

Estimating Pollutant Load Reductions Resulting from Control and Removal of Invasive Plant and Animal Species and Establishment of Native Species (August 2025)

Introduction

This guidance document has been developed by the Hawaii Department of Health (HDOH) Surface Water Protection Branch (SWPB) to support watershed management efforts by addressing additional considerations related to the removal of invasive plant and animal species, as well as the reintroduction of native species. In addition to describing these activities, this guidance identifies them as potential best management practices (BMPs) that may be eligible for Clean Water Act Section 319 funding when incorporated into an approved watershed-based plan or acceptable alternative plan, as appropriate. It also 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 Nonpoint Source (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 guidance 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 species¹ 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 A-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 A-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 hooved mammals to reduce erosion caused by trampling and vegetation removal, as well as nutrient and bacterial impacts from defecation in and around water bodies.

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 guidance 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 guidance 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.

³ <https://efotg.sc.egov.usda.gov/#/state/HI/documents>

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 guidance describes each of these required inputs in further detail along with recommended values and sources for GIS data inputs.

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 A-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 A-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): $R = 0.5 \times P \times 17.02$, where R is the rainfall erosivity value in the proper SI units and P is the annual rainfall in mm/year.

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/>

<p>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 transported downstream by precipitation or runoff. The soil erodibility raster must be in units of $t \cdot h \cdot ha / (ha \cdot MJ \cdot mm)$.</p>	<p>Raster</p>	<p>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 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.</p>
<p>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.</p>	<p>Raster</p>	<p>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.</p> <p>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.</p>
<p>Watersheds: A map of the boundary of the watershed.</p>	<p>Vector (polygon/multipolygon)</p>	<p>The USGS Watershed Boundary Dataset has vector watershed delineation data available at different hydrologic unit levels for the entire state of Hawaii.¹²</p> <p>The Hawaii Statewide GIS Program has vector watershed delineation data available that was created by the Division of Aquatic Resources (DAR).¹³</p> <p>The InVEST suite includes the DelineateIt 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 DelineateIt section of the InVEST suite.¹⁴</p>

⁹ <https://www.nrcs.usda.gov/resources/data-and-reports/soil-survey-geographic-database-ssurgo>

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>

		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
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 A-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 IC₀ 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 A-4 multiplied by the terrain factor	.CSV file	Table A-4 shows the C factors for land use/land covers in Hawaii, and Table A-5 shows the terrain factor by geologic origin.

¹⁵ <https://www.usgs.gov/streamstats>

<p>from Table A-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.</p>		
<p>Workspace: The folder where outputs will be written.</p>	<p>Folder name</p>	<p>--</p>

Table A-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 A-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 A-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	--	--

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)

Maui, Molokai, Lanai and Kahoolawe		All Islands	
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

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.

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 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:

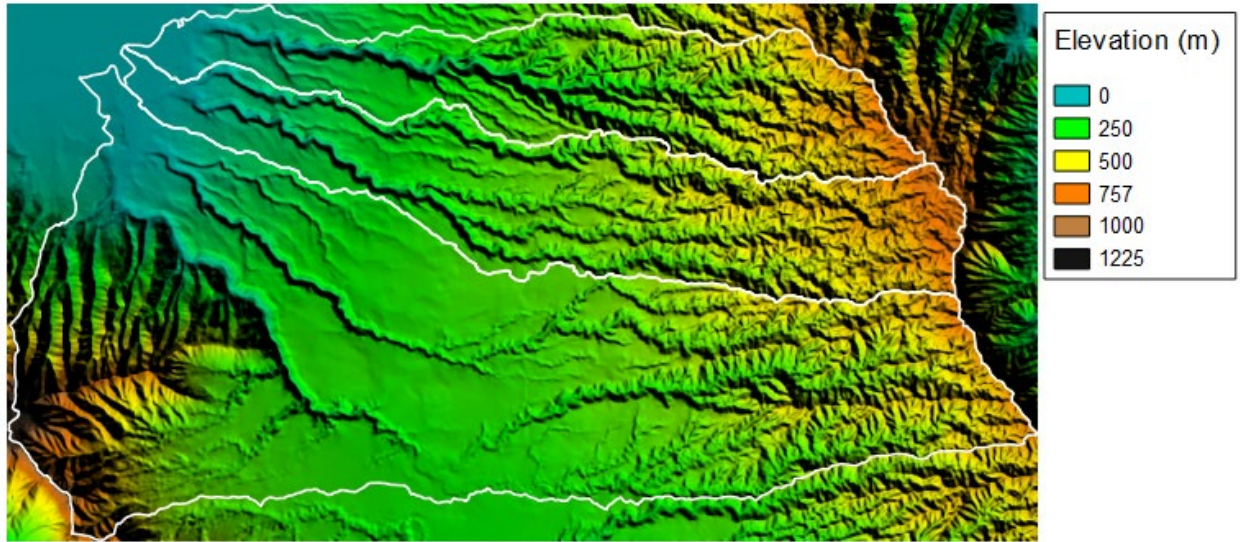
- The P factors in the biophysical table should be decreased for each land use/land cover type where an erosion reduction practice will be implemented.
- Alternatively, the land cover/land use raster should be edited to show how the land use/land cover would change with erosion reduction practices implemented. 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.

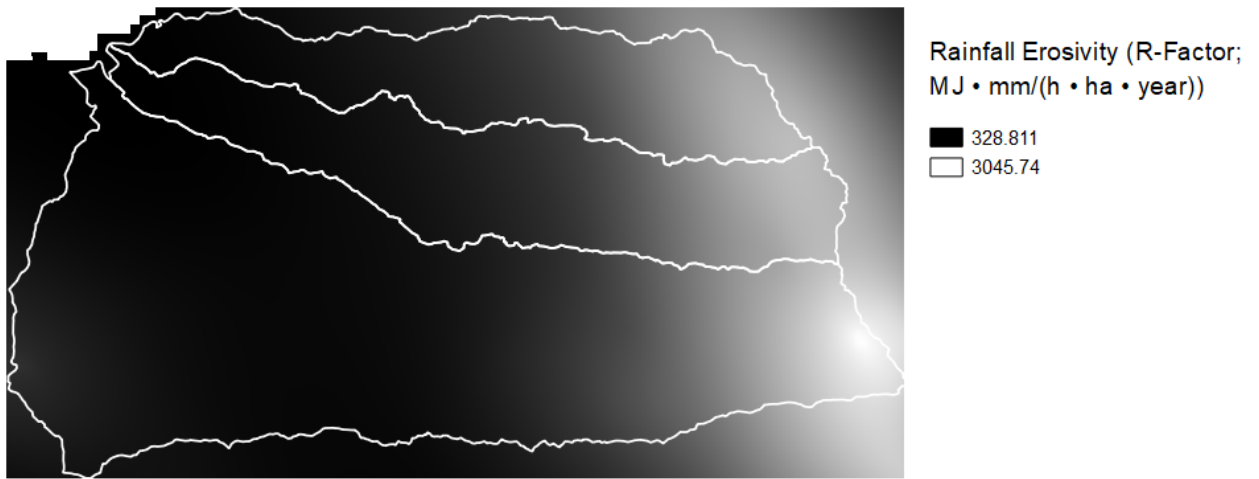
Example Use of the Procedure

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:

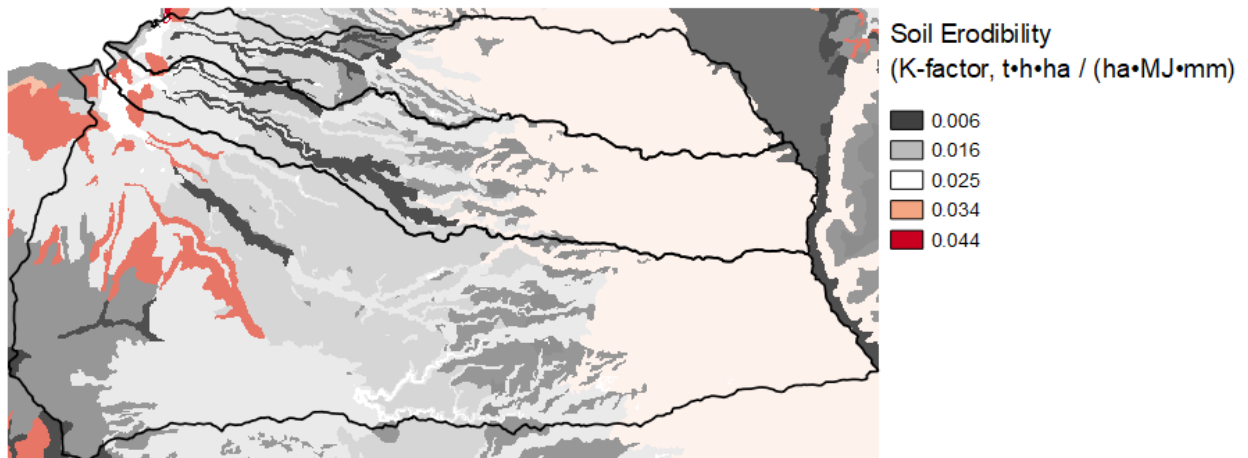
- Elevation Map: A DEM raster showing elevation in meters in the Kaiaka Bay and the surrounding area. This raster is a valid input for the InVEST model because the elevation is in meters and it extends beyond the Kaiaka Bay watershed boundary.



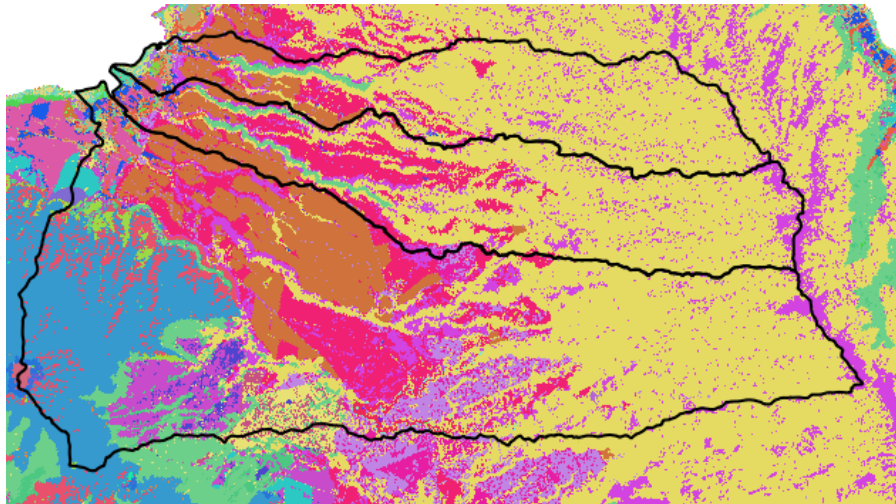
- **Rainfall Erosivity:** A rainfall erosivity map in raster format showing the rainfall erosivity throughout the Kaiaka Bay watershed in $\text{MJ} \cdot \text{mm}/(\text{h} \cdot \text{ha} \cdot \text{year})$, the units required by the model.



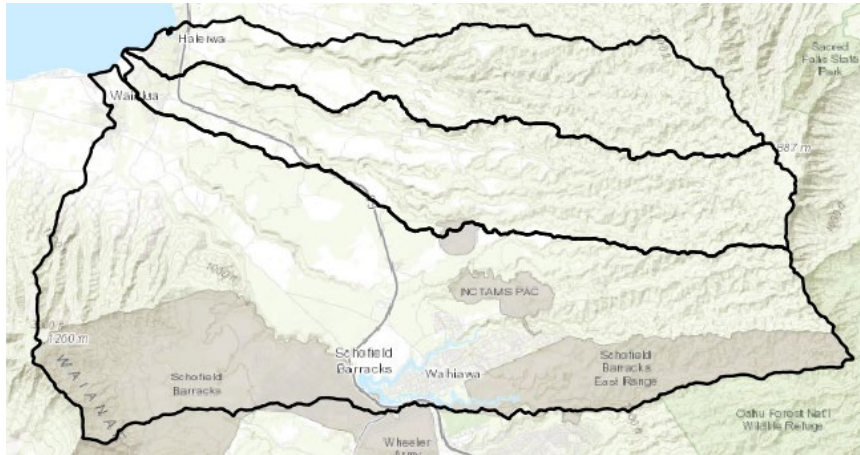
- **Soil Erodibility:** A map showing soil erodibility, or K factors, within the Kaiaka Bay watershed in raster format. The values in the raster format are in the proper units for the model, $\text{t} \cdot \text{h} \cdot \text{ha} / (\text{ha} \cdot \text{MJ} \cdot \text{mm})$.



- 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.

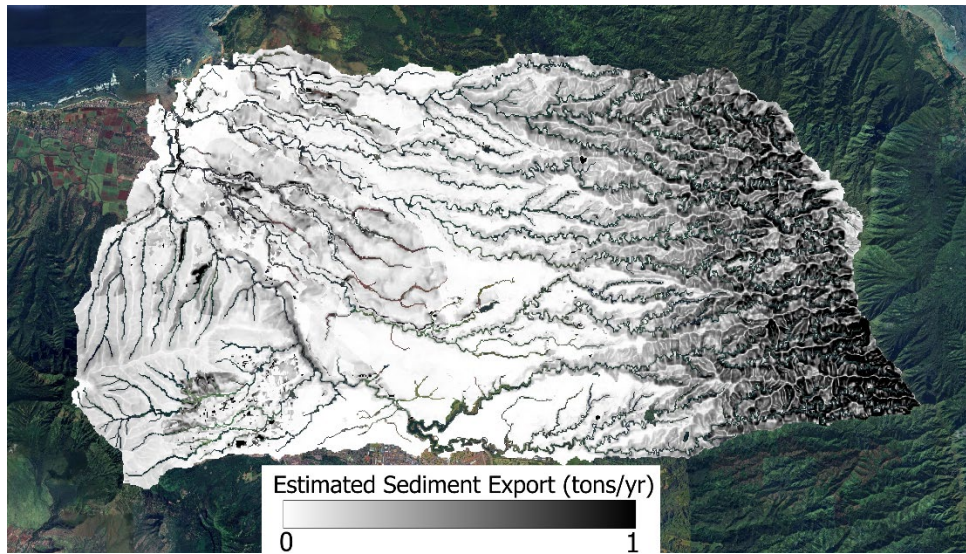


- Watershed boundary: A vector outlining the Kaiaka Bay watershed.



- 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 A-4 multiplied by the terrain factor from Table A-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:



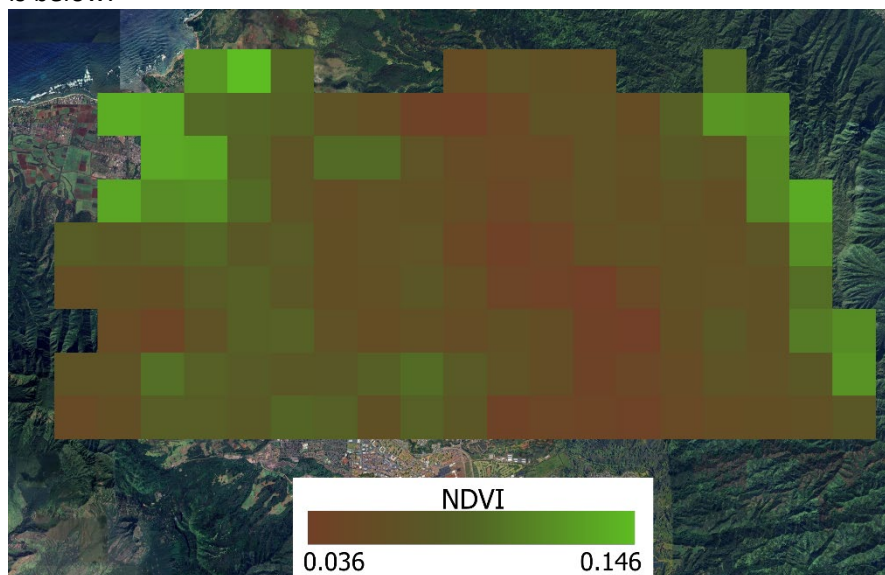
This raster indicates that the model expects the highest amount of sediment export to occur at the higher elevations of the watershed, but as discussed in the Step-by-Step Procedure section, the InVEST model tends to overestimate sediment export in high elevation areas. For this reason, multiple lines 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 A-6.

Table A-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

Class	Edge of Stream Sediment Load (lbs/acre/year)
Estuarine Scrub/Shrub Wetland	0.23
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 guidance, 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](#)

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