (certain exceptions apply)
    - Be within the time restrictions as to the number of years they can receive FSA assistance
- **Grant size/Funding:** Farm Ownership Loans may be used to purchase a farm, enlarge an existing farm, construct new farm buildings and/or improve structures, pay closing costs, and promote soil and water conservation and protection. The direct loans are available up to a maximum of $600,000. Microloans are also available. FSA will guarantee farm ownership loans through a commercial leader up to $1,776,000. The maximum repayment term is 40 years for both direct and guaranteed farm ownership loans.
- **Application process/cycle:** Farmers may apply for direct loans at their local FSA offices.
- **Applicable BMPs:** Specific BMPs not mentioned.
- **Website:** https://www.fsa.usda.gov/programs-and-services/farm-loan-programs/index

Healthy Forests Reserve Program (HFRP)

- **Agency:** USDA NRCS
- **Type:** Financial assistance
- **Target Land Use:** Conservation
- **Summary:** HFRP helps landowners restore, enhance, and protect forestland resources on private lands through easements and financial assistance. HRFP aids the recovery of endangered and threatened species under the Endangered Species Act, improves plant and animal biodiversity, and enhances carbon sequestration.
    - HFRP provides landowners with 10-year restoration agreements and 30-year or permanent easements for specific conservation actions. For acreage owned by an American Indian tribe, there is an additional enrollment option of a 30-year contract. Some landowners may avoid regulatory restrictions under the Endangered Species Act by restoring or improving habitat on their land for a specified period of time.
- **Eligibility/Requirements:**
    - Applicants must provide proof of ownership, or an operator (tenant) must provide written concurrence from the landowner of tenancy for the period of the HFRP restoration agreement.

    - Land must be privately owned or owned by Indian tribes and restore, enhance or measurably increase the recovery of threatened or endangered species, and improve biological diversity or increase carbon storage.
- **Grant size/Funding:** Unknown
- **Application process/cycle:** Apply at your local USDA Service Center.
- **Applicable BMPs:** Specific BMPs not mentioned.
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/easements/forests/

Legacy Resource Management Program

- **Agency:** Department of Defense (DoD)
- **Type:** Financial assistance – Grant
- **Target Land Use:** Military Land
- **Summary:** The program assists DoD in protecting and enhancing resources including projects that support regional ecosystem management initiatives, habitat preservation efforts, and invasive species control. Funding of projects requires that recipients enter into a bilateral agreement with DoD's contracting office.
- **Eligibility/Requirements:**
    - Projects must:
        - Have regional or DoD-wide significance and involve more than one military department
        - Be necessary to meet legal requirements or support military operations
        - Be more effectively managed at the DoD level
        - Not be an Executive Agent responsibility.
    - Projects include:
        - Development of ecosystem wide land management plans
        - Wildlife studies ensuring the safety of military operations
        - Identification of Native American human remains and cultural items in the possession or control of the DoD, or discovered on land under the jurisdiction of the Department, to the appropriate Native American tribes
        - Control of invasive species that may hinder military activities or degrade military training ranges
        - Establishment of a regional curation system for artifacts found on military installations.
- **Grant size/Funding:** Most funded projects range between $40,000 and $150,000.
- **Application process/cycle:** Contact the headquarters or regional location for application deadlines.
- **Applicable BMPs:**
    - Readiness and range sustainment
    - Cooperative conservation
    - Integrated natural resource management
    - Regional ecosystem management initiatives
    - National and international initiatives

    - Invasive species control
    - Monitoring and predicting migratory patterns of birds and animals
    - Cultural resource management
    - Historic preservation and force protection
    - Native American issues
    - Curation of archaeological collections, associated records and documents and management of archaeological sites, and
    - Program management.
- **Website:** https://www.federalgrantswire.com/legacy-resource-management-program.html#.YEELkGhKiUk

National Fish and Wildlife Foundation Grant

- **Agency:** National Fish and Wildlife Foundation (NFWF)
- **Type:** Financial assistance - Grant
- **Target Land Use:** All
- **Summary:** NFWF provides funding for projects that sustain, restore, and enhance our nation's fish, wildlife and plants, and their habitats. Conservation-related projects (including projects addressing NPS pollution) may also be eligible for award through the competitive grant process.
- **Eligibility/Requirements:** Varies
- **Grant size/Funding:** Funding amount unknown. NFWF awards matching grants utilizing federal funds provided by annual Congressional appropriations and agreements with federal agencies. These agencies include the U.S. Fish and Wildlife Service, NRCS, Bureau of Land Management, Bureau of Reclamation, National Oceanic and Atmospheric Administration, EPA, and USDA-Forest Service. NFWF also receives and awards contributions from select foundations, corporations, and other non-federal entities. Congress mandates that each federal dollar NFWF awards is leveraged with a non-federal dollar or equivalent goods and services. NFWF refers to these contributions as "matching contributions."
- **Application process/cycle:** Check website for Requests for Proposals.
- **Applicable BMPs:** Varies depending on funding program.
- **Website:** https://www.nfwf.org/apply-grant

Regional Conservation Partnership Program (RCPP)

- **Agency:** USDA NRCS
- **Type:** Financial assistance
- **Target Land Use:** Agricultural, Conservation
- **Summary:** RCPP works through partnerships to install and maintain conservation practices. Partner entities (e.g., non-profit groups, conservation districts, or other state or local agencies) submit project proposal to NRCS. The participating farmer applies to participate in the project once it has been selected.
- **Eligibility/Requirements:**
    - Partner Eligibility

        - Eligible organizations interested in partnering with NRCS on conservation projects can develop applications for the RCPP competition. The lead partner for an RCPP project is the entity that submits an application, and if selected for an award is ultimately responsible for collaborating with NRCS to successfully complete an RCPP project.
    - Producer and Landowner Eligibility
        - Once NRCS selects a project and executes an RCPP agreement with a lead partner, agricultural producers may participate in an RCPP project in one of two ways. First, producers may engage with project partners and delegate a willing partner to act as their representative in working with NRCS. Second, producers seeking to carry out conservation activities consistent with a RCPP project in the project's geographic area can apply directly to NRCS.
    - Land Eligibility
        - RCPP projects must be carried out on agricultural or nonindustrial private forest land or associated land on which NRCS determines an eligible activity would help achieve conservation benefits (i.e., improved condition of natural resources resulting from implementation of conservation activities).
        - Eligible conservation activities may be implemented on public lands when those activities will benefit eligible lands as determined by NRCS and are included in the scope of an approved RCPP project.
- **Grant size/Funding:** RCPP funding is $300 million annually.
- **Application process/cycle:** RCPP Classic funding announcements are typically scheduled for release in spring or summer.
- **Applicable BMPs:**
    - RCPP projects may include a range of on-the-ground conservation activities implemented by farmers, ranchers, and forest landowners, including:
        - Land management/land improvement/restoration practices
        - Land rentals
        - Entity-held easements
        - United States-held easements
        - Public works/watersheds
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/rcpp/

Watershed Partnerships Program Grant

- **Agency:** Hawaii Division of Forestry and Wildlife
- **Type:** Financial and technical assistance
- **Target Land Use:** Conservation
- **Summary:** The Watershed Partnerships Program provides technical and financial support for watershed partnership activities including the implementation of watershed management plans.
- **Grant size/Funding:** $4.4 million is awarded ($2.2 million is awarded annually).
- **Application process/cycle:** This grant is awarded once every 2 years through a competitive process.
- **Applicable BMPs:**

    - Invasive species control/management
    - Native plant restoration
- **Website:** https://dlnr.hawaii.gov/ecosystems/wpp/

Water Pollution Control Program (Section 106) Grants

- **Agency:** EPA
- **Type:** Financial assistance – Grant
- **Target Land Use:** All
- **Summary:** Section 106 grants can support a wide variety of water pollution prevention and control programs and activities, including:
    - Monitoring and assessing water quality
    - Developing water quality standards
    - Identifying impaired waters and total maximum daily loads
    - Managing national pollutant discharge elimination system permits
    - Ensuring compliance
    - Implementing enforcement actions
    - Protecting source water
    - Managing outreach and education programs
- **Eligibility/Requirements:**
    - A state or territory may receive Section 106 funds if it:
        - Has established and is operating appropriate devices, methods, systems, and procedures necessary to compile and analyze data on navigable waters
        - Has the authority to take action in cases of imminent and substantial endangerment to the health of persons
        - Provides EPA with water quality inventory data required by the CWA. The information on water quality inventory is contained in EPA's biannual water quality report, National Water Quality Inventory Report to Congress (305(b) report)
- **Grant size/Funding:** Varies based on annual EPA budget and allocation to the Section 106 program.
- **Application process/cycle:** EPA calculates Section 106 allotment funds to states, territories, and interstate agencies using an allocation formula that funds "on the basis of the extent of the pollution problem in the state."
- **Applicable BMPs:** Specific BMPs not mentioned.
- **Website:** https://www.epa.gov/water-pollution-control-section-106-grants

Technical Assistance Resources

College of Tropical Agriculture and Human Resources Cooperative Extension Service

- **Agency:** UH College of Tropical Agriculture and Human Resources (CTAHR)
- **Summary:** The CTAHR Cooperative Extension (CE) Service is a partnership between federal, state, and local governments and is responsible for providing science-based information and educational programs in agriculture, natural resources, and human resources.
- **Website:** https://cms.ctahr.hawaii.edu/ce

Conservation of Private Grazing Land Initiative

- **Agency:** USDA NRCS
- **Summary:** This initiative offers technical assistance to owners and managers of grazing land and seeks to improve grazing land management, soil erosion, energy efficiency, water conservation, and wildlife habitat.
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/farmbill/?&cid=nrcs143_008548

Conservation Technical Assistance Program

- **Agency:** USDA NRCS
- **Summary:** The CTA program provides technical assistance to individuals, communities, conservation districts, or state and local governments to conserve, maintain, and improve natural resources.
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/technical/

Current Research Information System

- **Agency:** USDA NIFA
- **Summary:** This information system provides documentation and reporting for ongoing agricultural, food science, human nutrition, and forestry research, education and extension activities for the USDA, with a focus on the National Institute of Food and Agriculture (NIFA) grant programs.
- **Website:** https://cris.nifa.usda.gov/

NRCS Field Office Technical Guide Pacific Islands Area

- **Agency:** USDA NRCS
- **Summary:** The FOTG contains technical information about conservation of soil, water, air, and related plant and animal resources. Technical guides are localized to apply to specific geographic areas. The FOTG is available electronically for users to search for FOTGs and other technical and financial information.

- **Website:** https://efotg.sc.egov.usda.gov/#/

State Technical Committees

- **Agency**: USDA NRCS
- **Summary:** State Technical Committees may include members from state and Federal agencies, tribes, agricultural and environmental organizations, and agricultural producers. The Committees meet regularly to provide information, analysis, and recommendations to NRCS.
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/pia/technical/stc/

Technical Service Providers (TSPs)

- **Agency:** USDA NRCS
- **Summary:** TSPs are individuals or businesses with technical expertise in conservation planning and design of conservation activities. TSPs are hired by farmers, ranchers, private businesses, nonprofit organizations, or public agencies to provide these services on behalf of the NRCS. Each certified TSP is listed on the NRCS TSP online registry.
- **Website:** https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/technical/tsp/

Appendix D: Expanded List of Practices to Reduce Nitrogen and Sediment Loads in the Waikele Watershed

The practices discussed in Sections 7 and 8 of the Waikele Watershed and TMDL Implementation Plan were used to model potential load reductions from practices most likely to be implemented in the watershed. However, this plan is not intended to limit the practices that may be used to achieve load reductions to only those practices used in the modeling. Hawaii Department of Health (DOH) recognizes that individual stakeholder goals, needs, and resources may lead to selection of different, yet equally effective, practices. The expanded best management practice (BMP) list below includes the modeled practices from the report along with a broader selection of practices that also might be appropriate for the land uses in the Waikele watershed. For each practice, the table identifies similar practices that may be suitable alternatives depending on site-specific conditions. For those practices not described in Section 7 of the report, the table also includes a practice description and links to select resources, where available, that may help stakeholders understand practice implementation and estimated costs and load reductions. This information is provided to help stakeholders identify and select the most appropriate practice for a specific site.

While DOH believes the table below includes many of the practices that are likely to be considered for reducing nonpoint source loads in the Waikele watershed, this set of practices is not intended to be comprehensive. Practices that do not appear in this list could be used to help achieve the necessary pollutant load reductions. However, because this plan includes load reduction estimates only for the practices described in the report, stakeholders submitting project proposals for certain funding sources may be required to develop load reduction estimates for projects that incorporate alternative practices.

Management Practice	Description[1]	Resources[2]	Similar/Related Practices
Access Road	A travel-way for equipment and vehicles constructed as part of a conservation plan; provides a fixed route for vehicular travel for resource activities, including timber, livestock, and agriculture management.	CPS 560	Heavy Use Area Protection
Agro-forestry	Integrating shrubs and trees into agricultural landscapes to achieve environmental and other benefits.	• USDA National Agroforestry Center • Agroforestry: Working Trees for Islands	• Riparian Forest Buffers • Windbreaks • Tree/Shrub Establishment
Bioretention Cell (Rain Garden)*	See Section 7.2, Practice 1		Constructed Wetlands
Brush Management	The management or removal of woody (non-herbaceous or succulent) plants, including those that are invasive and noxious.	• CPS 314 • Appendix A of the TMDL	Clearing and Snagging
Cesspool Replacement	Replacing cesspools with connection to an available sewer or an alternative on-site disposal system (e.g., septic system, aerobic treatment unit).	• Hanalei Bay WMP - Vol. 2 (Table 21) • Hawaii's CNPCP MMs (Urban/Onsite Disposal Systems)	
Channel Maintenance and Restoration*	See Section 7.2, Practice 2		Stream Stabilization
Check Dams	A small dam constructed across a drainage ditch, swale, or channel to lower the velocity of flow. Reduced runoff velocity reduces erosion and gullying in the channel and allows sediments to settle out. A check dam may be built from stone, sandbags filled with pea gravel, or logs.		
Clearing and Snagging	Removal of vegetation along the bank (clearing) and/or selective removal of snags, drifts, or other obstructions (snagging) from natural or improved channels and streams.	CPS 326	Brush Management

Management Practice	Description[1]	Resources[2]	Similar/Related Practices
Coir Logs/Wattles	Coir logs are densely packed; support soil and prevent it from being displaced by strong winds and water currents; ideal for installation on streambanks and slope vegetations. Coir wattles are comparatively lightly packed; filter out sediments; ideal for sediment control.		Erosion Control Fabric/Mats with Vegetative Plantings
Compost/Compost Structure	Composting is the decomposition of organic material into a stable final product with various uses, including as a soil amendment. A compost structure is designed to contain and facilitate aerobic decomposition of organic matter into compost.	CPS 317	Soil Amendments
Conservation Cover	Establishing and maintaining perennial vegetative cover to protect soil and water resources on land retired from agricultural production or other lands needing permanent protective cover that will not be used for forage production.	• CPS 327 • Wahikuli-Honokōwai Watershed Management Plan	Riparian Herbaceous Cover
Constructed Wetlands*	See Section 7.2, Practice 3		Bioretention Cell
Contour Orchard	"Contour orchard and other perennial crops" refers to planting orchards, vineyards, or other perennial crops so that all agricultural operations are done on or near the contour to reduce erosion/sedimentation and improve water infiltration.	CPS 331	
Cover Crop*	See Section 7.2, Practice 4		
Critical Area Planting	See Section 7.2, Practice 5		Erosion Control Fabric/Mats with Vegetative Plantings
Erosion Control Fabric/Mats with Vegetative Plantings	Erosion control mats are geotextiles that are composed of synthetic fabric and stabilize the ground while initial vegetative growth takes place. Vegetative plantings are native or non-invasive species used to permanently stabilize and protect the ground surface. The practices are used together to discourage erosion and generation of	• Mā`ili`ili WMP • Hanalei Bay WMP - Vol. 2	• Coir Logs/Wattles • Critical Area Planting

Management Practice	Description[1]	Resources[2]	Similar/Related Practices
	sediment from exposed soil surfaces, including those within drainageways.		
Feral Ungulate Fencing	See Section 7.2, Practice 6		Feral Ungulate Removal
Feral Ungulate Removal	Hunting or trapping wild goats, pigs, and other non-native hoofed mammals to reduce erosion caused by trampling and vegetation removal as well as nutrient and bacterial impacts from defecation in and around water bodies.	• Hanalei Bay WMP - Vol. 2 (Grazing Management: Livestock Fencing, Section 3.4.3.4) • CPS 297 (interim)	Feral Ungulate Fencing
Fertilizer Management Plan	See Section 7.2, Practice 7		
Field Border	See Section 7.2, Practice 8		• Filter Strip • Riparian Herbaceous Cover • Vegetative Barrier
Filter Strip	See Section 7.2, Practice 9		• Field Border • Riparian Herbaceous Cover • Vegetative Barrier
Gabions	Rock- filled “cages” or wire baskets used in many engineering applications, including the stabilization of streambanks or slopes.	Māʻiliʻili WMP	Rock Barrier
Grass Swale	See Section 7.2, Practice 10		Grassed Waterway
Grassed Waterway	A shaped or graded channel that is established with suitable vegetation to convey surface water at a non-erosive velocity using a broad and shallow cross section to a stable outlet. Used to convey runoff from terraces, diversions, or similar; to prevent gully formation; and to protect or improve water quality.	CPS 412	Grass Swale
Grazing Management System	See Section 7.2, Practice 11		Livestock Rotation

Management Practice	Description[1]	Resources[2]	Similar/Related Practices
Heavy Use Area Protection	Used to stabilize a ground surface that is frequently and intensively used by people, animals, or vehicles.	CPS 561	Access Road
Herbaceous Weed Treatment/Invasive Species Removal	The removal or control of herbaceous weeds, including invasive, noxious, and prohibited plants.	• CPS 315 • Waikele TMDL, Appendix A (infiltration)	
Irrigation Water Management	Determining and controlling the volume, frequency, and application rate of irrigation water to improve water use efficiency, minimize irrigation induced erosion, decrease degradation of water resources, etc. Can include sprinkler irrigation and other methods.	CPS 449	• Irrigation System – Micro Irrigation • Lo'i Management
Irrigation System – Micro Irrigation (Drip Irrigation)	An irrigation system for frequent application of small quantities of water on or below the soil surface as drops, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line. Suited to most agricultural crops and residential and commercial landscape systems, as well as steep slopes where other methods would cause excessive erosion.	CPS 441	Irrigation Water Management
Land Smoothing	Removing irregularities on the land surface to improve surface drainage, provide for more uniform cultivation, and improve equipment operation and efficiency.	CPS 466	
Lined Waterway	A waterway or outlet having an erosion-resistant lining of concrete, stone, synthetic turf reinforcement fabrics, or other permanent material. May be used to prevent erosion and protect and improve water quality.	CPS 468	
Livestock Rotation	See Section 7.2, Practice 12		Grazing Management System
Lo'i Management	For taro production, a protocol for: • Operating 'auwai outlet that keeps the gate closed during lo'i tilling and weed pulling. Promotes settling of sediment and prevents TSS from migrating to receiving waters.	Hanalei Bay WMP - Vol. 2	

Management Practice	Description[1]	Resources[2]	Similar/Related Practices
	• Tilling loʻi when dry. Prevents stirring up of sediment common to wet tilling practices, and promotes the traditional resting period for loʻi.		
Mulching	Mulching is applying plant residues or other suitable materials to the land surface.	CPS 484	
Riparian Forest Buffers	See Section 7.2, Practice 13		• Agro-forestry • Tree/Shrub Establishment
Riparian Herbaceous Cover	See Section 7.2, Practice 14		• Conservation Cover • Erosion Control Fabric/Mats with Vegetative Plantings • Field Border • Filter Strip • Tree/Shrub Establishment • Vegetative Barrier
Rock Barrier	A rock retaining wall constructed across the slope to form and support a bench terrace that will control the flow of water and check erosion on sloping land.	CPS 555	• Gabions • Terrace
Sediment Basin	See Section 7.2, Practice 15		Sediment Traps
Sediment Traps	See Section 7.2, Practice 16		Sediment Basin
Soil Amendments	Using amendments derived from plant or animal residues to improve the physical, chemical, and biological properties of the soil.	CPS 808	• Compost • Fertilizer Management Plan

Management Practice	Description[1]	Resources[2]	Similar/Related Practices
Stream Stabilization (Streambank and Shoreline Protection)	Treatment(s) used to stabilize and protect banks of streams or constructed channels and shorelines of lakes, reservoirs, or estuaries.	CPS 580	• Channel Maintenance and Restoration • Gabions • Lined Waterway • Riparian Forest Buffers • Riparian Herbaceous Cover
Terrace	See Section 7.2, Practice 17		Rock Barrier
Tree/Shrub Establishment	See Section 7.2, Practice 18		• Riparian Forest Buffers • Agro-forestry
Vegetative Barrier	See Section 7.2, Practice 19		
Water Bars	Road construction feature that is used to prevent erosion on sloping roads; diagonal channel across the road that diverts surface water	Hawaii's CNPCP MMs (Forestry)	
Windbreaks	Establishing, enhancing, or renovating windbreaks, also known as shelterbelts, which are single or multiple rows of trees and/or shrubs in linear or curvilinear configurations. Reduces wind erosion, among other benefits.	CPS 380	Tree/Shrub Establishment

* These practices were included in the STEPL modeling and are described in more detail in Section 7.2.

[1] The practice descriptions are adapted from various resources, primarily the Pacific Islands Area Natural Resources Conservation Service (NRCS) Conservation Practice Standards (CPS), the Hanalei Bay Watershed Management Plan, and the Ma'ili'ili Watershed Management Plan.

[2] **CPS** = Conservation Practice Standards established by the U.S. Department of Agriculture (USDA) NRCS for the Pacific Islands Area (PIA). All CPSs can be found in Section 4 of the Hawaii/PIA area of NRCS's electronic Field Office Technical Guide (FOTG). Section 1 of the FOTG includes cost data and other useful reference information for many of the practices.
Hanalei Bay WMP - Vol. 2 = Watershed Management Plan for Hanalei Bay Watershed, Volume 2: Strategies and Implementation, April 2014
Mā`ili`ili WMP = Mā`ili`ili Watershed Management Plan, July 2014
Hawaii's CNPCP MMs = Hawaii's Management Measures for the Coastal Nonpoint Pollution Control Program, October 2010
Waikele TMDL = Turbidity, Sediment, and Nutrient Total Maximum Daily Loads for the Waikele Watershed, February 2019

APPENDIX E. ADDENDUM TO THE WAIKELE WATERSHED PLAN

August 2025

Estimating Pollutant Load Reductions Resulting from Control and Removal of Invasive Plant and Animal Species and Establishment of Native Species

Introduction

This addendum has been developed by the Hawaii Department of Health (HDOH) to address additional considerations and updates relevant to watershed management efforts. This addendum supplements the Waikele Watershed Plan include activities and additional guidance related to the removal of invasive plants and animals, as well as the reintroduction of native species. In addition to including these activities in the menu of best management practices (BMPs) that are eligible for 319 funding, this addendum provides an approach for calculating the pollutant reductions associated with these restoration activities. These pollutant reductions can be used by project managers and sub-grantees to develop individual project plans and by HDOH to calculate annual pollutant reductions for the broader NPS program.

Pollutant Loading from Invasive Species

Invasive plants and animals are an increasingly challenging source of pollution in many of Hawaii's watersheds. Invasive plants, such as miconia, have shallow root systems, which are unable to stabilize the soil and are susceptible to erosion and landslides during rainfall events. Invasive animals, such as feral hogs, are destructive grazers, uprooting plant material and exposing additional areas to erosion.

As a result, sediment is the primary pollutant of concern from invasive species, although other pollutants may also be transported during rainfall events (e.g., nutrients and bacteria). Sediment has been identified by HDOH as a pollutant of concern across the state and is a focus of water quality improvement efforts. This watershed-based plan already includes a discussion of pollutants of concern and the load reductions needed to return the impaired waters to attainment. This addendum supplements that discussion; invasive species are one of multiple pollutant sources to be addressed.

Pollution Control Practices

Across Hawaii, many organizations (including federal, state and local government, as well as watershed groups) are working to mitigate these problems. In many cases, this involves removing the invasive species and replacing them with native species. Native plant species[1] are better adapted to the soils and climate and provide improved soil retention, among other benefits. Excluding invasive animals, such as using fencing to block access to an area, allows vegetation to recover and thrive.

Table 1 below includes BMPs that can address pollutant loading caused by invasive species.[2] As shown by the large number of potential BMPs, vegetative plantings are a common element of many BMPs; ensuring that native species are used (and in the necessary quantities for establishment) will help to restore native plant communities. Managing invasive animal species is typically limited to exclusion or removal.

[1] See, for example, https://dlnr.hawaii.gov/forestry/plants/ for a discussion of native plant species.

[2] The table shows only a selection of BMPs. Other BMPs may also accomplish the goals of invasive removal and re-establishment of native species. Watershed planners should consult with HDOH when developing project plans to ensure BMP eligibility.

Table 1. Selection of BMPs to Address Invasive Species

Management Practice	Description
Bioretention Cell (Rain Garden)	Depression consisting of native plant species and soil mixtures that receives stormwater flow and infiltrates to treat pollutants.
Channel Maintenance and Restoration	Practices used to control sediment and plant pollution into waterways during earthwork such as stream bank stabilization or habitat enhancement. Examples include floating booms and silt curtains extended across river or stream banks downstream of work.
Constructed Wetlands	Creation of an artificial wetland ecosystem to improve the quality of stormwater runoff or other water flows. A constructed wetland provides biological treatment in areas where wetland function can be created or enhanced. Constructed wetlands also can be used to treat runoff from agricultural land uses and stormwater runoff and other contaminated flows from urban areas and other land uses. The practice involves establishment of inlet and outlet control structures for an impoundment designed to accumulate settleable solids, decayed plant matter, and microbial biomass and support propagation of hydrophytic vegetation.
Critical Area Planting	Establishment of permanent vegetation in areas with heavy erosion problems. Particularly useful for areas that need stabilization before/after flood events.
Grassed Waterway	A shaped or graded channel that is established with suitable vegetation to convey surface water at a non-erosive velocity using a broad and shallow cross section to a stable outlet. Used to convey runoff from terraces, diversions, or similar; to prevent gully formation; and to protect or improve water quality.
Herbaceous Weed Treatment/Invasive Species Removal	The removal or control of herbaceous weeds, including invasive, noxious, and prohibited plants.
Sediment Basin	Captures and retains stormwater runoff until sediments settle out; water is released through engineered outlet.
Feral Ungulate Fencing	A structural conservation practice that prevents movement of ungulates across a given boundary. Within areas impacted by feral ungulate presence, fences prevent their movement into the forested lands. Ungulate fencing prevents direct contact of fecal matter with waterways, allows for restoration of vegetation, and reduces bacteria and nitrogen loadings and sediment input into waterways.
Feral Ungulate Removal	Hunting or trapping wild goats, pigs, and other non-native hoofed mammals to reduce erosion caused by trampling and vegetation removal, as well as nutrient and bacterial impacts from defecation in and around water bodies.

Through this addendum, these BMPs are now eligible for funding under Section 319 to address water quality concerns caused by invasive species (if the BMPs were not already identified in the original plan). Implementation of these BMPs will lead to a reduction in pollutant loading in the watershed. The original watershed-based plan may include information on specific locations or land use types that may be most appropriate for invasive species BMPs. Additional information can be found in other resources,

such as the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service's *Field Office Technical Guide* for Hawaii.[3]

Calculating Pollutant Reductions

Accounting for the total pollutant reductions is an important step in tracking water quality improvements. HDOH and watershed stakeholders develop watershed-based plans under the state's nonpoint source pollution (NPS) program; these plans include a projected level of pollutant reduction for the proposed project.

There are various models that can be used to calculate the pollutant reductions associated with BMP implementation. HDOH researched the advantages and disadvantages of each model, including the ease of use for watershed project managers and evaluating the model's appropriateness for use in Hawaii. After reviewing several models, HDOH selected the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model.

Description of the InVEST Model

InVEST is a suite of models focused on ecosystems and how they connect to downstream economics. This addendum is focused on the sediment delivery ratio model in the InVEST suite. The InVEST sediment delivery ratio model was chosen by HDOH because it is easy to use and its ability to estimate sediment loading both with current condition and with BMPs implemented. Additionally, the InVEST model can be modified to accommodate the unique geologic conditions in Hawaii.

The InVEST sediment delivery ratio model is focused on sediment loading and erosion. The model outputs a set of maps showing the sediment erosion, including the amount of sediment soil loss per pixel, and the amount of erosion that is prevented by the presence of vegetation per pixel. The effect of BMPs on sediment erosion can be measured by comparing model outputs ran under the current conditions against model outputs ran with BMPs implemented. To calculate the annual soil loss per pixel, the InVEST model uses the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1997). Along with the factors that are in the RUSLE equation (rainfall erosivity, soil erodibility, slope length gradient, cover management, and support practice), this addendum recommends including an additional terrain factor to accommodate for the geology of Hawaii. The inclusion of the terrain factor prevents the model from overestimating the soil loss in places with geologically new basaltic bedrock which has minimal soil cover (Falinski, 2016). The required data inputs for this model are integrated into the RUSLE equation. To determine the effects of BMPs on sediment load reduction and erosion, the model should be run with altered data inputs.

The required data inputs include GIS data, a table, and five additional values. These five inputs are described in detail in the Step-by-Step Procedure below. To measure the reduction in sediment load and erosion with BMP implementation, these inputs can be changed to integrate the increase in vegetation that would come along with BMP implementation. The Step-by-Step Procedure section of this addendum describes each of these required inputs in further detail along with recommended values and sources for GIS data inputs.

[3] https://efotg.sc.egov.usda.gov/#/state/HI/documents

Step-by-Step Procedure

The step-by-step procedure begins with collecting and creating the proper data inputs for the current conditions in the watershed and running the InVEST model with those data inputs. After the first model run, the next step is to use multiple lines of evidence, including model outputs and other information, to determine the most appropriate areas in the watershed to implement BMPs. Next, the model should be run again with inputs that incorporate the impacts that BMPs would have on the land cover or support practices. The reduction in pollutant loading is the difference between the two model output runs. The steps to compile each data input and descriptions of each required data input are shown in Table 2. All GIS inputs must be the same coordinate reference system. The coordinate reference system must be projected and in linear units of meters.

Table 2. Required Data Inputs for the Invest Model

GIS Data Inputs		
Input Name and Description	**Data Type**	**Suggested Sources**
Digital Elevation Model: A digital elevation map (DEM) showing elevation in meters. The map should be clipped beyond the watershed boundary.	Raster	The 3D Elevation Program (3DEP) from USGS.[4] The best available resolution for the state is 1/3 arc-second.
		The Hawaii Statewide GIS Program's Digital Terrain Model.[5] Data is only available for portions of the state and as a JPEG or PNG, so it must be converted to a raster format. The resolution is 1 meter, and the elevation values are in meters.
Erosivity: A map of rainfall erosivity in units of MJ • mm/(h • ha • year). The map should illustrate both intensity and duration of rainfall.	Raster	For the island of Hawaii, NOAA's digitized version of the rainfall erosivity map from the Agriculture Handbook No. 703.[6] The units are US customary units, so the units must be converted by multiplying each value by 17.02 (Renard, et al., 1997).
		For the island of Oahu, NOAA's digitized version of the rainfall erosivity map from the Agriculture Handbook No. 703.[7] The units are US customary units, so the units must be converted by multiplying each value by 17.02 (Renard, et al., 1997).
		The rainfall erosivity map on page 57 of the Agriculture Handbook No. 703. This map must be digitized into raster data by a GIS specialist and units must be converted to SI by multiplying each value by 17.02 (Renard, et al., 1997).
		A rainfall erosivity raster can be made using precipitation from the Hawaii Climate Data Portal.[8] Rainfall erosivity can be calculated using the Roose equation (Renard and Freimund, 1994): R = 0.5 x P x 17.02, where R is the rainfall erosivity value in the proper SI units and P is the annual rainfall in mm/year.
Soil Erodibility: A map showing the soil erodibility in the watershed. Soil erodibility, also called K factor, is the likelihood of soil particles to erode and be	Raster	Soil data, including K factors, is available from the Soil Survey Geographic Database (SSURGO).[9] This database provides raster data of soil type in an area of interest, and a table showing the K factor of each soil type. Raster

[4] https://apps.nationalmap.gov/downloader/
[5] https://geoportal.hawaii.gov/datasets/HiStateGIS::hawaii-dtm-elevation/about
[6] https://www.fisheries.noaa.gov/inport/item/48225
[7] https://www.fisheries.noaa.gov/inport/item/48230
[8] https://www.hawaii.edu/climate-data-portal/data-portal/
[9] https://www.nrcs.usda.gov/resources/data-and-reports/soil-survey-geographic-database-ssurgo

transported downstream by precipitation or runoff. The soil erodibility raster must be in units of t · h · ha / (ha · MJ · mm).		data of K factors in a projected coordinate system will have to be generated by combining the soil raster data and the K factor table.
Land Use/Land Cover: A map showing the land use and land cover within the watershed. The C-CAP raster described below must also be combined with geology data. Each pixel should be categorized by its land use/land cover and geologic origin from the geology dataset. Every combination of land use/land cover and geologic origin should be assigned a unique LULC code.	Raster	NOAA has C-CAP high resolution land cover raster data available for the entire state of Hawaii from 2021.[10] NOAA's land cover data has a resolution of 1-meter and includes up to 25 classifications including forests and urban development.
		Geology data for the state of Hawaii is available for download from USGS.[11] This data is available as shapefiles, so it must be converted to raster data.
Watersheds: A map of the boundary of the watershed.	Vector (polygon/ multipolygon)	The USGS Watershed Boundary Dataset has vector watershed delineation data available at different hydrologic unit levels for the entire state of Hawaii.[12]
		The Hawaii Statewide GIS Program has vector watershed delineation data available that was created by the Division of Aquatic Resources (DAR).[13]
		The InVEST suite includes the Delineatelt tool, used for generating watersheds based on user inputs. This tool outputs a GeoPackage containing a vector with the model's estimated watershed delineations. More information on this tool can be found in the Delineatelt section of the InVEST suite.[14]
		Watershed delineations can be generated using a USGS StreamStats's tool.[15] Delineations can be downloaded as vectors.
Other Required Data Inputs		
Input Name and Description	**Data type**	**Suggested Input Value**

[10] https://coast.noaa.gov/digitalcoast/data/
[11] https://pubs.usgs.gov/of/2007/1089/
[12] https://www.usgs.gov/national-hydrography/watershed-boundary-dataset
[13] https://geoportal.hawaii.gov/datasets/HiStateGIS::watersheds-dar-version/about
[14] https://storage.googleapis.com/releases.naturalcapitalproject.org/invest-userguide/latest/en/delineateit.html
[15] https://www.usgs.gov/streamstats

Threshold Flow Accumulation: The minimum number of pixels that flow into another pixel for it to be classified as a stream.	Number of pixels	This value should be determined by the user via trial and error. Users should test different values until the streams on the output maps resemble the streams in the watershed.
Borselli k Parameter: A calibration parameter in the sediment delivery ratio equation.	Number	This value is based on watershed location. Table 3 shows the Borselli k Parameter by location.
Maximum SDR Value: The maximum sediment delivery ratio a pixel is allowed to have.	Number between 0 and 1	For all watersheds in the state of Hawaii, the value should be 0.5 (Falinski, 2016).
Borselli IC_0 Parameter: A calibration parameter in the sediment delivery ratio equation.	Number	For all watersheds in the state of Hawaii, the value should be 0.1 (Falinski, 2016).
Maximum L Value: The maximum allowed slope value in the slope length-gradient factor.	Number	For all watershed in the state of Hawaii, the value should be 122 (Falinski, 2016).
Biophysical Table: A table mapping each LULC code to its cover-management factor (C) and support practice factor (P). One column should be named "lucode" and contain the LULC code from the land cover and land use raster. The other two columns should be named "usle_c" and "usle_p" and contain the associated C factor and P factor, respectively. The C factor indicates how much erosion is likely to occur at this land use/land cover type. The smaller the C factor value, the less erosion is expected to come from that type. To account for the terrain factor in the model run, the C factor in the biophysical table should be modified. The C factor for each LULC code should be the original C factor from Table 4 multiped by the terrain factor from Table 5 that is associated with the geologic origin under that LULC code. The P factor indicates whether erosion reduction practices are implemented in that area. A value of 1 means there are no erosion reduction practices implemented in that land cover/land use type and a smaller value indicates best management practices are implemented in that land cover/land use type.	.CSV file	Table 4 shows the C factors for land use/land covers in Hawaii, and Table 5 shows the terrain factor by geologic origin.
Workspace: The folder where outputs will be written.	Folder name	--

Table 3. Borselli k Parameter by Watershed Location (Falinski, 2016)

Watershed Location	Borselli k Parameter
Windward part of the island of Hawaii	4
Leeward part of the island of Hawaii	2.5
Oahu	2.5
Maui	2
Lanai	2
Molokai	1.25
Kahoolawe	2.4
Kauai	1.6
Niihau	1.5

Table 4. C Factor Values for Land Use/Land Cover (Falinski, 2016)

Land Use/Land Cover	**C Factor**	**Land Use/Land Cover**	**C Factor**
Evergreen	0.014[16]	Developed, Medium Intensity	0.01
Scrub Shrub	0.014[17]	Impervious Surface	0.001
Bare Land	0.7	Palustrine Scrub Shrub Wetland	0.003
Pasture/Hay	0.05	Palustrine Emergent Wetland	0.003
Grassland	0.05	Unconsolidated Shore	0.003
Open Water	0	Estuarine Forested Wetland	0.003
Cultivated Land	0.24[18]	Estuarine Scrub Shrub Wetland	0.003
Developed, Low Intensity	0.03	Estuarine Emergent Wetland	0.003
Palustrine Forested Wetland	0.003	Background	0
Open Space Developed	0.05	Palustrine Aquatic Bed	0

Table 5. Terrain Factor by Geologic Origin (Falinski, 2016)

Hawaii		**Oahu, Kauai and Niihau**	
Geologic origin	**Terrain factor**	**Geologic origin**	**Terrain factor**
Hamakua Volcanics	1	Honolulu Volcanics	1
Hawi Volcanics	1	Kolekole Volcanics	1
Hilina Basalt	0.001	Koolau Basalt	1
Hualalai Volcanics	0.001	Waianae Volcanics	1
Kahuku Basalt	0.001	Kiekie Volcanics	1
Kau Basalt	0.001	Koloa Volcanics	1
Laupahoehoe Volcanics	0.1	Paniau Basalt	0.1
Ninole Basalt	1	Waimea Canyon	0.1
Pololu Volcanics	1	--	--
Puna Basalt	0.001	--	--
Maui, Molokai, Lanai and Kahoolawe		**All Islands**	

[16] Evergreen forest: 0.035 for Hamakua and Kohala volcanoes
[17] Scrub/shrub: 0.05 for leeward volcanic units
[18] Cultivated land: 0.4 for pineapple (Lanai) or 0.51 for sugarcane crop (central Maui)

Geologic Origin	Terrain factor	Geologic origin	Terrain factor
East Molokai Volcanics	1	Open water	1
Hana Volcanics	0.001	Fill	1
Honolua Volcanics	1	Alluvium	1
Honomanu Basalt	1	Landslide Deposits	1
Kalaupapa Volcanics	1	Slope Deposits	0.001
Kanapou Volcanics	1	Tephra Deposits	0.1
Kaupo Mud Flow	1	Beach Deposits	0.1
Kula Volcanics	0.01	Lagoon Deposits	1
Lahaina Volcanics	1	Older Dune Deposits	1
Lanai Basalt	1	Younger Dune Deposits	0.1
Wailuku Volcanics	1	Talus and Colluvium	0.1
West Molokai Volcanics	1	Marine Conglomerate and Breccia	0.1
--	--	Caldera Wall Rocks	0.001

The most relevant output is the "sed_export.tif', showing the sediment exported from every pixel. Because of the geology of Hawaii, data on the pixel level from this raster may be inaccurate. The model tends to predict higher sediment export from areas with steeper slopes. In Hawaii, high slopes occur in high elevation areas where the sediment supply may be naturally limited by the unique geology of Hawaii. Therefore, the model overestimates the amount of sediment export in the mountains because it assumes unlimited sediment supply in steep areas with thin or little soil. For this reason, the sediment export raster data should not be used as the sole or main method for determining where BMPs should be implemented within the watershed.

The sediment export raster can be combined with land use/land cover data to determine which land use classes are disproportionately contributing to sediment loading. The amount of sediment mass exported per acre for each land use can be calculated by adding up the value of every pixel in the sediment export raster in each land use and dividing that sum by the number of acres that the land use covers.

It is crucial that multiple lines of evidence are considered when determining where BMPs should be implemented. The normalized difference vegetation index (NDVI)[19] is a satellite-based measurement that could be useful in identifying areas with minimal vegetation which may be susceptible to increased erosion. The NDVI quantifies vegetative health and density. NDVI values closer to positive 1 indicate the presence of abundant and healthy vegetation, and a value closer to 0 indicates there is less vegetation (NASA, 2025). Looking at NDVI data in a raster format would allow a user to visualize areas within the watershed that have little vegetation or unhealthy vegetation, indicating that the area could benefit from BMP implementation. If the resolution of the NDVI data is a lower resolution, it may be difficult to pinpoint areas where BMP implementation would be the most valuable. Therefore, further evidence should be used when selecting areas for BMP implementation. A high resolution and recent satellite image can supplement older land use/land cover data and lower resolution NDVI raster data. A satellite image can be used to more accurately identify areas with minimal vegetative cover which could benefit most from BMP implementation. Further useful evidence can be collected on-site in the watershed. If possible, a person can walk along streams in the watershed and identify locations in the watershed

[19] One potential source of NDVI data is NOAA's Suomi National Polar-orbiting Partnership (Suomi NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Vegetation Indices (VNP13A2) Version 2 data product which can be queried using the 'modisfast' R package.

where BMP implementation would be the most advantageous, such as locations with invasive plant species, minimal vegetation and/or the presence of feral ungulates. Each of the options listed above is important evidence that should be considered when the user is deciding on locations for BMP implementation.

After determining where BMPs will be implemented, the next step is to re-run the model with inputs that account for the BMPs that would be implemented to determine how they would affect sediment loading. The model inputs for the revised run should remain almost entirely the same. A different directory should be entered into the Workspace field or the results from the last model run will be overwritten. Additionally, either the support practice factors in the biophysical table or the land use/cover raster should be edited:

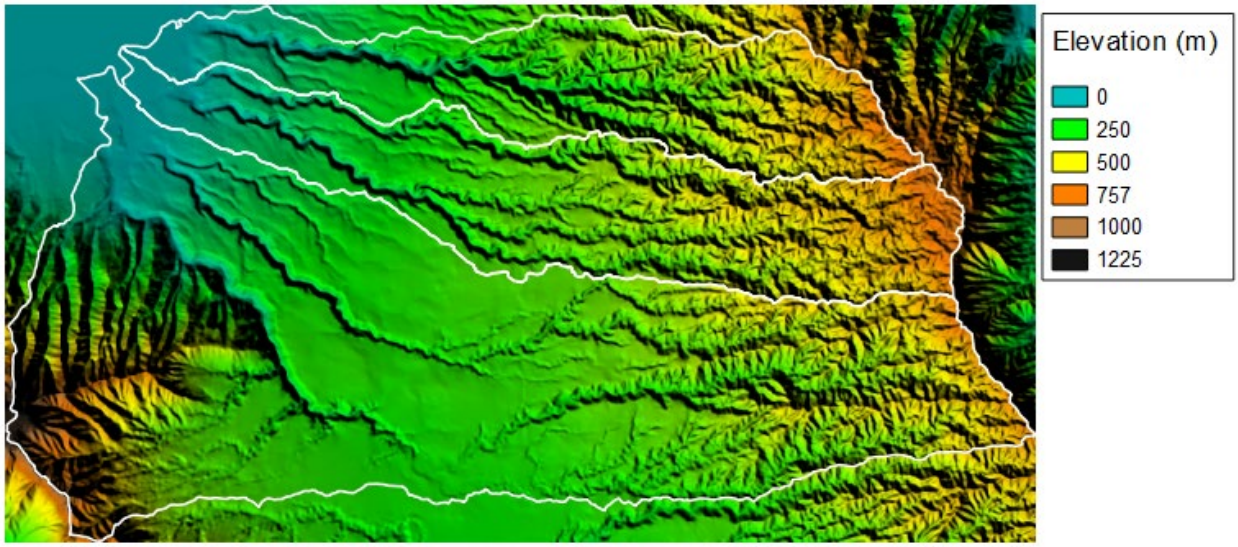
- The P factors in the biophysical table should be decreased for each land use/land cover type where an erosion reduction practice will be implemented.
- Alternatively, the land cover/land use raster should be edited to show how the land use/land cover would change with erosion reduction practices implemented. For example, bare land could be changed to a type of forest cover if a best management practice would be to plant native species on non-vegetated land.

To determine the effect that the implementation of best management practices would have on sediment exports, the outputs from both model runs can be compared. The sum across every pixel in "sed_export.tif" outputs illustrate how much sediment load reduction would occur with BMP implementation on the watershed level.

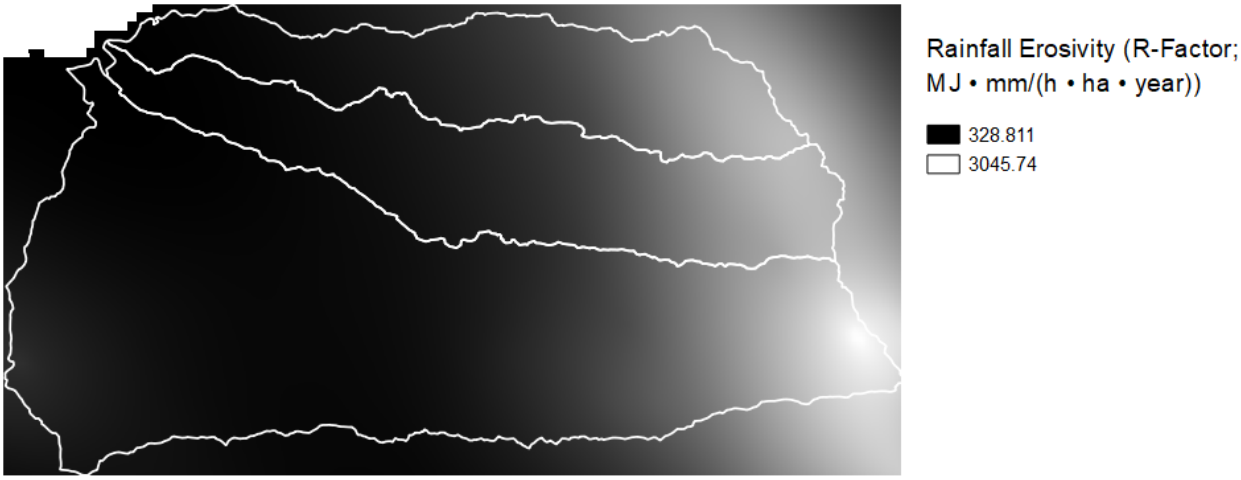
Example Use of the Procedure

To illustrate the Step-by-Step Procedure, this section looks at an example watershed: Kaiaka Bay. The Kaiaka Bay watershed is on the coast of the island of Oahu. The Kaiaka Bay and several streams that drain into the bay are listed as impaired. Both invasive plant species and feral ungulates are thought to cause high levels of erosion in this watershed, making the Kaiaka Bay watershed a good example watershed for the procedure (AECOM et al., 2018). The GIS data inputs for the InVEST model must all be in the same projected coordinate reference system, so every GIS data input is in the NAD83 coordinate reference system. The data inputs used for running the model with current conditions are below:

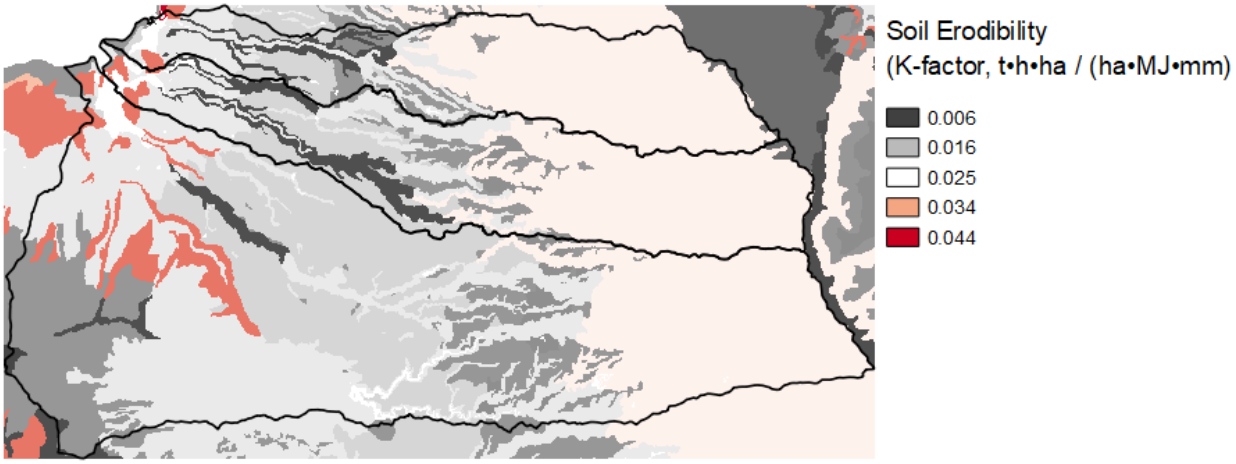
- Elevation Map: A DEM raster showing elevation in meters in the Kaiaka Bay and the surrounding area. This raster is a valid input for the InVEST model because the elevation is in meters and it extends beyond the Kaiaka Bay watershed boundary.



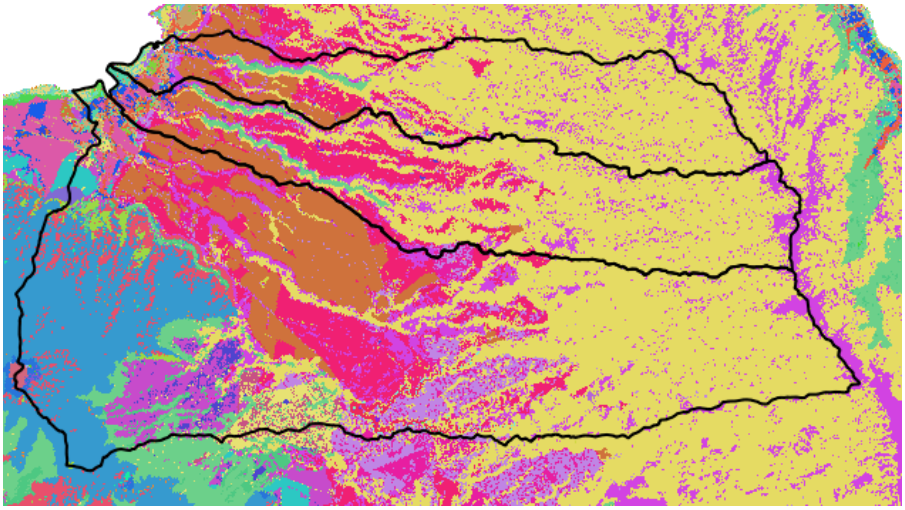
- Rainfall Erosivity: A rainfall erosivity map in raster format showing the rainfall erosivity throughout the Kaiaka Bay watershed in MJ • mm/(h • ha • year), the units required by the model.



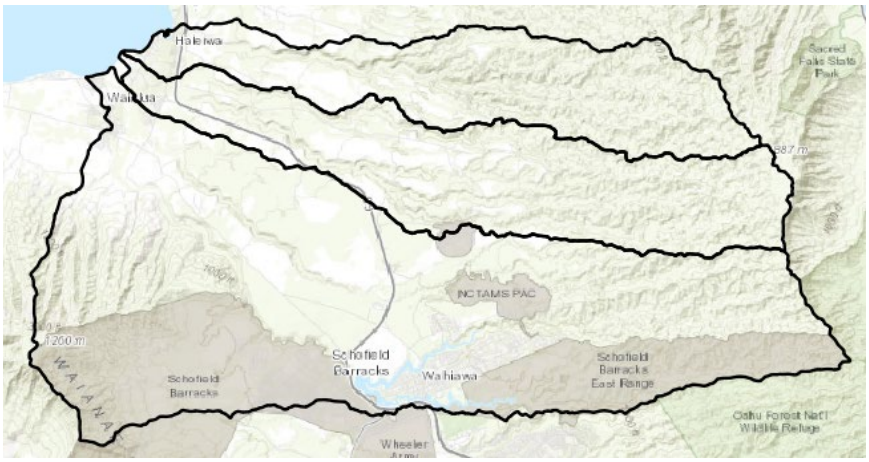
- Soil Erodibility: A map showing soil erodibility, or K factors, within the Kaiaka Bay watershed in raster format. The values in the raster format are in the proper units for the model, t • h • ha / (ha • MJ • mm).



- Land Use & Land Cover and Geologic Formation: A raster categorizing the land in Kaiaka Bay watershed by their land use/land cover and their geologic formation. This raster has over 1000 land cover/geologic formation categories, but not all categories have pixels that belong to them. Each land cover/geologic formation category has a unique LULC code so that this raster can be connected to the biophysical table.



- Watershed boundary: A vector outlining the Kaiaka Bay watershed.



- Threshold Flow Accumulation: 200. Value was derived through trial and error, and was identified when the delineated stream network approximately matched the "real" stream network for the watershed.

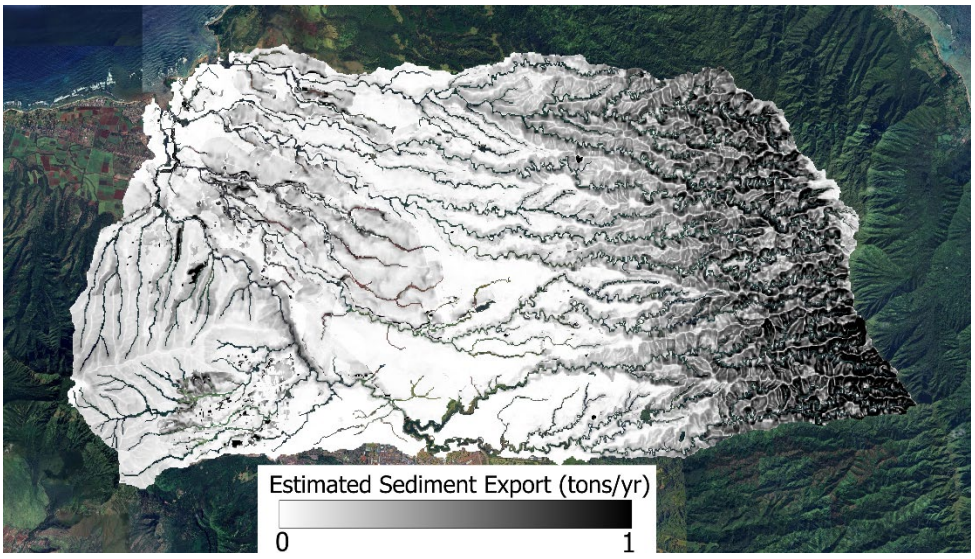
- Borselli k Parameter: The Borselli k parameter for this model run is 2.5, the value for all watersheds on Oahu.

- Maximum SDR Value: The maximum SDR value for this model run is 0.5, the value for all watersheds on the state of Hawaii.

- Maximum L Value: The maximum L value for this model run is 122, the value for all watersheds on the state of Hawaii.

- Biophysical Table: The biophysical table for this model run contains a column with each LULC code from the land use and land cover raster. Each LULC code is mapped to a modified C factor that is the original C factor from Table 4 multiplied by the terrain factor from Table 5 or the geologic origin associated with the LULC code. For example, a small piece of land in the Kaiaka Bay watershed is scrub shrub land (C factor = 0.014) with beach deposits as its geologic formation (terrain factor = 0.1), so the modified C factor in the biophysical table is 0.0014. The P factor for every LULC code is 1 because no support practices have been implemented in this watershed.

Once the inputs have been gathered, the baseline scenario is run. The model outputs suggest that a disproportionate amount of sediment export is occurring in the mountainous area of the Kaiaka Bay watershed. The sediment export raster is shown below:



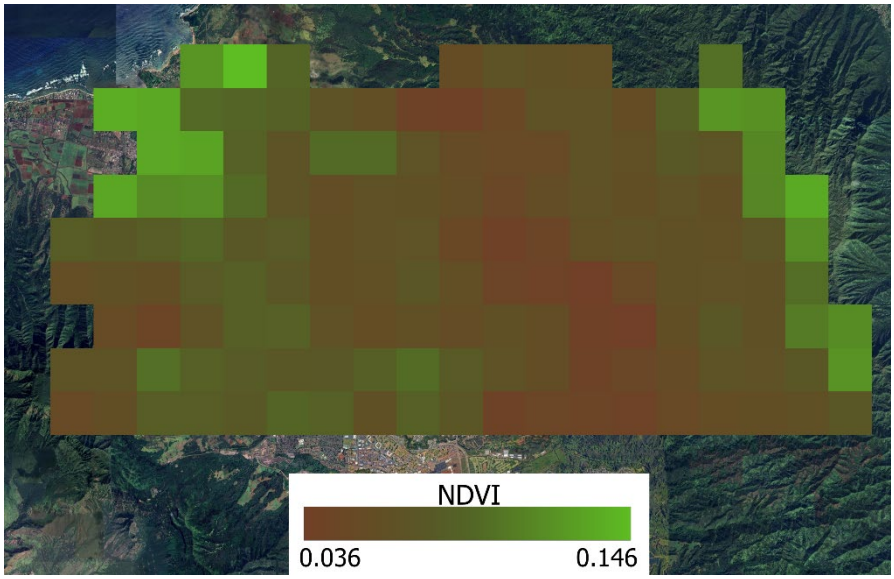
This raster indicates that the model expects the highest amount of sediment export to occur at the higher elevations of the watershed, but as discussed in the Step-by-Step Procedure section, the InVEST model tends to overestimate sediment export in high elevation areas. For this reason, multiple lines of evidence are considered when deciding on the locations for BMP implementation in this example. To determine the land class/land uses that contribute the most to sediment export relative to their area in the watershed, the pounds of sediment exported per acre is important evidence to evaluate as well. This value is calculated by adding the sediment export for every pixel in each land use/land cover and then dividing this sum by the acres each land use covers in the watershed. For example, bare land covers 405 acres of land in the Kaiaka Bay watershed and the model estimates that 1790.5 pounds of sediment are exported from bare land each year, so the pounds of sediment load per acre per year for bare land is 1790.5 divided by 405 which is 4.42. The sediment load per acre for each land use is shown in Table 6.

Table 6. Pounds of Sediment Load Per Acre Per Year by Land Use

Class	Edge of Stream Sediment Load (lbs/acre/year)
Developed, High Intensity	0.00
Developed, Med Intensity	0.00
Developed, Low Intensity	0.00
Developed, Open Space	0.11
Cultivated Crops	1.08
Pasture/Hay	0.26
Grassland/Herbaceous	0.44
Evergreen Forest	1.37
Scrub/Shrub	0.90
Palustrine Emergent Wetland	0.01
Palustrine Forested Wetland	0.01
Palustrine Scrub/Shrub Wetland	0.01
Estuarine Forested Wetland	0.03
Estuarine Scrub/Shrub Wetland	0.23

Class	Edge of Stream Sediment Load (lbs/acre/year)
Unconsolidated Shore	0.00
Bare Land	4.42
Open Water	0

This table indicates that bare land areas contribute the most sediment per acre in the Kaiaka Bay watershed, so bare land within the watershed may be a beneficial target for BMP implementation. Planting native plant species could minimize the sediment load coming from areas that are currently bare land by transforming it into vegetative cover (or evergreen forest in terms of land cover classes). Currently, bare land covers 405 acres of the watershed and the sediment export from this land is 1790.5 pounds. To calculate the amount of sediment load from this land after BMP implementation, assuming all the bare land becomes evergreen forest, the acres of bare land should be multiplied by the sediment load per acre for evergreen forest. This returns a value of 554.85 pounds of sediment load per year from this land, a 1235.65 pound decrease. These calculations should be considered when selecting locations for BMP implementation, but additional evidence should be evaluated as well. As discussed in the Step-by-Step Procedure section, NDVI data can be useful evidence as well. The NDVI data in raster format for the Kaiaka Bay is below:



The pixels with a lower NDVI index, which are shown in darker brown, are less vegetated areas. This image indicates that the middle section of the Kaiaka Bay watershed is less vegetated, so BMP implementation could be especially valuable in this area. However, the resolution of this raster data is low, so it is difficult to use it to precisely choose locations for BMP implementation. Therefore, other evidence such as high-resolution satellite images and drone footage can be used to pinpoint areas with minimal or invasive vegetation. As an additional line of evidence, people familiar with the Kaiaka Bay watershed can be interviewed to collect information on areas with minimal vegetation, invasive plants and/or feral ungulates. Furthermore, a person can walk along streams in the Kaiaka Bay watershed and document the most eroded areas. The information gathered from the InVEST model run, the NDVI index raster, satellite images, drone footage, interviews and documentation from someone on site should all be carefully considered when determining where BMPs should be implemented.

Useful Resources and Materials

To supplement the information included in this addendum, more information on the InVEST model and using this model in the state of Hawaii is linked below:

- More information on the InVEST sediment ratio delivery model including background information, required data inputs, and guidance on interpreting outputs is here: SDR: Sediment Delivery Ratio — InVEST® documentation
- More information on the InVEST DelineateIt tool discussed in the Step-by-Step Procedure to create watershed boundaries: DelineateIt — InVEST® documentation
- Further details on the Kaiaka Bay watershed: Kaiaka Bay Watersheds Characterization
- For more information on running the InVEST model for watersheds in Hawaii, including the rationale for many of the non-GIS inputs see Predicting Sediment Export into Tropical Coastal Ecosystems to Support Ridge to Reef Management [dissertation], available for download here: (PDF) PREDICTING SEDIMENT EXPORT INTO TROPICAL COASTAL ECOSYSTEMS TO SUPPORT RIDGE TO REEF MANAGEMENT

References

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