KAIAKA BAY

WATERSHED-BASED PLAN

APPENDIX A:

GEOMORPHIC ASSESSMENT OF POAMOHO STREAM

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November 2016

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Geomorphic Assessment of Poamoho Stream

Kaiaka Bay Watershed-Based Plan
Oahu, Hawaii

Revised Final
November 2016

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1 INTRODUCTION

A geomorphic assessment of Poamoho Stream was conducted in order to better understand the current state of the natural function of the stream and watershed as well as determine the potential direction of the health of the system. The watersheds in the study area include: Opaeula, Kiikii, Paukauila, Kaukonahua, Helemano, and Poamoho. The watershed map provided in Figure 1-1 illustrates the spatial relationship of the study area. The lower watersheds Kiikii and Paukauila are developed and generally just convey flows from the upper watersheds to the Pacific. A Total Maximum Daily Load (TMDL) study (DOH, 2009) was conducted for the upper Kaukonahua watershed and includes information for the majority of the watershed. The Opaeula, Helemano, and Poamoho have similar hydrologic and hydraulic characteristics. For this assessment it is assumed that Poamoho Stream is representative of the watersheds that collectively discharge to the Kaiaka Bay.

The Kaukonahua watershed was included in the GIS analysis for this geomorphic assessment, but due to the Wahiawa Reservoir and the Waianae Mountains, the geomorphic issues related to the Kaukonahua watershed are somewhat different (DOH, 2009).

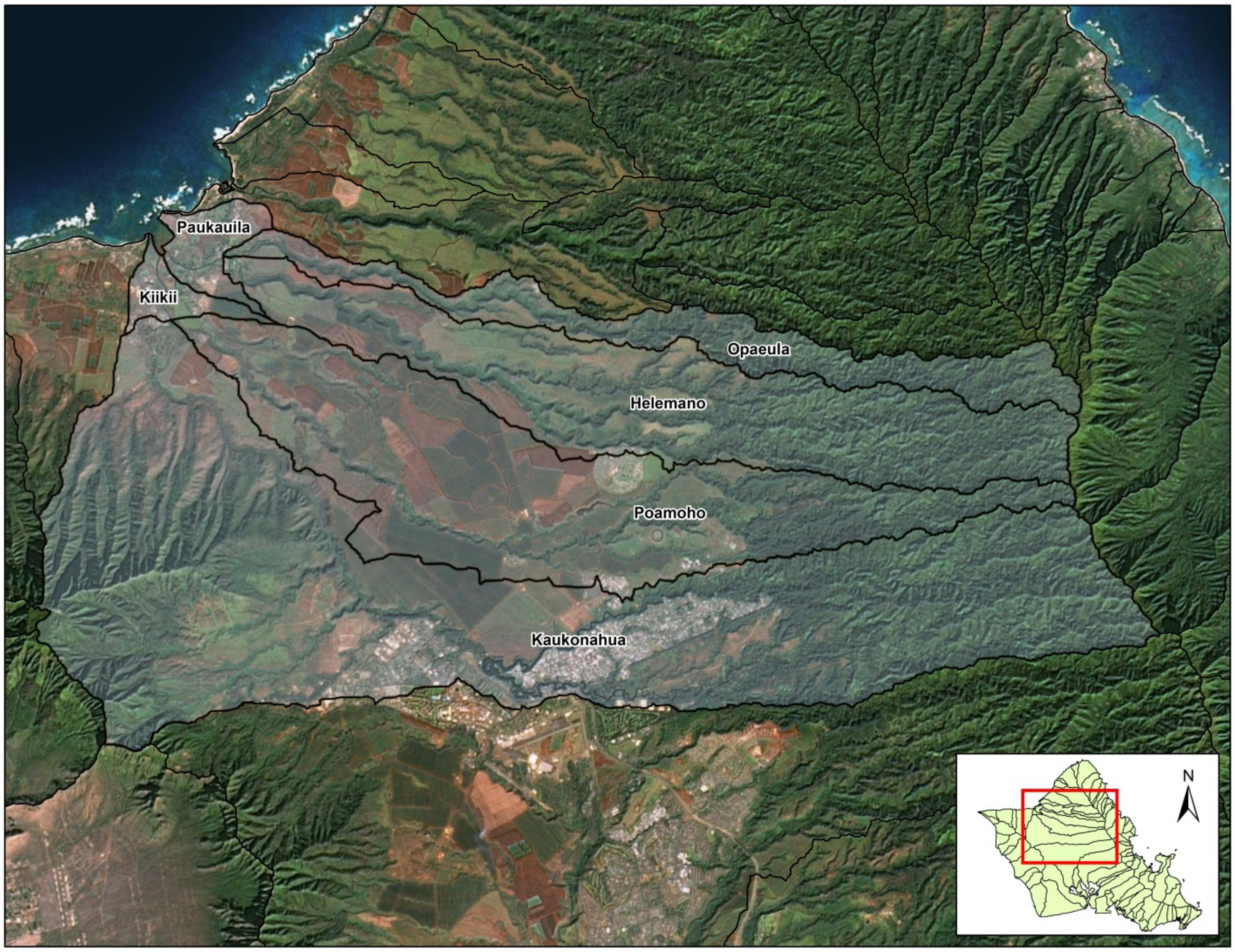


Figure 1-1 Kaiaka Bay Study Area

1.1 Watershed and Stream Health

In order to understand the interaction between the streams and the land within the study area, it is important to understand the natural dynamics of a stream system. All stream systems exist in a state of “dynamic equilibrium,” which refers to a system’s ability to maintain a generally consistent balance related to a set of characteristics. Lane (1955) defined this balance in a river system as a relationship between sediment load, sediment size, stream slope, and discharge (Figure 1-2). Any change in one of these parameters will result in a natural adjustment in one or more of the other parameters to balance out the system. If the adjustment is not made, the result will be either degradation or aggradation of the river.

For the streams within the study area, events of mass wasting and landslides can abruptly alter the volume and size of sediment entering the system. As the sediment from these slides work through the stream, the system adjusts to allow the increased material load to be transported to the ocean. The ability of the stream to transport the material being delivered from upstream can be described by its capacity and competency.

Competency is a measurement of a stream’s ability to transport the largest particle delivered from upstream while capacity is a measurement of the total volume or load of sediment that can be carried by the stream. Capacity can be evaluated based on a channel’s unit stream power while competency can be measured based on its shear stress. When the size and/or load of material delivered from the watershed exceeds the channel’s current capacity and competency, the channel will seek equilibrium by increasing its shear stress and unit stream power which it does by adjusting its hydraulic geometry. These adjustments are accomplished through phenomenon such as avulsion to increase the slope and aggradation of the floodplain to increase the channel depth.

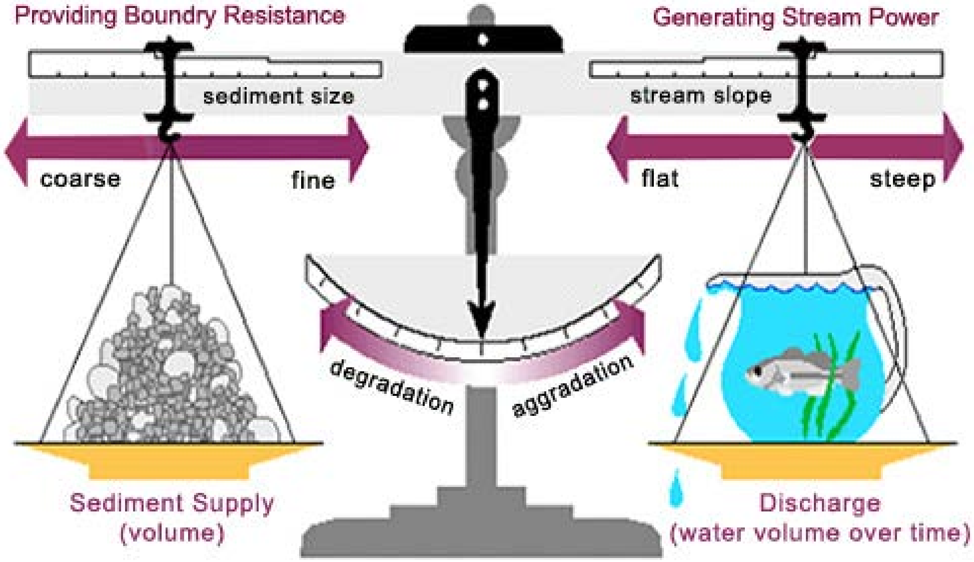


Figure 1-2 Lane’s Dynamic Equilibrium Diagram

1.2 Watershed Health

Degradation of watershed health may result due to a range of natural and human activities. Any change within a healthy watershed may alter the historic and natural functions that shaped and developed the stream system. Collectively the impact of human activities within a watershed may alter the natural watershed attributes that formed the elements critical to the health of the watershed and stream. A watershed characterization and geomorphic assessment is used to evaluate watershed health stressors, how the watershed will respond to the stressors and to identify the indicators of watershed health. Figure 1-3 provides the three processes that are important for the watershed characterization and geomorphic assessment: stressors, response, and key indicators.

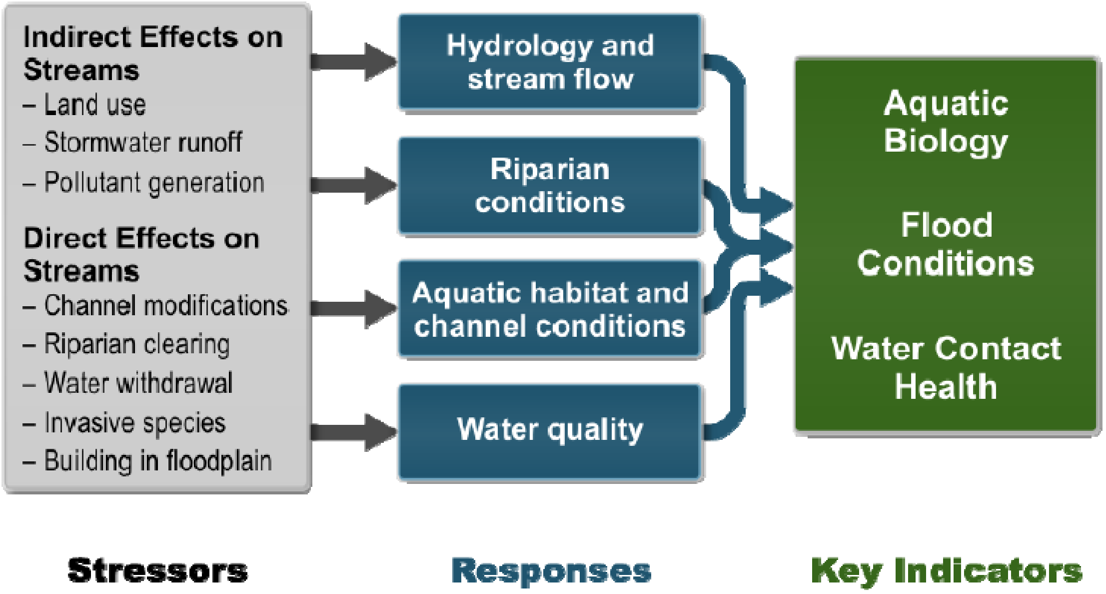


Figure 1-3 Watershed Characterization and Assessment Process (Booth et al., 2005)

Stressors can be described as activities that change the physical nature of the land within a watershed and are defined as Indirect or Direct.

- Indirect – Land use changes, storm water runoff, pollution generation.
- Direct – Channel modification (hydromodification), riparian loss, water use, invasive species, and floodplain encroachment.

Responses are best described as the watershed health constituents affected by the stressors. The responses impact both the watershed hydrology and habitat, both riparian and terrestrial.

- Hydrology – Changes in peak flows and flood frequency, baseflow, and storm water runoff volume.
- Habitat – Changes in riparian condition and stream channel condition affect aquatic and terrestrial habitat, increase in pollutants entering the waterways directly affects aquatic and terrestrial species.

Key Indicators are the signals of watershed health and they focus on geomorphic conditions, flooding impacts, and the presence of aquatic and terrestrial species.

To better address and identify the stressors, responses and key indicators of watershed health two approaches were incorporated into the Poamoho Stream geomorphic assessment: a desktop analysis and a field investigation. Both approaches are necessary for developing watershed wide understanding of connection between historic and current conditions that impact the natural function of the fluvial system.

Figure 1-4 illustrates how the elements of the geomorphic assessment are connected to the natural functions of the healthy watershed.

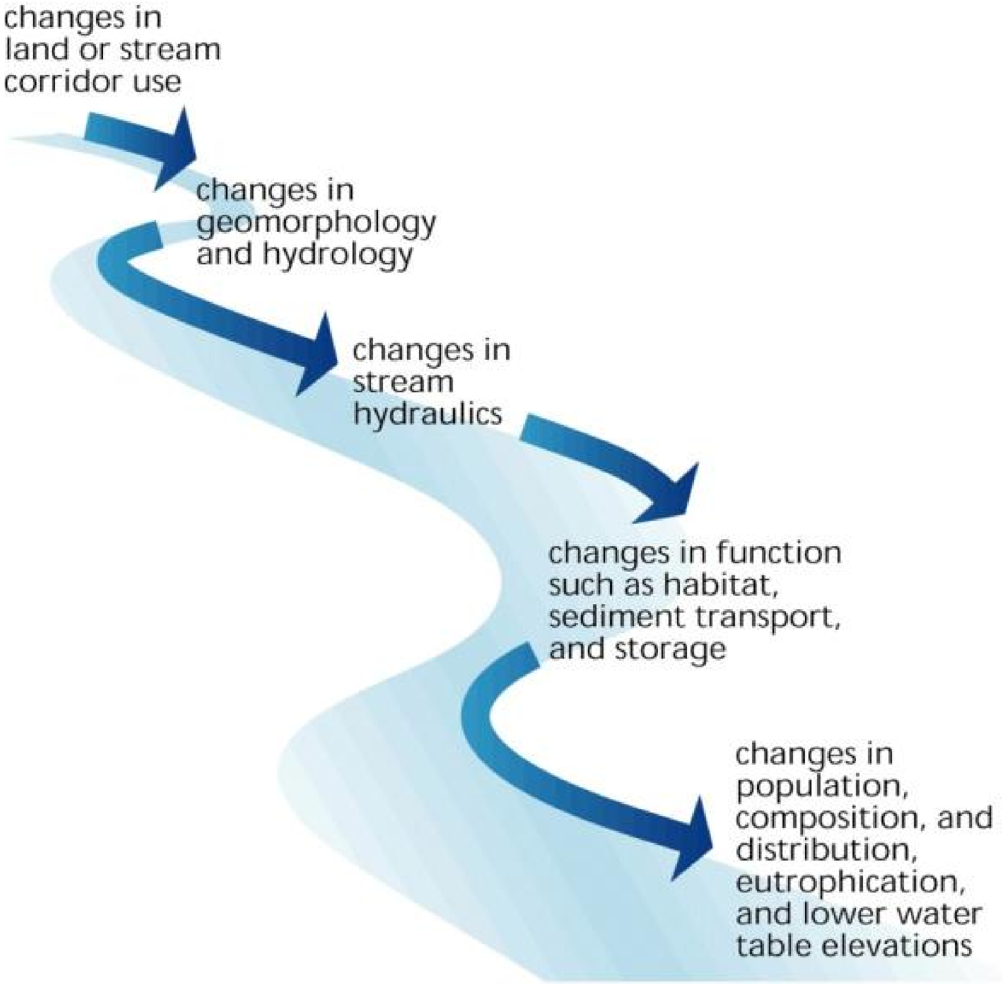


Figure 1-4 Watershed Health Connectivity

The desktop approach allows for the assessment of large scale spatial information as well and tabular time series data. Information used in the Poamoho Stream project included:

- Precipitation
- Stream Flow
- Soils
- Land Use – Land Cover
- Vegetation
- Stream Slopes
- Watershed Slopes
- Height Above River

The field investigation serves two purposes, it potentially allows for sight verification of the desktop information but more importantly it provides detailed site specific information that may impact the natural healthy function of the project area watershed. The Poamoho Stream field investigation attempted to document:

- Stream Flow and Water Clarity
- Streambed Material
- Source Material
- Streambanks
- Channel Planform and Characteristics
- Agricultural Land Use

The following sections provide a discussion of the data used in the desktop analysis as well as a summary of the field investigation.

2 DESKTOP WATERSHED ANALYSIS

The initial phase of the geomorphic assessment of the Kaiaka study area was conducted using datasets including Geographic Information Systems (GIS) and recorded gaged data. The data used and presented in this section are intended to present information that impacts the geomorphic character of the watersheds.

2.1 Precipitation and Stream Flow

Rainfall and resulting runoff and stream flow are considered to be the drivers of the interaction between water and the land surface. Rainfall is the only input source for creating natural flows in the streams. Understanding the volume and intensity of precipitation and the resulting flows are important for understanding stream functions related to sediment transport.

Figure 2-1 provides a graphic representation of annual average precipitation within the study area. The upper extents of the watersheds within the Koolau Mountains receive the greatest volume of precipitation at over 200-inches per year. As the mountain slopes reach the Oahu plain, the precipitation is reduced to 50-inches or less.

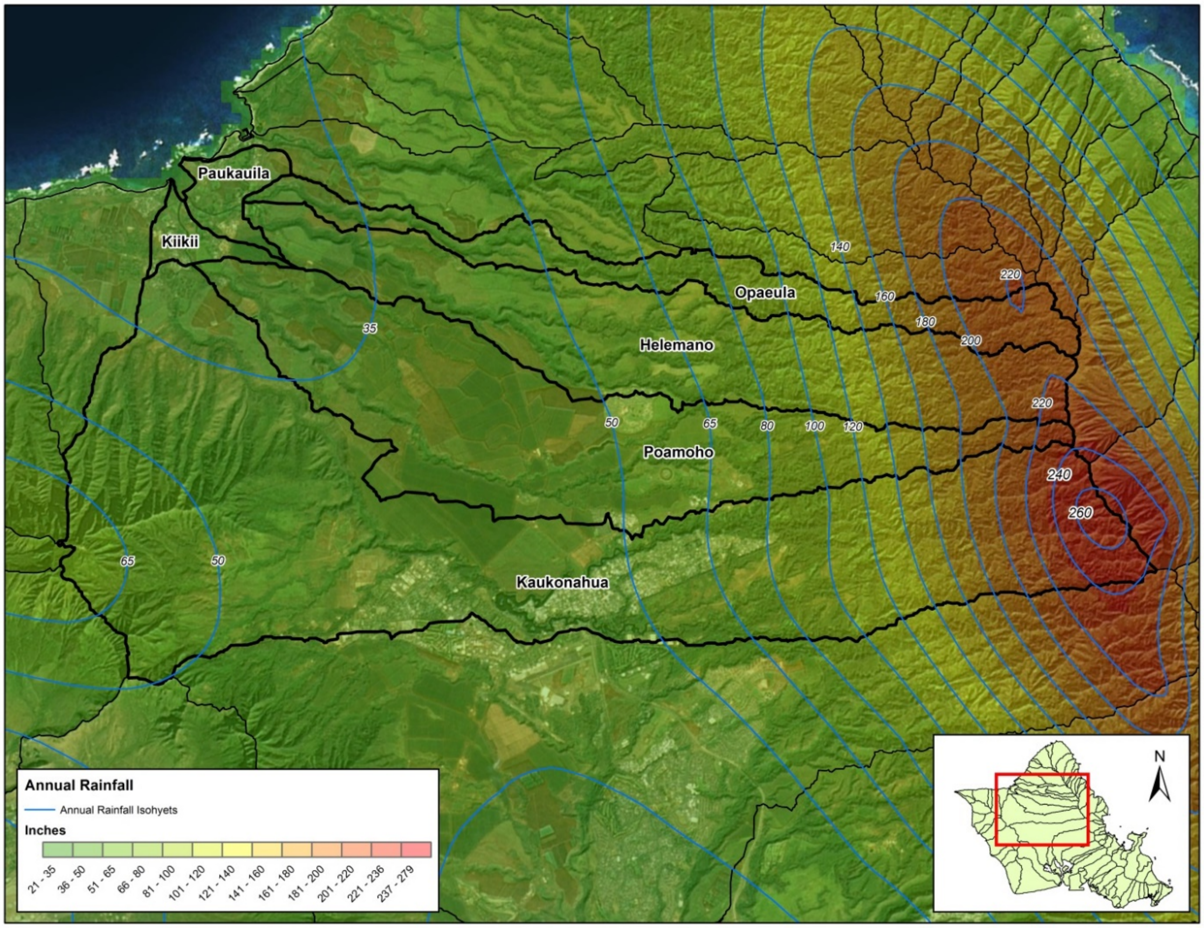


Figure 2-1 Average Annual Precipitation

Based on the average annual precipitation data, the total volume of precipitation interacting with each watershed was estimated. The mean volumes shown in Table 2-1 are based on the watershed area and the mean precipitation value.

Table 2-1 Annual Precipitation for the Kaiaka Study Area Watersheds

Watershed	Basin Area (acres)	Min (in)	Max (in)	Mean (in)	Mean Volume (ac-ft)
Helemano	9,353	31	226	91	70,927
Kaukonahua	25,159	31	279	77	161,437
Kiikii	592	31	32	31	1,529
Opaeula	3,810	31	220	109	34,607
Paukauila	866	31	33	31	2,237
Poamoho	11,675	30	235	59	57,402

If no losses of precipitation were experienced, the total volume of precipitation would be converted to runoff and stream flow. Looking at recorded stream flow in the study area will provide a better understanding of how much of the precipitation is lost to groundwater recharge, evapotranspiration, and diversions and therefore not available for stream flow.

Recorded stream flow gages are typically operated and maintained by the United States Geological Survey (USGS). For the Kaiaka study area the number of stream flow gages are limited. Table 2-2 lists the gages with available data. As the period of record indicates, none of the gages are currently operational and collecting data. Of the data collected, only two gages provided daily flow records. It is likely the “Peak Only” gages are located on ephemeral stream reaches with only storm related flows.

Table 2-2 Available Kaiaka Study Area USGS Stream Flow Gages

USGS Stream Gage	Drainage Area (mi^2)	Period of Record	Flow Records
16343000 Helemano Stream at Haleiwa	14.4	1967 – 1982	Daily and Peak
16211200 Poamoho Stream at Waialua	12.7	1967 - 2003	Peaks only
16350000 Opaeula Stream near Haleiwa	5.9	1956 - 2004	Peaks Only
16345000 Opaeula Stream near Wahiawa	3.0	1959 - 2003	Daily and Peak
16211000 Poamoho Stream near Wahiawa	1.8	1947 - 1974	Peaks Only
16340000 Anahulu River near Haleiwa	13.9	1958 - 2003	Peaks Only

Using the USGS StreamStat Web site, the estimated peaks flows associated with various recurrence intervals were found.

Table 2-3 lists the published peak flows. The StreamStat page did not provide estimated storm peaks for the other gages although they could be estimated using established methods. The larger storms are rare events and typically do not have a great deal of impact on stream morphology from one year to the next. The smaller storms such as the 2-year or smaller which occur on a more regular basis tend to be responsible for maintaining the geomorphic character of the watershed and riparian area.

Table 2-3 USGS Estimated Peak Flows

USGS Gage	Recurrence Interval				
	2-Year	5-Year	10-Year	25-Year	100-Year
16343000	3,990	9,490	14,500	22,500	37,400
16350000	1,510	2,920	4,070	5,770	8,730
16345000	1,950	2,980	3,690	4,600	6,000
16340000	2,570	4,630	6,460	9,410	12,100

Another important aspect of stream flow is the amount of time a flow occurs in a stream. Because of the small, steep watersheds found in Hawaii as well as high rainfall intensity, Hawaiian streams tend to be flashy in nature with high flows only lasting over a short period. Duration curves are used to illustrate the percentage of time flows are exceeded within a stream and therefore the amount of time energy is available to impact the watershed health. Using the daily flow data from the Helemano gage, the USGS established the duration curve shown in Figure 2-2. For the Helemano Stream duration curve 10percent of the time flow at the recording gage is going to be greater than 14 cubic feet per second (cfs), with flows of 215 cfs being exceeded only 1percent of the water year (Oct 1 through Sept 30). Based on the duration curve in Figure 2-2, the Helemano Stream at the gage site is ephemeral with no flows approximately 60 percent of the time.

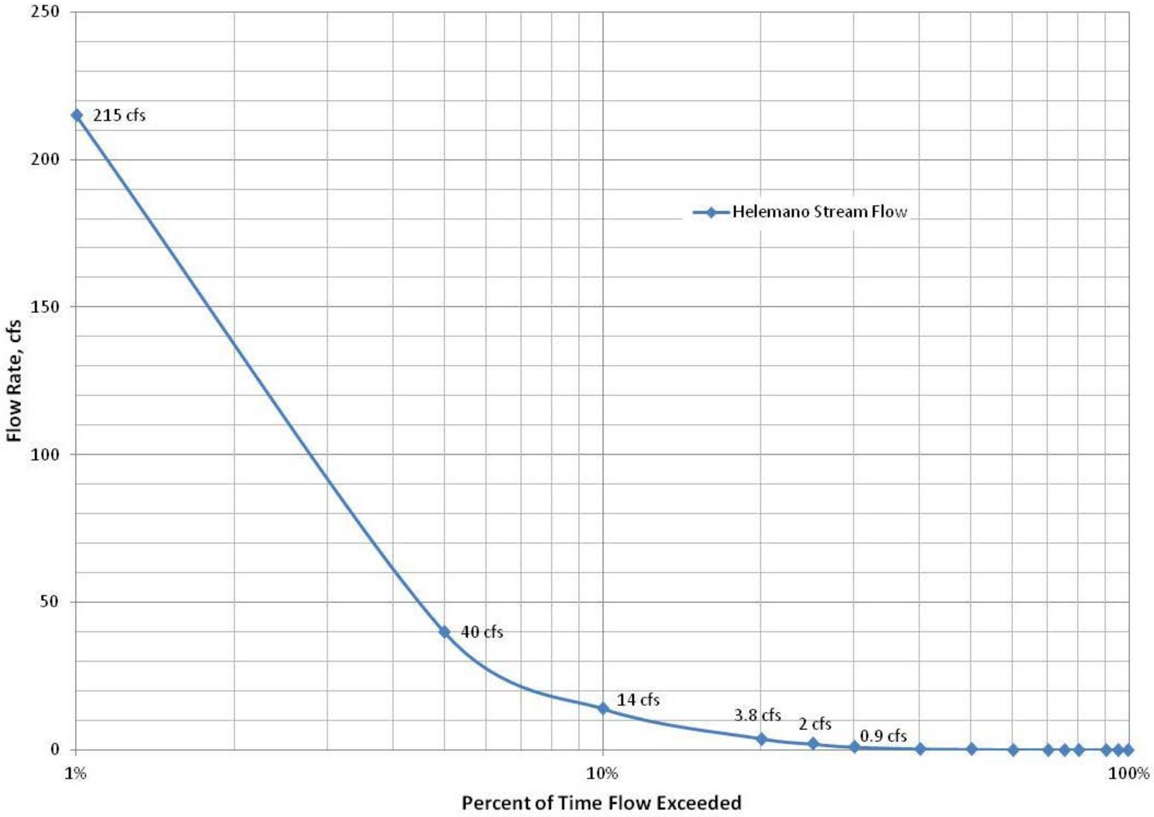


Figure 2-2 Helemano Stream Duration Curve

Using the Helemano Stream gage (Table 2-2) a comparison between the mean average volume of precipitation (Table 2-1) and the mean volume of recorded flow was conducted. Based on the gage data, the USGS estimated the overall annual average daily flow is 12.44 cfs. Extending the average daily flow over the entire year results in an annual flow volume of 9,000 acre-feet. This value is approximately 13 percent of the total precipitation. A similar estimate was completed for the Opaeula Stream gage (16345000) resulting in flows equaling approximately 30 percent of the precipitation.

The losses accounted for between the precipitation total and stream flows include: evapotranspiration, groundwater recharge, and diversions. Evapotranspiration is the volume of water transpired plants as well as evaporation volumes from the soils. Groundwater recharge is the volume of water that infiltrates and contributes to groundwater reserves. Agricultural practices on Oahu have historically included interbasin water transfers using tunnels and siphons to divert water from one stream to another. Many of the diversions are still used to supply water while many are still active but not maintained. Within the Kaiaka study area diversions impact the stream flow character of the system by removing and storing most base flows in off-line reservoirs. During large storms the capacity of the diversion is relatively small compared to the flood flows so the resulting peaks are not significantly impacted.

2.2 Soils

The soils of the Hawaiian Islands are composed of weathered remnant basaltic lava flows. The soils in the Kaiaka study area range from various silty clays in the lower elevations to rocky mountainous lands in the steep upper slopes. Within the watershed context, soil characteristics such as infiltration rate and water holding capacity help determine the fate of precipitation.

Figure 2-3 illustrates the distribution of soils found in the study area. Wahiawa silty clay dominates the agricultural landscapes and rough mountainous land in the upper regions. Within the stream channels, Helemano silty clay and Rock land dominate the lower reaches, while the upper streams maintain the same Rough mountainous land classification as the adjacent land area.

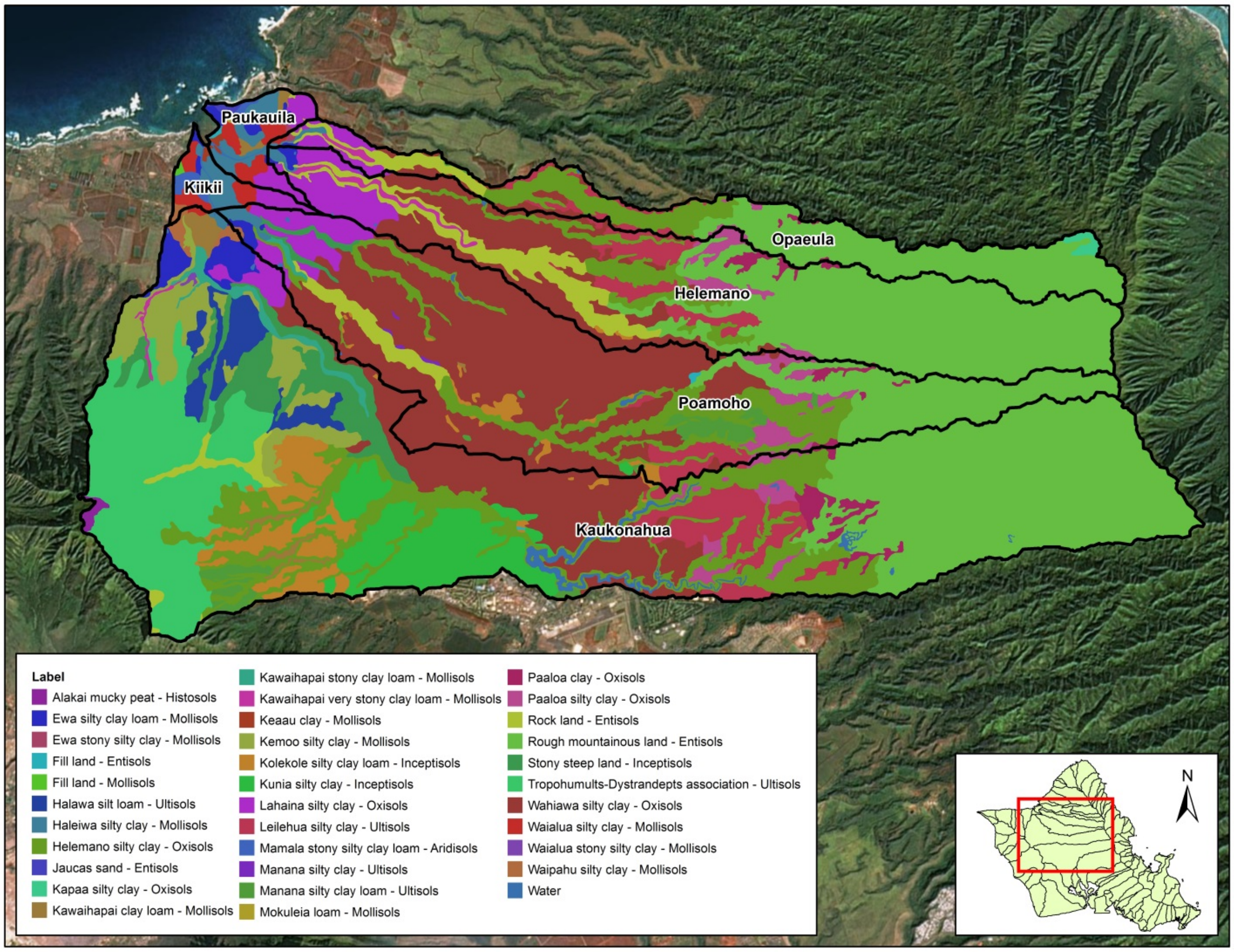


Figure 2-3 Soil Types within the Kaiaka Study Area

The soil characteristics shown in Table 2-4 suggest the majority of the soils in the study area are not easily eroded due to precipitation. The high infiltration rates of the three dominant soils mean generally that precipitation intensity would need to exceed the infiltration rate for runoff to occur. The K Factor designates a soils susceptibility to sheet and rill erosion cause by overland water flow. The range for the K Factor is 0.02 to 0.69, with higher values indicating greater erosion potential. The low K Factor values for the three dominant soils in the study area suggests that sheet and rill erosion are not likely a significant factor in the overall loading of sediment to the streams.

Table 2-4 Properties of Major Soils in the Kaiaka Study Area

Soil Name	Infiltration (Saturated) (in/hr)	K Factor
Helemano	2.5	0.17
Wahiawa	1.0	0.15
Rough mountainous land	3.0	0.20

Soil order (Figure 2-4) is another parameter that helps describe the nature of a soil. For the Kaiaka study area, the dominant soil orders are Entisol in the upper regions and stream canyons and Oxisols in the agricultural areas.

- Entisols – Typically the presence of Entisols mean the soil has not been in-place long enough for horizons to develop.
- Oxisols – Weathered material low in fertility, most common on gentle slopes of geologically old surfaces in tropical and subtropical regions. Like entisols the soil order lacks developed horizons. The clay particles form an aggregate structure allowing for rapid permeability.

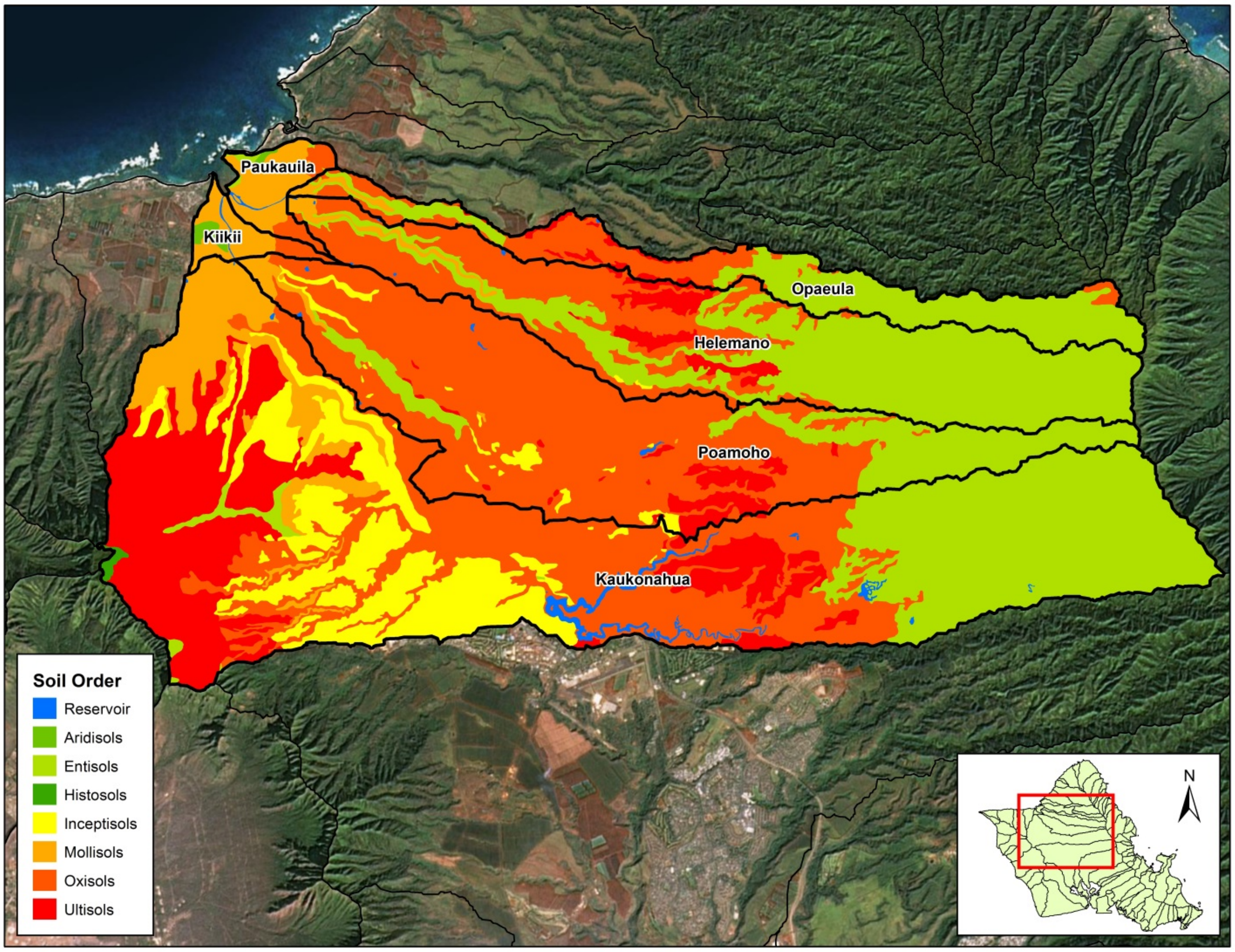


Figure 2-4 Soil Order within the Kaiaka Study Area

The hydrologic characteristics of the dominant soils as well as the understanding of the soil order suggests that typical rainfall events do not create conditions leading to surface erosion from sheet and rill erosion. The soils are described as having relatively high infiltration rates compared to typical rainfall intensity.

2.3 Land Cover and Land Use

How the land surface is used and the types of vegetation covering it impact the fate of precipitation by altering the ground cover, surface infiltration, and water use. Using data from the Coastal Change

Analysis Program (CCAP, 2015), Figure 2-5 illustrates the 2011 land use and land cover within the Kaiaka study area. Table 2-5 tabulates the total area for each of the land uses for each of the watersheds.

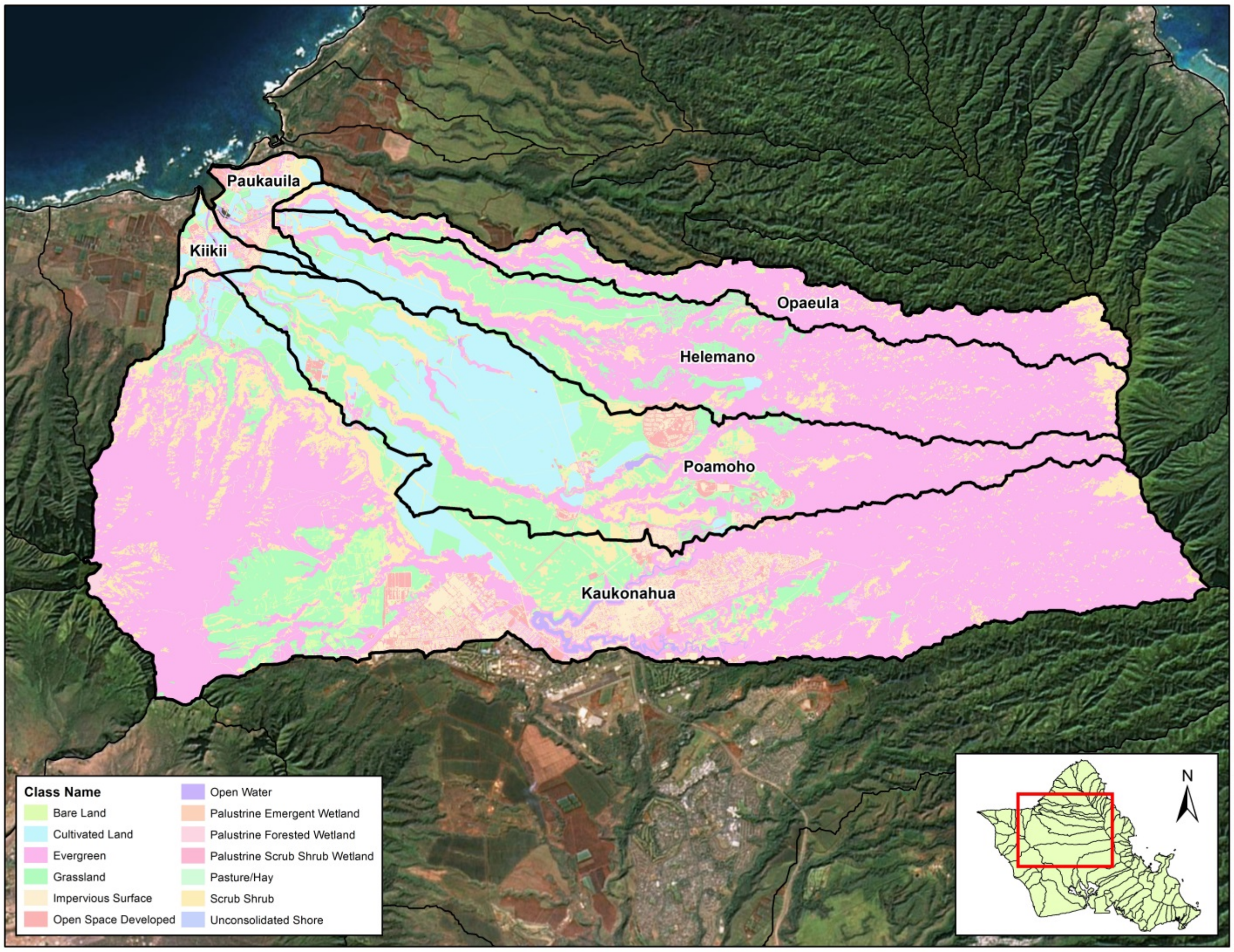


Figure 2-5 Land Use and Land Cover with the Kaiaka Study Area

Based on the 2011 data, 55 percent of the total area is consider forested, with cultivated crops representing the next largest land use at 15 percent. Within the study watershed only 3.5 percent is considered developed or impervious. The lack of impervious surfaces in the watershed translates to a hydrologically healthy watershed where precipitation is allowed to infiltrate instead of runoff from paved surfaces.

Also provided in Table 2-5 is the 2005 land use acreage. Between 2005 and 2011 the greatest change in land use was a decrease in cultivated lands. The lost cultivated land appears to be mostly re-categorized as grasslands but it is more likely the land was just allowed to go fallow. Figure 2-6 highlights the areas where the land use designation was changed between 2005 and 2011. As indicated in the figure, the pineapple fields in the Poamoho watershed show the greatest density of land use change.

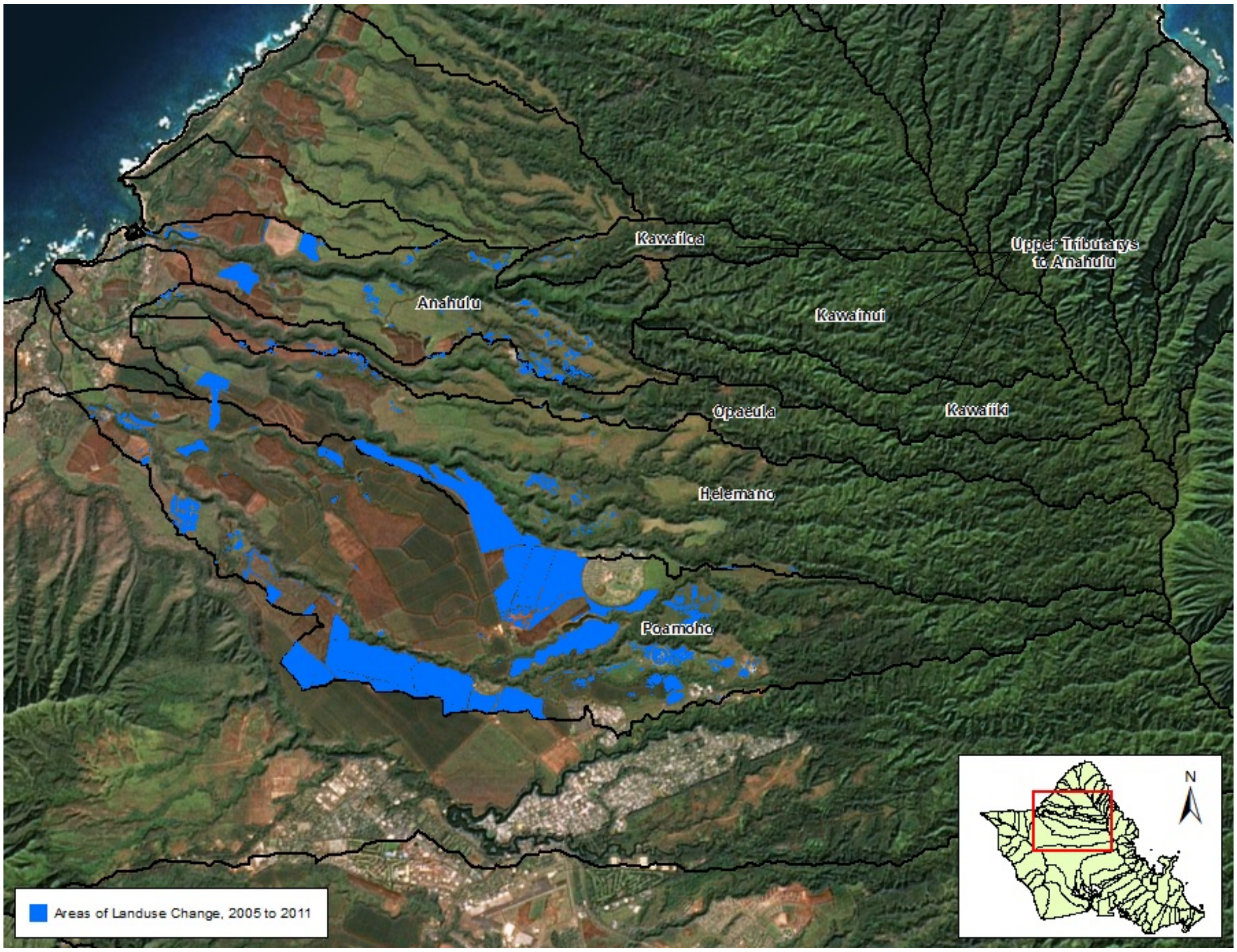


Figure 2-6 Limits of Land Use Designation Changes between 2005 and 2011.

Table 2-5 Distribution of Land Use with Kaiaka Study Area

C-CAP Land Use Designation	Land Use Acreage Based on C-CAP 2005 and 2011 Data												
	Helemano Stream		Kaukonahua Stream		Kiikii Stream		Opaeula Stream		Paukauila Stream		Poamoho Stream		Total Area
	2011	2005	2011	2005	2011	2005	2011	2005	2011	2005	2011	2005	
Bare Land	19.4	14.8	329.6	301.0	8.8	17.7	9.4	8.7	9.2	5.5	74.8	60.9	123.8
Cultivated Land	654.7	902.5	854.8	1974.8	220.2	221.9	182.4	183.0	220.8	245.4	3752.0	4859.3	5440.8
Estuarine Forested Wetland									6.1	6.1			
Estuarine Scrub Shrub Wetland					0.5	0.5			0.3	0.3			
Evergreen	5739.5	5697.5	14870.6	14908.7	60.8	62.6	2709.3	2696.1	122.6	125.4	3526.6	3457.5	19408.8
Grassland	1704.6	1533.1	3398.2	2566.2	54.8	49.3	283.6	316.1	85.2	106.2	2114.4	1322.3	4898.3
Impervious Surface	133.1	132.3	1793.5	1684.2	129.8	126.3	55.0	54.6	167.7	165.3	513.8	471.1	887.9
Open Space Developed	29.1	28.5	701.2	738.4	66.2	67.0	2.5	2.6	98.5	89.0	309.2	246.5	370.2
Open Water	3.4	2.4	214.8	215.4	12.5	13.1	2.8	2.8	17.5	18.3	35.4	32.3	61.5
Palustrine Emergent Wetland	8.2	7.9	10.4	8.9	8.6	8.6	0.1	0.1	32.0	32.4	8.5	10.6	22.1
Palustrine Forested Wetland			69.8	70.0									0.7
Palustrine Scrub Shrub Wetland	0.4	0.4	1.8	1.8	1.0	1.0			4.3	4.3	1.6	1.6	6.2
Pasture/Hay	3.0	3.0	0.0				2.1	0.1			0.7		5.8
Scrub Shrub	1056.7	1029.8	2923.3	2698.7	27.8	23.9	562.4	545.4	99.9	66.7	1333.7	1209.2	3990.8
Unconsolidated Shore	0.2	0.2			0.9	0.1			1.7	0.9	1.4	1.0	10.7
Grand Total	9352.4	9352.4	25168.1	25168.1	592.0	592.0	3809.5	3809.5	865.7	865.7	11672.3	11672.3	35227.6

2.4 Vegetation

Both natural and anthropogenic changes to the vegetation can provide evidence of watershed changes such a historic stream channels, access to shallow ground water sources, and land form changes. The Gap Analysis program (GAP) data shown in Figure 2-7 provides an estimate of the type of vegetation found throughout the Kaiaka study area. Areas designated as “Alien” vegetation are likely location where disturbances have occurred, either natural or anthropogenic. The large alien forest designation in the middle of the watersheds are likely due to man-made impacts such as deforestation from cattle grazing or clearing of land for natural resources. In the upper watersheds the alien vegetation designation is likely the result of landslide areas being revegetated with invasive species. The presence of alien vegetation throughout the study area indicates the land surfaces have been actively changing. The locations of alien vegetation may indicate the locations of historical sediment loads resulting from landslides.

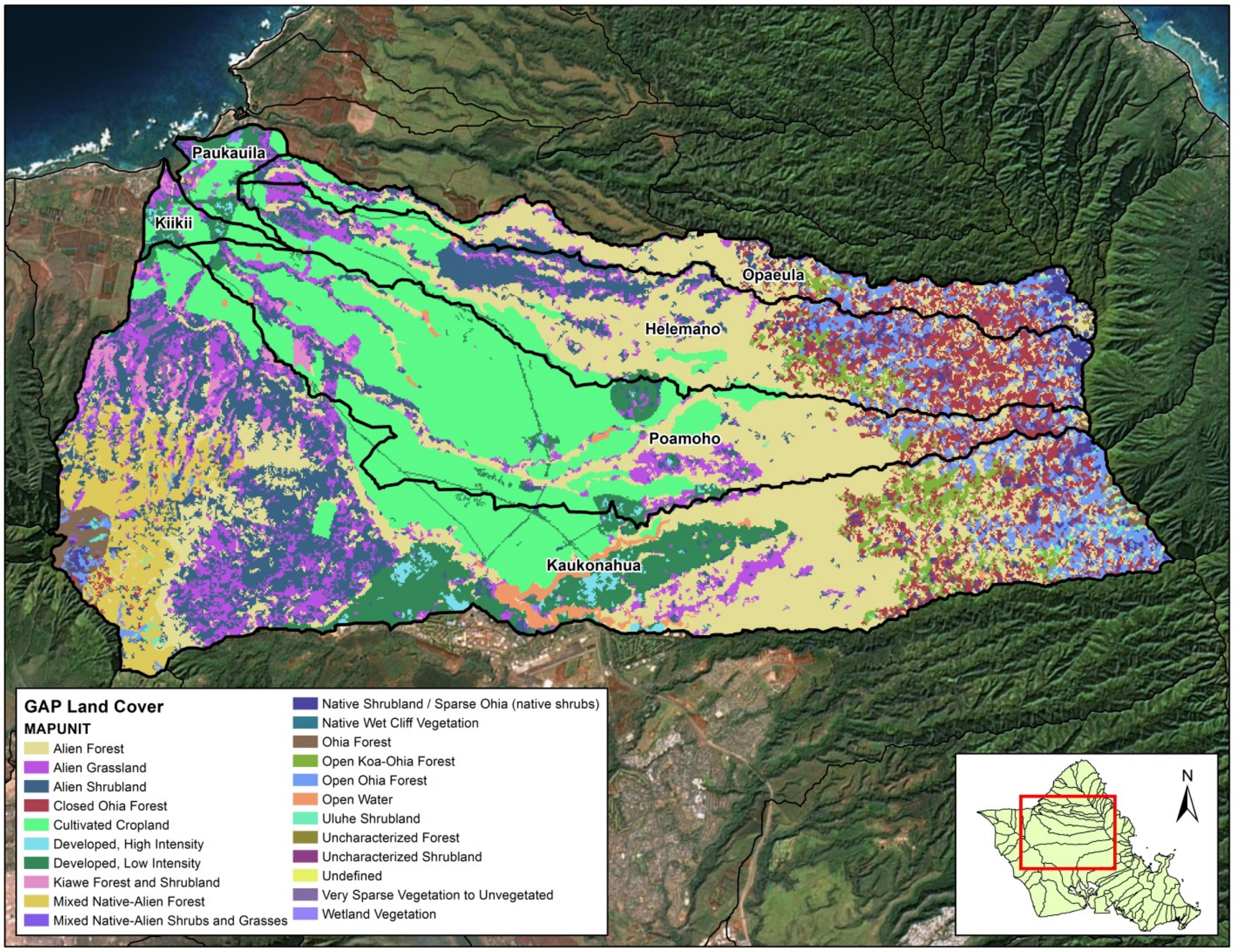


Figure 2-7 Vegetation Type Distribution in the Kaiaka Study Area

2.5 Watershed Slopes – Stream Slopes

Watershed slopes control the movement of surface water and sediment as both are controlled by the force of gravity. The steeper the land slope, the greater the chance of surface material mobilizing during rainfall event. Recent LiDAR data was used to map the land slopes within the Kaiaka study area. The LiDAR data was not available for upper elevations but did include at least some portion of the more confined reaches. Figure 2-8 shows the slopes for the Poamoho Stream. The highlighted portions provide greater detail to specific conditions found throughout the stream.

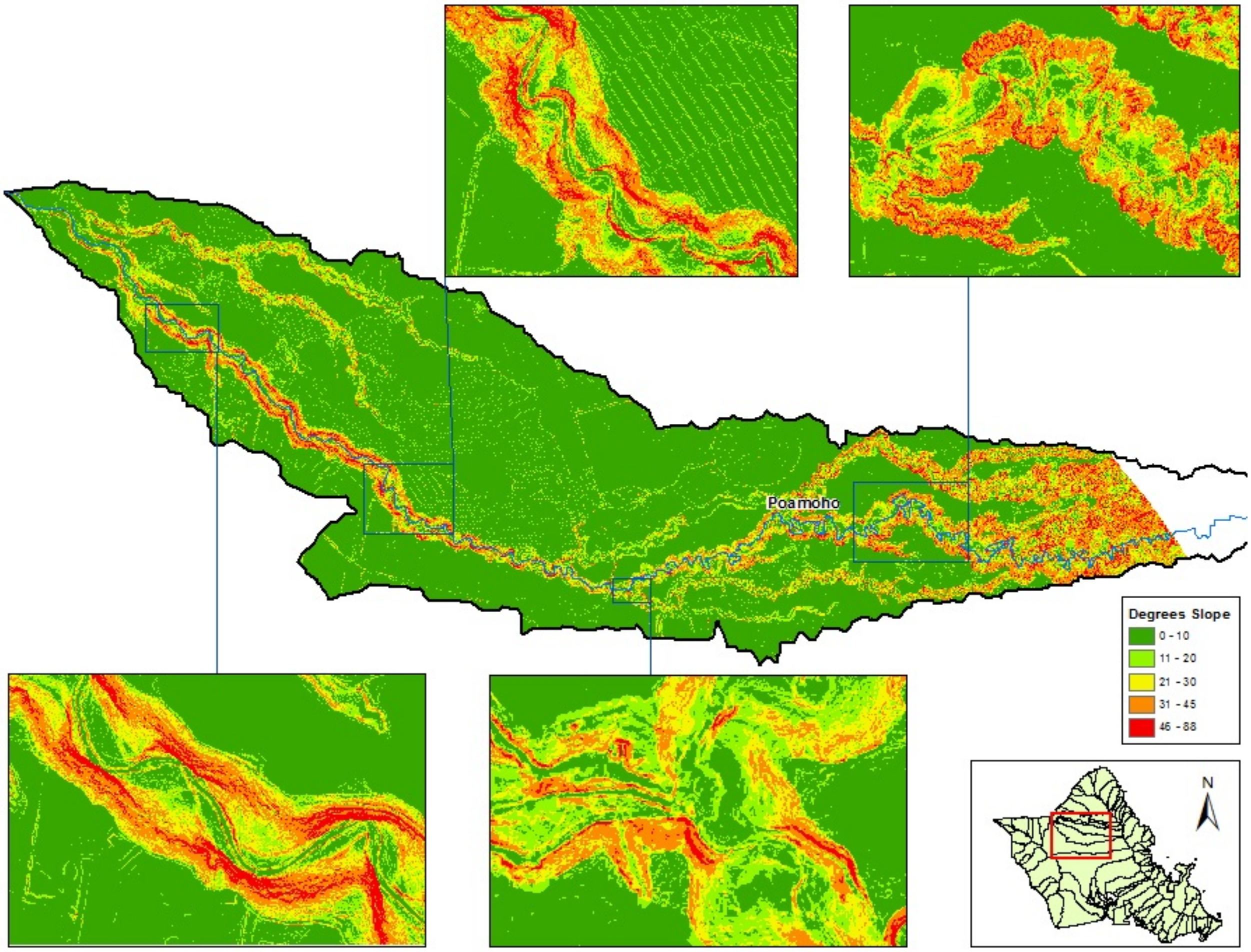


Figure 2-8 Representation of Land Slopes in Poamoho Stream

The slopes in the lower watershed show steep canyon walls with gentler slopes within the narrow valley. The current stream alignment shows that the energy of the stream is impacting the slopes of the canyon by removing the supporting alluvium deposited from slope failures. Where the stream is not flowing at the base of the canyon walls, support material from multiple slope failures has accumulated along their bases. As the channel alignment naturally migrates within the partially confined canyon, the stream energy will be directed towards stored sediment at the base of the slope.

In the upper Poamoho Stream watershed the entire terrain is mountainous with steep slopes leading directly into the stream channel. As no floodplains exist in the upper watershed this illustrates that there is no storage of transported material in the upper watershed and that all eroded sediment is transported downstream.

The LiDAR data was also used to estimate the slopes of the streams. This was completed by projecting the elevation of the terrain data on the centerline of the stream. The results of the process are shown in Figure 2-9. The length of the stream shown in the figure is based on the extent of the LiDAR coverage, not the actual stream length. The Anahulu Stream only had partial LiDAR coverage resulting in a short stream profile.

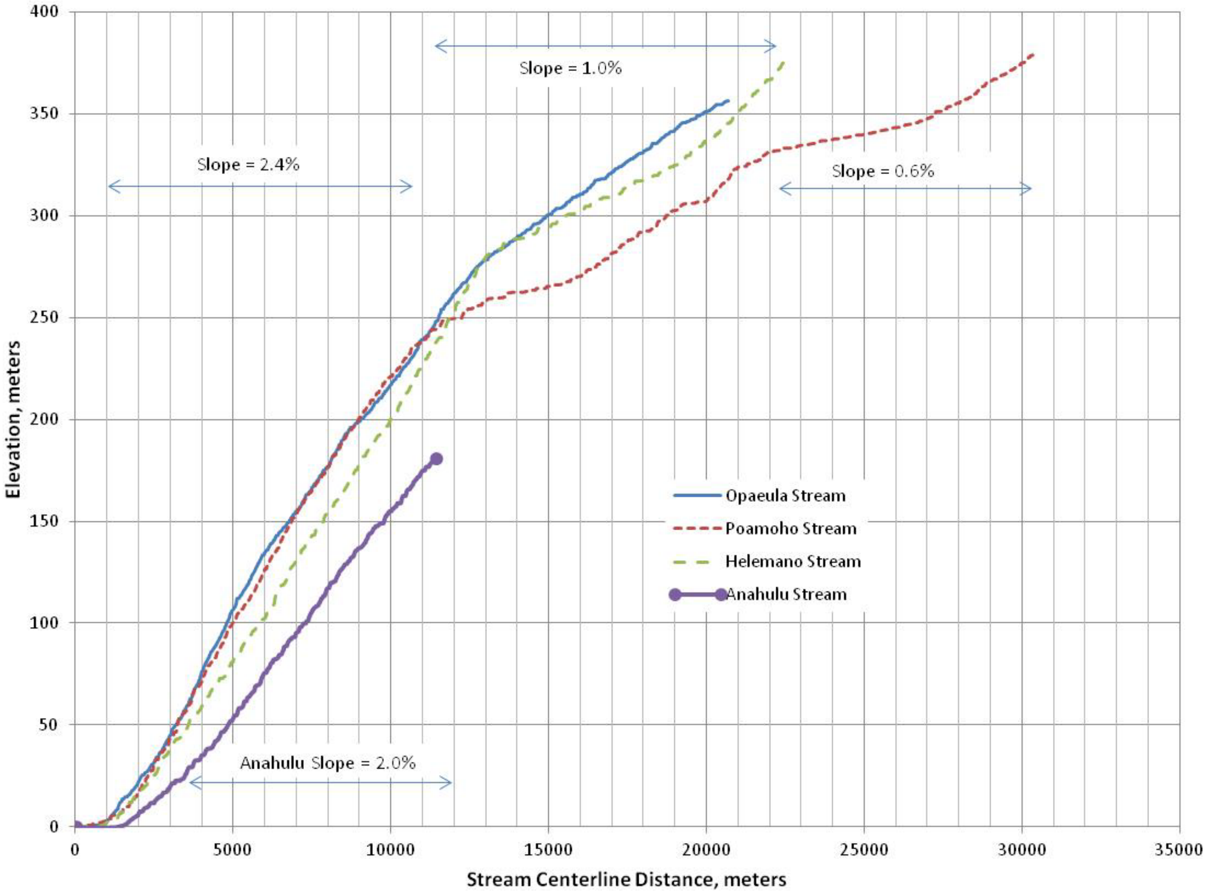


Figure 2-9 Comparison of Stream Channel Profiles

The lower 1,000 to 2,000 meters of the streams have very low slopes and are likely impacted by tidal elevations. Within the partially confined canyon reaches, the streams maintain a high slope likely to transport the larger cobble and boulder material that dominates within the reach. As the streams enter the confine upper reaches, the sediment size delivered to the stream from landslides is generally sand and gravel which requires less energy to transport so the stream can maintain a lower slope. Based on Lane's Balance (Figure 1-2) any changes to the size of the material transported by the streams or the associated flows would result in a change of slope. As all of the streams have generally the same stream profile it may be assumed the size and volume of sediment in each stream is similarly proportional to the volume of flows.

2.6 Height Above River

The height above river (HAR) analysis technique provides a tool for assessing the presence of floodplains as well as secondary and historic flow paths. HAR assigns the underlying LiDAR elevation onto the developed stream centerline. The process then assesses the adjacent elevation relative to the stream water surface elevation. Figure 2-10 illustrates the HAR results for Poamoho Stream. The presented HAR results are limited to elevations project to be 10-feet or less above the stream elevation. The results show Poamoho Stream has a somewhat confined area that will likely be inundated during high flow events. But the figure also reveals areas with secondary channels and broad floodplains.

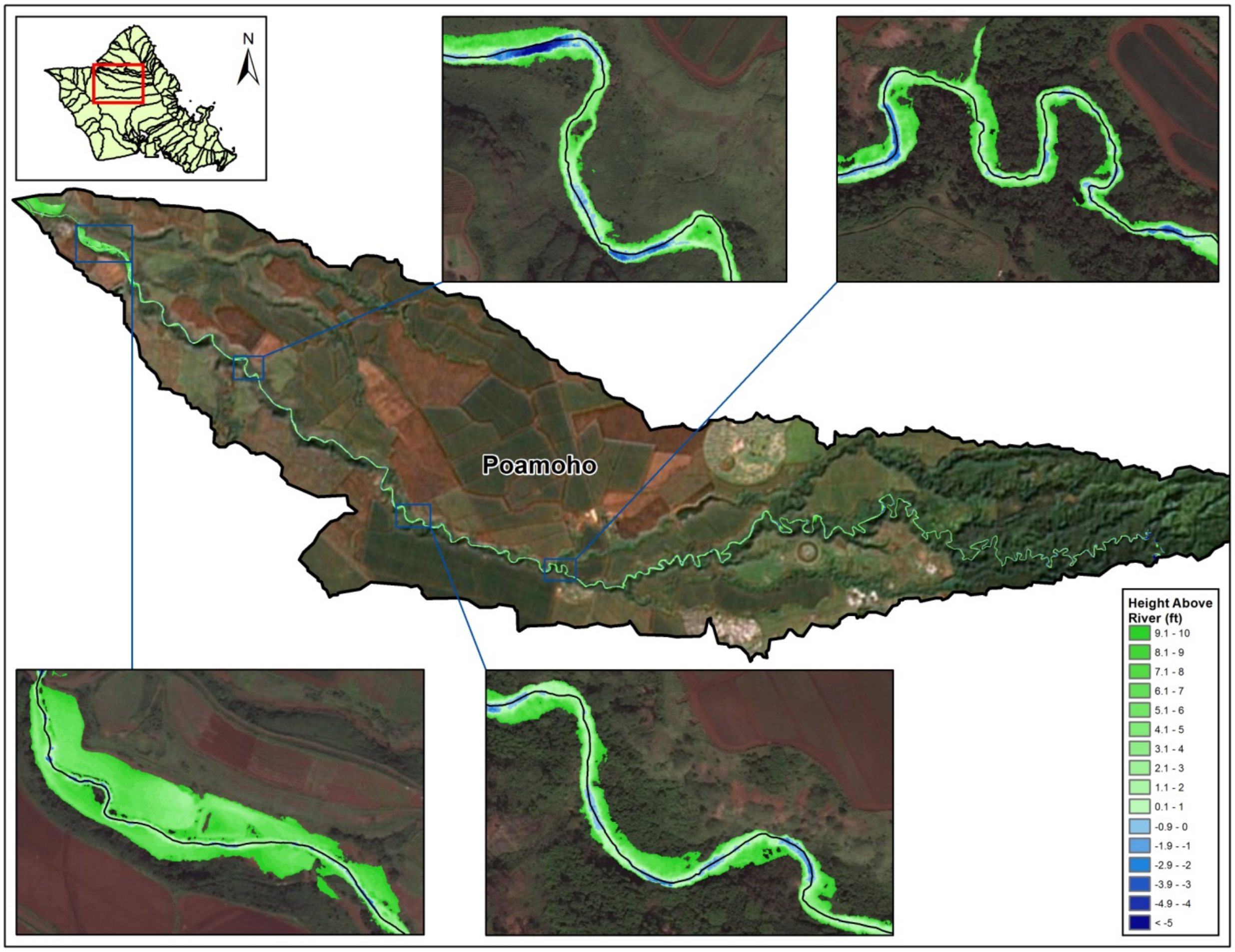


Figure 2-10 HAR Results for Poamoho Stream

The inset of the lower stream segment indicates the floodplain is very near the same elevation as the stream. The HAR also indicates the presence of push-up levees keeping high flows from entering the cultivated floodplain. The area protected by the push-up levees provides a good opportunity to restore natural floodplain function in the Poamoho Stream system.

3 FIELD INVESTIGATION

Poamoho Stream was selected to conduct two-day field investigation and data gathering effort on August 31 and September 1, 2015. Poamoho Stream was selected based on accessibility, Dole owns almost the entire watershed which allowed for the investigation to be continuous along the stream length. Also, Poamoho Stream is the largest of the four streams considered in the study area and provided a good variety of channel and riparian area conditions. Day 1 of the site investigation started near the Kaheaka Road bridge crossing. The team entered the stream and hiked upstream, recording site conditions at multiple locations. The second day involved investigating the upper watershed and agricultural areas. This included driving the Dole pineapple field along the top of the stream canyon and also hiking the stream above the Dole Tanada Reservoir.

Figure 3-1 shows the locations visited on het two days and also the general path of travel outside of the stream channel. Following is a summary of the findings. A complete record of data collection sheets and photographs are located in Appendix A

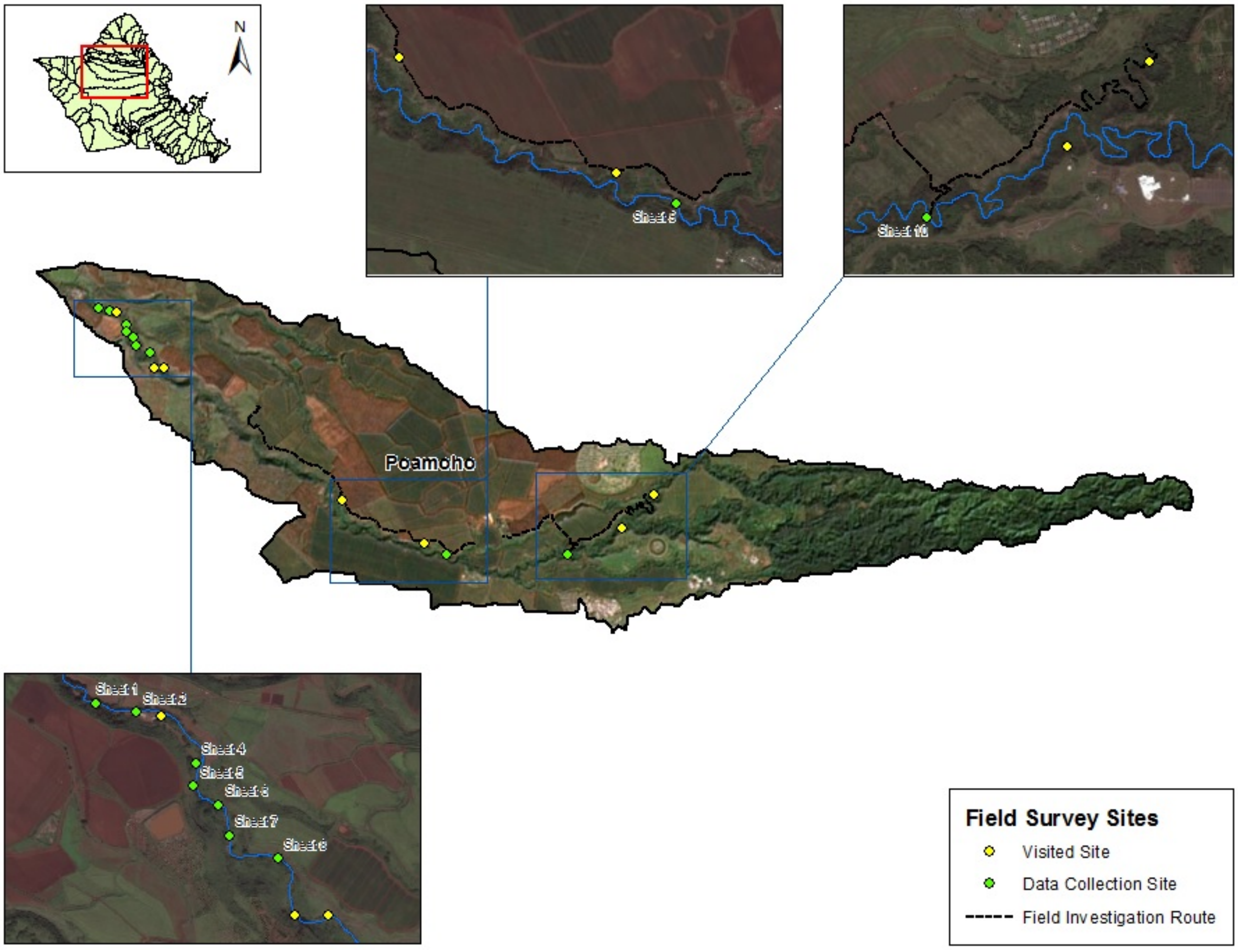


Figure 3-1 Field Investigation Data Collection Locations

3.1 Stream Flow and Water Clarity

Poamoho Stream is an ephemeral stream in the lower reach due to Dole diversions farther up in the watershed. As a result of recent heavy rains, during the two days of site observations the stream was flowing at approximately 15 cfs. The flow rate is based on the measured flow depth and width and an estimated flow velocity. Photo 3-1 shows the Poamoho Stream condition upstream of Kaheaka Rd. near the Kaheaka Rd crossing, Poamoho Stream appears to be backwater influenced from Kaukonahua Stream and potentially the tidal elevation.

Photo 3-1 Distribution of Land Use with Kaiaka Study Area

The previous week the Island of Oahu received large rainfall events. Evidence of debris lines and flattened vegetation found throughout the lower reach of the stream suggests recent high flows were approximately 3 to 4 feet higher than flows during the site investigation.

Photos of the water color and clarity were collected at multiple locations along the stream. The color of the water was generally consistent at all the locations recorded in the lower reach (first day). On the second day the middle stream reach was found to be orange in color, likely from high sediment content. The origins of the high sediment load were not identified but the potential location of the sources was likely a side tributary as the upper stream reaches did not exhibit the orange color. The following series of photos provide a representative example of the condition of the stream flow.

Day 1 – Lower Reach

Throughout the Day 1 field investigation the water color and clarity was found to be relatively consistent. The flow appears to be turbid, likely due to remnant suspended material from the earlier high flows.

Day 2 – Near Dole Plantation

This sample is taken at the Striker Brigade crossing approximately 2,000-ft downstream of Kamehameha Highway crossing. The orange color suggests high suspended clay content. A visual inspection of the stream from the Kamehameha Highway bridge also found the flow to be orange.

Day 2 – Upstream of Dole Plantation

This sample is taken from the Poamoho Stream approximately 2,000-ft upstream of the Kamehameha Highway crossing. This location is upstream of the high clay content flow source. As the overflow from Tanada Reservoir was also relatively clear, the potential sources of the high sediment content are: a localized slide, the tributary that drains the Whitmore Village and NCTAMS areas, or the residential area serviced by Nui Avenue.

Day 2 – Near Kaheaka Road Crossing

The orange color had either dissipated or had not reached the bridge crossing location. As 6-hours had passed since the first Day 2 sample and this photo were taken it is more likely that dissipation occurred as the stream sample locations were approximately 7 miles apart.

3.2 Stream Bed Material

The bed material of Poamoho Stream was documented through photos. Based on the findings throughout the Day 1 visit it is suggested that the bed material throughout the lower reach is “bi-modal” in natural. This references two sources of material; local material input delivered from rock falls and bank erosion and transported finer material from the upper watershed. In the upper watershed the bed material also appears to be bi-modal. In the upper watershed, most of the material is coming from local sources as the extent of the watershed is near this location. The gravel sized material and smaller is very similar between the two locations. The larger material is more angular reflecting likely more recent introduction into the stream and limited downstream movement which tends to smooth the edges of the rocks. The photos below illustrate the type and size of bed material in the Poamoho Stream.

Day 1 – Lower Poamoho Stream

Day 2 – Upper Poamoho Stream

In portions of the stream channel protected from high flow velocities the accumulated sediment is much finer. The finer material in Photo 3-2 is covering the coarse material which means it was deposited on the falling limb of the flow hydrograph. Photo 3-3 illustrates the consistency of the bed material from Poamoho Stream in the reach near the Tanada Reservoir.

Photo 3-2 Fine Material Deposited in Protected Areas

Photo 3-3 Granular Stream Bed Material in the Upper Poamoho Stream

The bed material in Photo 3-3 is composed of particles in the sand to gravel size. There is very little evidence of fine sediments in the stream as they are flushed from the system due to flow velocities associated with most flow rates.

3.3 Source Material

Throughout the field investigation multiple sites were found that provided local source material to the stream. These locations were all associated with near vertical slopes. As the desktop land slope revealed (Figure 2-8), the study area streams are confined in canyons with canyon walls of varying slopes. Photo 3-4 is a typical pool at the base of a vertical face.

Photo 3-4 Under-cutting of a Vertical Face on Poamoho Stream

Rock material from the exposed face in Photo 3-4 created the pool. The size of the material that fell into the stream at this location is too large to be transported by stream energy. As the pool creates a near zero velocity environment, suspended and transported loads will settle in the pool creating an aggradation area that has the potential to become higher than the adjacent floodplain. During future high flow events the increased stream bed elevation may cause a channel avulsion, creating a new stream alignment. The stream at the base of this vertical slope is typical of those found in the lower reach of Poamoho Stream.

Smaller material released by slope failures also was observed to be entering the channel. The site shown in Photo 3-5 is an example of the recent small debris slide on banks of the stream. Future high flow events will transport this material through the lower reach of Poamoho Stream and discharge into the Kaiaka Bay.

Photo 3-5 Recent Slope Failure Adjacent to Poamoho Stream

The Poamoho Stream canyon walls have multiple areas of recent slope movement. In many cases the volume of the material fills a portion of the valley floor with a portion entering the stream. The finer material is transported downstream while the larger material remains in place. The material that does not enter the stream comes to rest at a stable slope, as shown in Figure 2-8, and becomes vegetated with invasive grasses. The exposed surfaces in Photo 3-6 are from recent slides and grasses can be seen vegetating the debris slopes.

Photo 3-6 Evidence of Slope Failure on the Poamoho Canyon

3.4 Streambanks.

Exposed streambanks provide the opportunity to see historic fluvial geomorphic characteristics. The dotted line in Photo 3-7 illustrates a layer of gravel approximately 3-feet above the water surface. The gravel material is streambed deposits and marks a historic streambed elevation. As the Lane's Diagram (Figure 1-2) suggests, for the stream to drop the channel invert, there must have been changes related to some aspect of flow and/or sediment volume and size.

Photo 3-7 Evidence of Previous Streambed Elevation

Similarly in the upper watershed, the exposed Poamoho stream bank reveals a layer of rocks that represents a historic deposition of stream bed materials. The rock layer in Photo 3-8 is likely a remnant of historic bed channel invert.

Photo 3-8 Upper Poamoho Watershed Historic Streambed

In Photo 3-9, the deposition of the larger material is indicative that the stream alignment has migrated across the partially confined canyon floor and that the bed elevation has lowered. The historic channel was located in the floodplain where fine sediment was deposited during high flow events. When the current channel alignment with lower elevations crossed the historic channel alignment, it exposed the historic remnant channel.

Photo 3-9 Evidence of Earlier Poamoho Streambed Elevations

3.5 Channel Planform.

The lower Poamoho Stream is a partially confined channel within the canyon walls and is a step-pool channel type. A step-pool stream classification is defined as a repeating sequence of steps and pools formed by material large enough to not be transported during high flows events. The step-pool characteristic also includes steep-gradient with little floodplain development (Buffington, 2013). Photo 3-10 shows an example of the step-pool in Poamoho Stream.

The upper reach of Poamoho Stream is classified as a Cascade channel. For this classification the channel is described as confined by valley walls and in direct contact with hillslopes. The channel slope provides for efficient transport of sand and gravel sized materials supplied from adjacent hillslopes. Boulders found in the stream channel are deposited from adjacent hillslopes with typical stream energy too low to transport. Photo 3-11 shows the Poamoho Stream within the confined portion of the watershed.

The boulders shown in the photo have been deposited from the adjacent slopes and have come to rest on the far side of the stream. The stream energy is configured to transport large volumes of sediment resulting from landslides. When there is not a source of sediment the stream energy is directed toward the channel bed and banks. The small drainage area in the upper watershed leads to low flows between storm events, limiting the overall sediment transport capacity of the stream.

Photo 3-10 Step-Pool Channel Classification on Poamoho Stream

Photo 3-11 Upper Poamoho Stream Channel

In the partially confined channel lower reach, geomorphic features suggesting the natural dynamic of Poamoho Stream were identified. Photo 3-12 shows a section of the stream with multiple channels. In many locations in the lower reach, gravel bars had become stabilized with vegetation creating multiple channels. Multiple channels mean flow conditions can provide additional, temporary storage of transported sediment.

Photo 3-12 Split Flow Conditions and a Vegetated Gravel Bar in Lower Poamoho Stream

Multiple side channels were found on the canyon floor. The typical side channel was less than 10-feet wide with larger bed material. Photo 3-13 shows the exposed flow path of a side channel entering Poamoho Stream. Because of the dense guinea grass, may of the channels were only identified at the bifurcation or confluence points.

The dynamic geomorphic conditions at stream confluences are shown in Photo 3-14. Upstream of the confluence the stream channel contains large boulders. After the confluence the stream bed has fewer boulders and the stream banks are composed of finer material.

Photo 3-13 Evidence of Side Channels along Lower Poamoho Stream

Photo 3-14 A Confluence on the Poamoho Stream

3.6 Agricultural Land Use

The land adjacent to the Poamoho Stream is owned by Dole with a majority of the useable land currently in pineapple production. The field investigation included looking at the potential of the agricultural area impacting the geomorphic character of the watershed.

On August 23rd, the week prior to the site visit, the Dole Pineapple field received over 2.6-inches of precipitation over a 6-hour period. Photo 3-15 shows accumulated sediment that washed off one of the pineapple fields as well as surface erosion channel developing in the hardened driving surface. For this to occur, the intensity of the rainfall likely was greater than the infiltration rate of the soil, allowing for surface runoff. As shown in Table 2-4, the saturated infiltration rate for the Wahiawa silty clay is 1-inch per hour.

Agricultural practices for pineapple include constructing earthen barriers around crops. These are intended to keep sediment from leaving the planted areas. The circled areas in Photo 3-15 highlight barrier breaches that allowed for sediment to leave the row crop areas and potentially reach the stream below.

Photo 3-15 Sediment near the Rim of the Poamoho Stream Canyon

Larger berms were found constructed along the top of the canyon. In most cases it appeared the larger berms succeeded in trapping the sediment prior to flowing over the edge into the canyon. Photo 3-16 shows a location where the larger berms have trapped sediment along the canyon rim.

Photo 3-16 Accumulated Sediment Washed from the Pineapple Fields

Evidence of sediment flowing into the guinea grass bordering the canyon rim indicates material may have reached the walls of the canyon and potentially Poamoho Stream. Limited access due to thick vegetation and steep slope limited the investigation of sediment flows and whether they eventually reached the stream or were trapped on the banks. It is likely that any runoff carrying sediment would infiltrate into the accumulated debris field at the base of the cliffs. As the flow infiltrates the loosely compacted material, the larger sediment is filtered out prior to the flow eventually reaching Poamoho Stream.

During the previous days investigation of the stream downstream of this location, the team only identified one location where flow from the above the canyon may be entering the stream. Pineapple farming practices include the use of black plastic sheeting to hold in soil moisture. Old plastic pieces are commonly seen on the land surface. Photo 3-16 shows many little plastic strips in the sediment. No plastic was documented in Poamoho Stream or along the banks so it is unlikely that concentrated flows of sediment are typically conveyed from the pineapple fields to the stream.

4 DISCUSSION OF FINDINGS

The fluvial geomorphology of Hawaiian streams is distinctive. Due to the young age of the islands many of the streams and their watersheds are still in the development stage, adapting to provide the amount of “work” required in shaping the landscape. Using geomorphological strategies developed from studies on the more developed continental regions may not accurately take into account the processes occurring in the Kaiaka study area as well as the rest of the islands.

Hawaiian streams and even watersheds are still evolving. The high stream density in the upper watersheds will eventually lead to stream erosion and avulsion that will capture upper watersheds into new streams. Under this scenario the geomorphic corrections will be dramatic as the stream, with the suddenly larger watershed, will need to modify its downstream geometry to accommodate the increased flow and sediment. The abandoned stream will also correct itself to accommodate the smaller flows and likely less sediment.

Typically a stream can be defined as having three geomorphic regions: Source, Transport and Response. The source reach is located in the upper watershed where steep slopes are a prominent feature. Landslides provide the sediment source for the stream. The transport area is characterized by having the ability to convey the incoming sediment through the reach with only minimal storage and additional erosion. The lower response reach is where stream energy drops, creating areas of deposition. As deposition continues in one location, the streambed elevation rises until the flow seeks a new flow path with an increase slope.

In the upper reaches, streams in the Kaiaka study area are Source reaches, configured to effectively move large amounts of sediment resulting from slide events. On Oahu it is estimated that 90 percent of the total annual suspended sediment load was produced during less than 2 percent of the time (Doty, 1981). Between slide events the stream energy is too high for the average daily load of sediment so the streambed does not have many fines. Due to the confined nature of the stream in the upper forested watershed the streams are not allowed to develop meanders to reduce stream slope and thus energy. The result is the confined stream start incising to drop the slope.

In the lower watershed the stream channel is partially confined to a narrow canyon. Between transporting volumes of sediment, the additional stream energy causes the stream to meander within the canyon to create a lower channel slope. The channel migration is also driven by landslide and rock falls pushing the stream across the canyon floor by blocking the channel flow paths.

The unstable canyon slopes are driven by the stream channel transporting of the alluvium material accumulated along the toe of the canyon walls. Once the material that provided support for the vertical canyon walls is removed by the stream, the stream energy attacks the base of the cliffs eventually causing another slide to occur. As the material from the slides accumulates eventually the stream is again pushed into a new flow path and the process begins anew.

The confined nature of the study area streams as well as agricultural land use impacts the both the riparian and uplands vegetation through most of the watersheds. Although the riparian corridors are populated with a majority of invasive species, the corridors are continuous for most of the stream length, providing for unrestrictive movement of terrestrial species. The agriculture areas provide very little natural habitat. In the Upper watershed the forested areas are continuous from the ridgeline to the stream channel. These conditions allow for unrestricted movement of terrestrial species including wild boar and birds.

The establishment of vegetation on landslide and rock fall areas is dominated by invasive species. In the upper Poamoho Stream watershed, strawberry guava trees dominate the riparian landscape. The reoccurring rainfall events provide the moist environment for easy propagation of seeds transported downslope by gravity and by stream flow. The drier climate of the lower canyon does not provide a good environment for the guava.

Guinea grass was likely introduced as a forage crop for cattle in the area. As the cattle industry downsizes the guinea grass was able to grow and produce seeds that have been distributed throughout the area. Where adequate canopy exists to block out direct sun the guinea grass is less dense. If replacement of the invasive grass is desired, the development of a thick natural canopy needs to be including in the strategy.

Vegetation impacts on soil erosion and deposition was identified in both the upper and lower Poamoho Stream corridor. Tree roots are exposed and are stabilizing stream banks from further erosion. In many locations, vegetation had stabilized gravel bars against erosion creating sections of multiple channels. Dense ground cover also created surface roughness that allows for a slowing of the flow velocities and deposition of transport sediment on overbank areas and side channels.

No water quality sampling was conducted other than comparing water color throughout Poamoho Stream. During the first day of the stream investigation, the water was somewhat turbid, likely as a result of the recent high rainfall and subsequent flows. During the second day, the middle section of Poamoho stream was found to be visibly orange, likely from a high suspended sediment concentration. Further investigations of the stream upstream and downstream found the water color to be similar to the previous day.

Based on the findings from the geomorphic assessment of the Poamoho Stream the stressors, responses and indicators found are shown in Table 4-1. Potential efforts for impacting watershed health should focus on the items listed as stressors.

Table 4-1 Summary of Stressors, Response and Indicators of Watershed Health in Poamoho Stream

Stressors	Response	Indicators
Water Diversions Push-up Levees Landslides Land Use Changes	Increased Sediment Wash off Decreased Low Flows Invasive Vegetation Cover	Stream Channel Incision Streambank Erosion Invasive Vegetation WQ Impacts Lack of Aquatic Species Diversity

The overall goal of the Kaiaka Bay project is to develop approaches designed to reduce the volume of sediment being conveyed and discharged from the many streams. To efficiently reach this goal, it is important to maintain a balance in the watershed based on Lane's dynamic-equilibrium principle. Using approaches intended to reintroduce natural functions to reaches of the streams that have been impacted by anthropogenic actions will lead to a more stable geomorphic condition.

As the majority of the sediment and larger material currently being transported through Poamoho Stream appears to be the result of natural conditions, trying to control the source will likely have adverse consequences. The greatest potential is to provide elements in the lower watershed that allow floodplain development and increased inundation. The natural function of floodplains is to reduce stream energy during high flow events and therefore create conditions for sediment to be trapped.

4.1 Potential Mitigation Approaches

The HAR analysis presented in Section 2.6 was refocused on the lower reaches of the Poamoho, Opaeula, and Kaukonahua streams to determine the spatial extent of potentially available floodplain as shown in Figure 4-1. The re-introduction of floodplain functions in the lower watershed will allow for transported sediment to be stored instead of discharging to the ocean.

Table 4-2 Floodplain Restoration Potential Sediment Removal for Kaiaka Bay

Height Above Stream (feet)	Incremental Inundation (acres)	Potential Annual Sediment Deposition
2-3	22.9	37 tons
3-4	49.8	80 tons
4-5	72.3	117 tons
Total Area	**145 ac**	**234 tons**

Completed floodplain restoration projects have estimated as increase in sediment deposited on floodplains from 1.7 mm/yr to 11.3 mm/yr. Based on the potential inundation areas provided in Table 4-2 and the sediment deposition rate in the floodplain it is estimated that 234 tons (approximately 8,700 cubic yards) of sediment can be trapped on the floodplains per year. This reflects the amount of sediment not entering the Kaiaka Bay. As the sediment accumulates, the elevation of the floodplain increases, resulting in less potential storage opportunity. Removal of the deposited material on a regular schedule may provide for long term improvements of the water quality entering the bay.

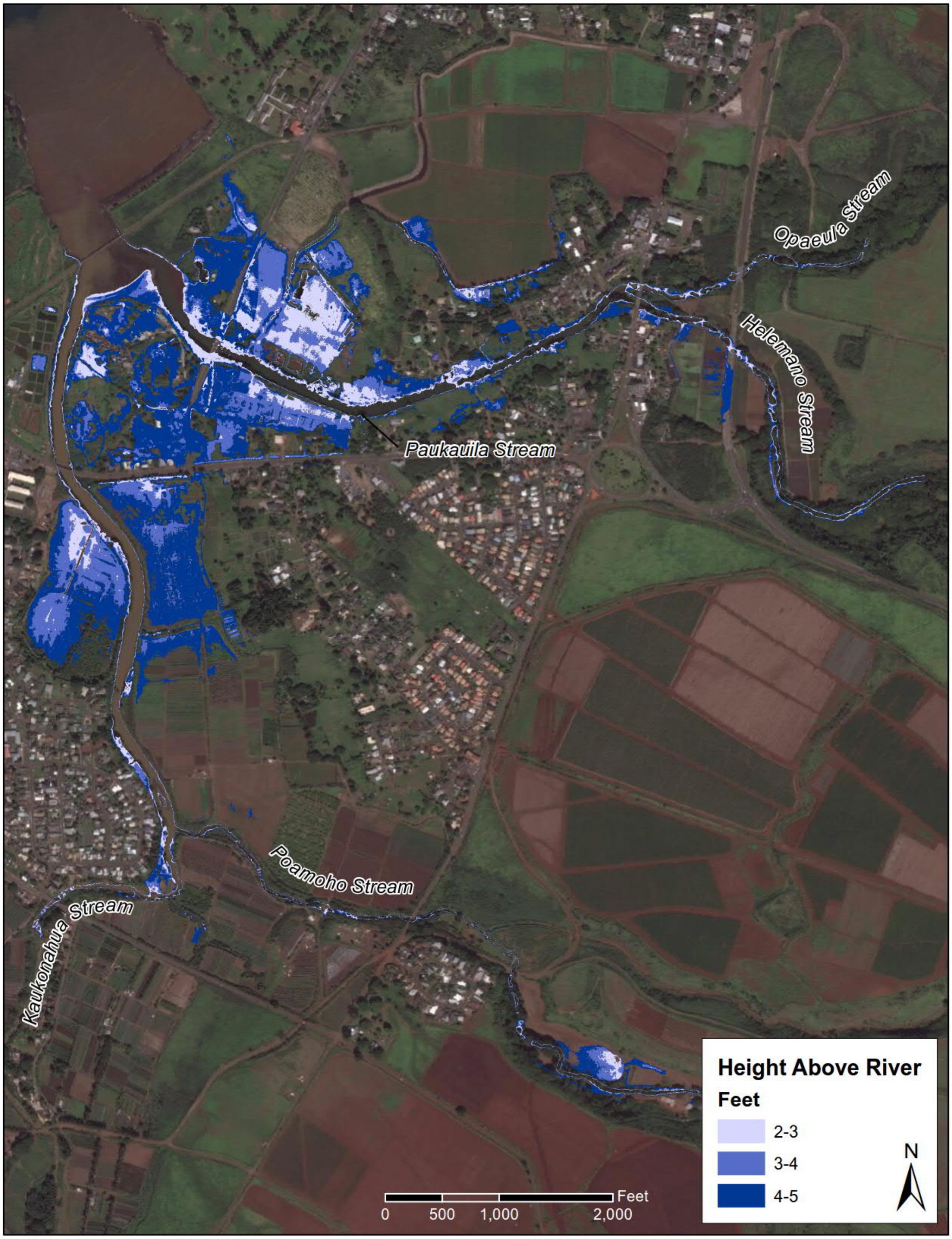


Figure 4-1 Potential Floodplain Function Restoration Areas near Haleiwa

A second potential improvement would be the use of contour farming on Dole Plantation. Although the contribution of sediment to the stream system generated by pineapple operations appear to be limited, altering the orientation of the crop rows can be effective in reducing sediment transport during large rainfall events. Using contour lines developed from the LiDAR data along with aerial photography the spatial extent of pineapple crops planted on the contour were estimated. Figure 4-2 represents the initial results of the analysis. Regions of the pineapple fields with crop alignment estimated to be less the 45-degrees are represented as On Contour.

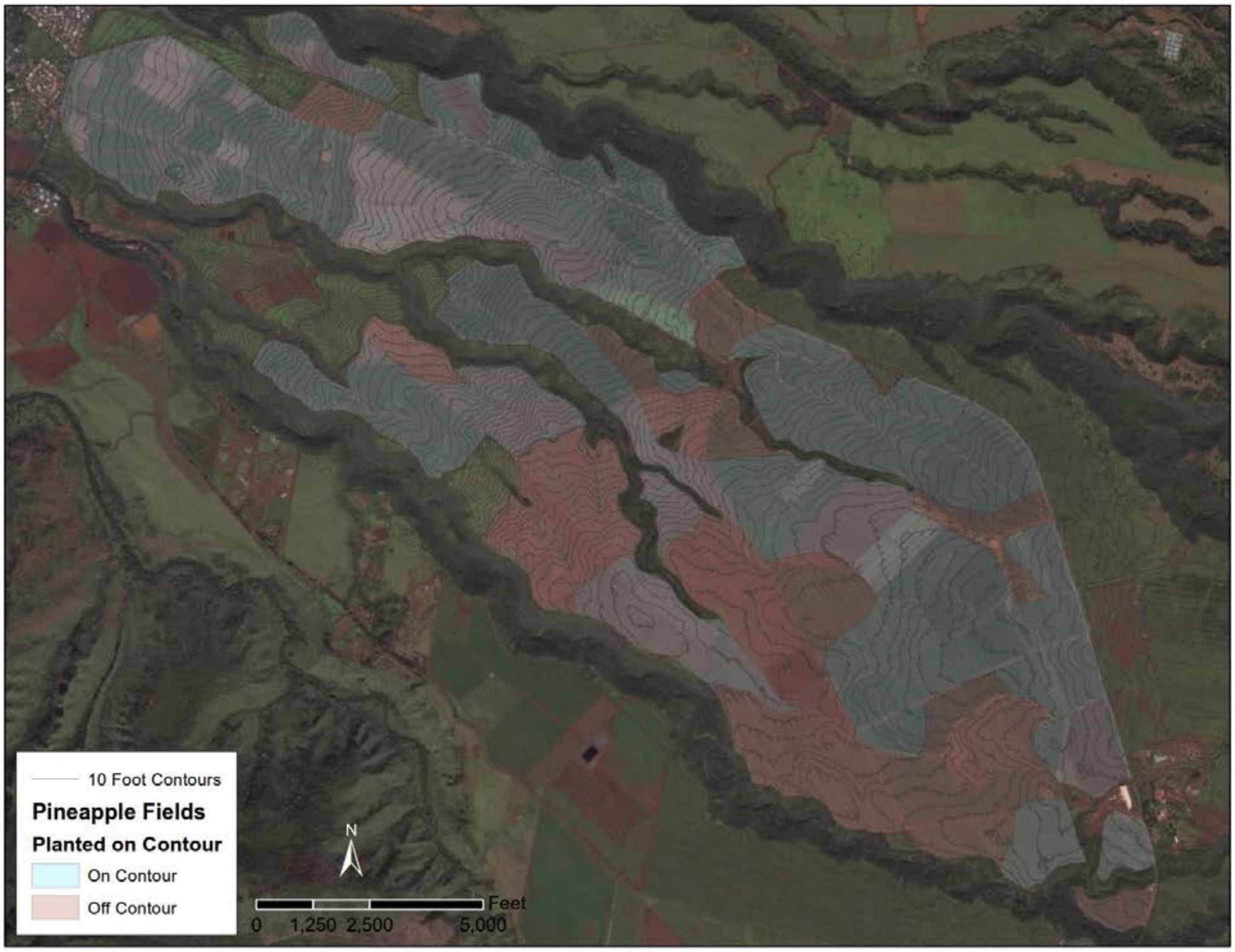


Figure 4-2. Estimated Pineapple Fields Planted on Contour

Based on the region assessed, approximately 2,660 acres are planted on the contour while 1,110 acres are not. Converting the crop alignment to follow the contour has the potential to reduce sediment wash-off by 50% while encouraging water storage and infiltration.

The accumulated sediment shown in Photos 3-15 and 3-16 are associated with areas not planted on the contour. Although the accumulated sediment did not appear to have a direct link to the current stream alignment, the material is likely being stored on the canyon slopes. As the stream migrates across the valley floor the stored material will be transported downstream, so it would be advantageous to reduce the volume of potential transportable sediment stored in the watershed.

Appendix A
Field Investigation Data Collection Sheets and Photos

#1

Stream Name: Poamoho

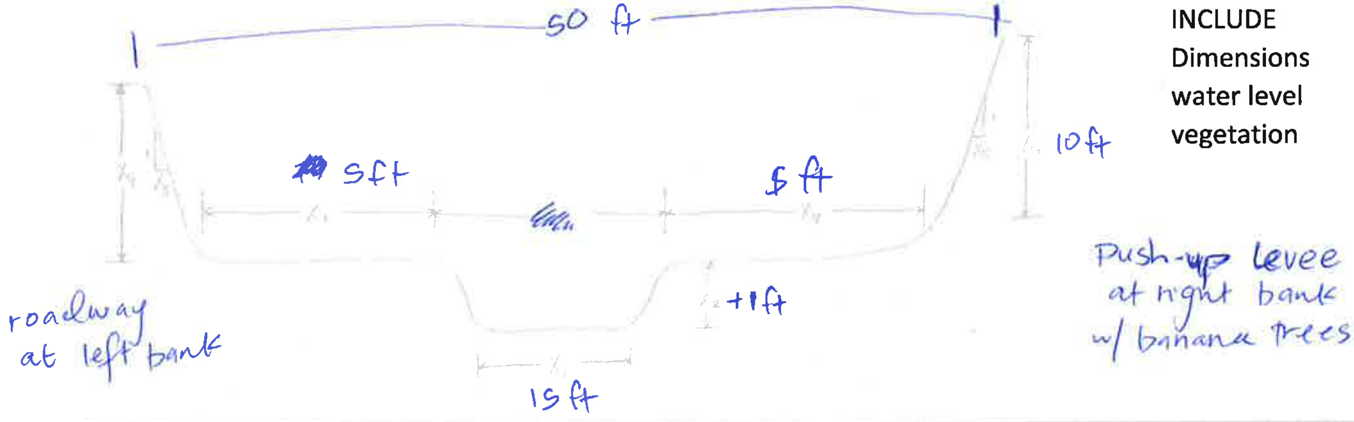
Date: 8/31/15

GPS Coordinates: 21°33' 39.8" N 158°06'29.2" W SP or UTM #285

Photo #	Description
5728	Water quality
5729	stream looking upstream
5730	stream looking downstream
5731	left bank
5732	substrate w/ field notebook
5733	right bank
5734	bed material
5735	" "

Channel Geometry Sketch

INCLUDE
Dimensions
water level
vegetation



Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity see photo 5728

Depth 1 ft

Velocity 1 ft/sec

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor : none, well mixed.

Subsurface

Streambanks

Erosion (Photo) lots of bank erosion, roots holding things together

Vegetation guinea grass, ~~eucalyptus~~, java plum, albizia, malia

Floodplain Description

Vegetation: types, canopy, understory

Deposition/Erosion

Roadway on ~~right~~ left bank

Banana on ~~left~~ right bank.

Field Data Sheet 1

Photo #5728- Water Quality

Photo #5729- Upstream

Photo #5730- Downstream

Photo #5731- Left Bank

Photo #5732- Substrate

Photo #5733- Right Bank

Photo #5734- Bed material

Photo #5735- Bed material

#2

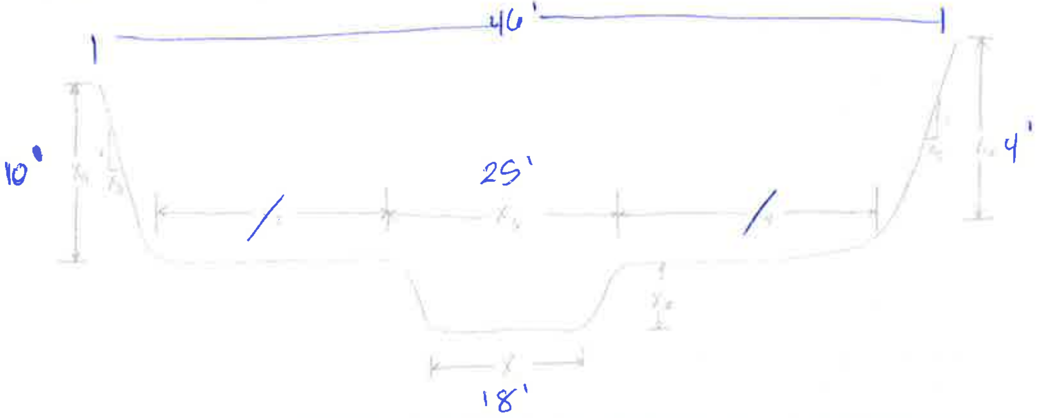
Stream Name: Poamoho

Date: 8/31/15

GPS Coordinates: 21° 33' 36.3" N 158°06'17.1" SP or UTM

Photo #	Description
5736	Water quality
5737	~~stream bed material~~ down stream
5738	upstream
5739	bed material

Channel Geometry Sketch



INCLUDE
Dimensions
water level
vegetation

headcut reach
~15' ΔH
over 300' stream

no push up levees

Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity

Depth 1ft

Velocity

Migratory Barriers - Aquatic/terrestrial

none

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo)

Vegetation african tulip, albizia, Java plum, guinea grass (dominant understory

Floodplain Description

Vegetation: types, canopy, understory right bank - mangoes (or lychee)

Deposition/Erosion

Field Data Sheet 2

Photo #5736- Water Quality

Photo #5737- Downstream

Photo #5738- Upstream

Photo #5739- Bed Material

#4

Stream Name: Poamoho

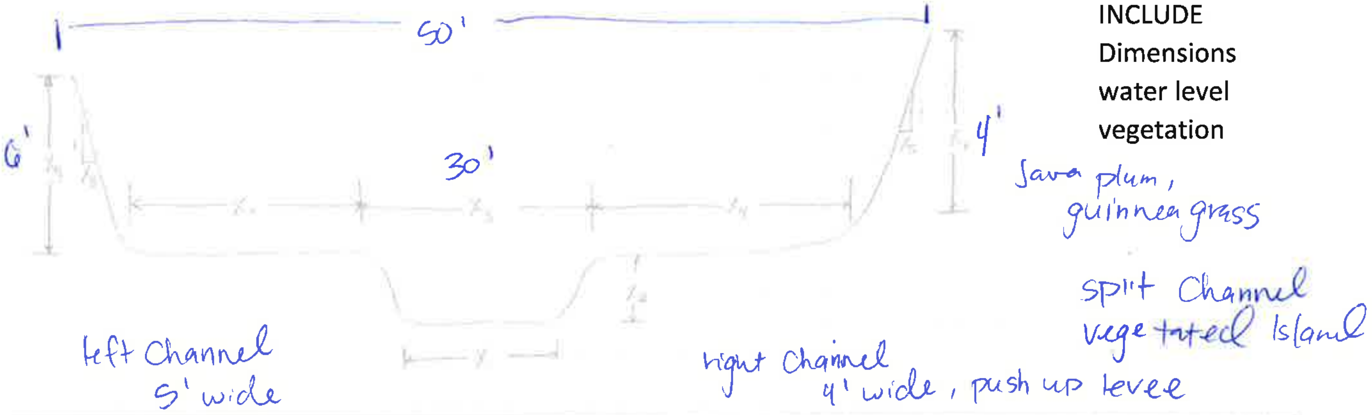
Date: 8/31/15

GPS Coordinates: 21° 33' 30.0" 158° 06' 06.9" SP or UTM

Photo #	Description
5741	Water quality
5742	upstream
5743	down stream
5744	left bank
5745	right bank
5746	right bank / stream erosion / historic bank
5747	bed material
5748	abandoned side channel.

Channel Geometry Sketch

INCLUDE
Dimensions
water level
vegetation



Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity

Depth

Velocity

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo) erosion 3' Through historic bed on right channel.

Vegetation Java plum, guinnea grass

Floodplain Description

Vegetation: types, canopy, understory

Deposition/Erosion

left bank - road, vegetation, boulders
right bank - push up levee → 50' vegetation, guinea grass, java plum.

Field Data Sheet 4

Photo #5741- Water Quality

Photo #5742- Upstream

Photo #5743- Downstream

Photo #5744- left bank

Photo #5745- Right Bank

Photo #5746- Right bank, historical bank

Photo #5747- Bed Material

Photo #5748- Abandoned side channel

#5

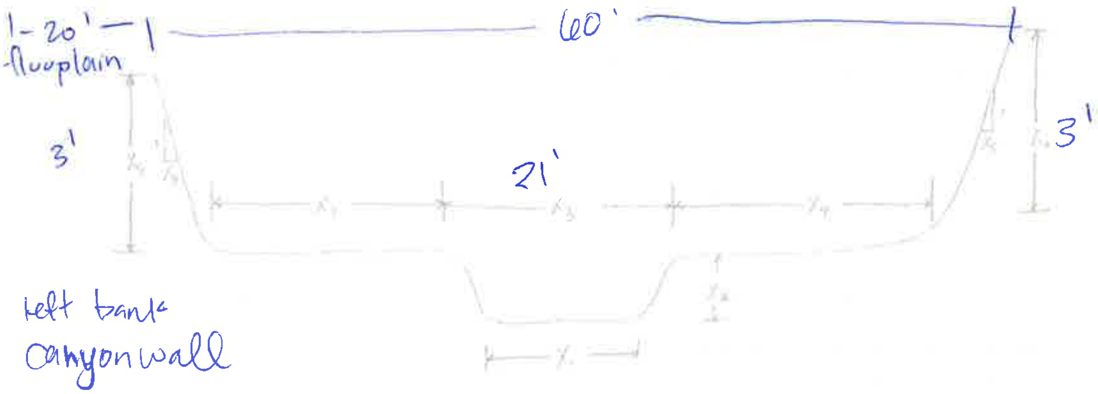
Stream Name: Poamoho

Date: 8/31/15

GPS Coordinates: 21° 33' 26.3" 158° 06' 07.2" SP or UTM

Photo #	Description	
57 49	bed	57 57 - stream bed
5750	left bank canyon wall	57 58 . stream bed.
5751	upstream	
5752	dowstream	
5753	water quality	
5754	left bank	
5755	right bank	
5756	By-pass channel.	

Channel Geometry Sketch



INCLUDE
Dimensions
water level
vegetation

right bank - high flow bypass channel. photo 5756

Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity

Depth

Velocity

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo) no signs of bank erosion, very large boulders

Vegetation Java plum, Christmas berry, guinnea grass, koa haole.

Floodplain Description

Vegetation: types, canopy, understory left flood plain, ~20' wide, 3' high.

Deposition/Erosion right flood plain vegetated grass

Field Data Sheet 5

Photo #5749- Bed material

Photo #5750- Left bank, canyon wall

Photo #5751- Upstream

Photo #5752- Downstream

Photo #5753- Water quality

Photo #5754- Left bank

Photo #5755- Right Bank

Photo #5756- Bypass Channel

Photo #5757- Streambed

Photo #5758- Streambed

#6

Stream Name: Poamoho

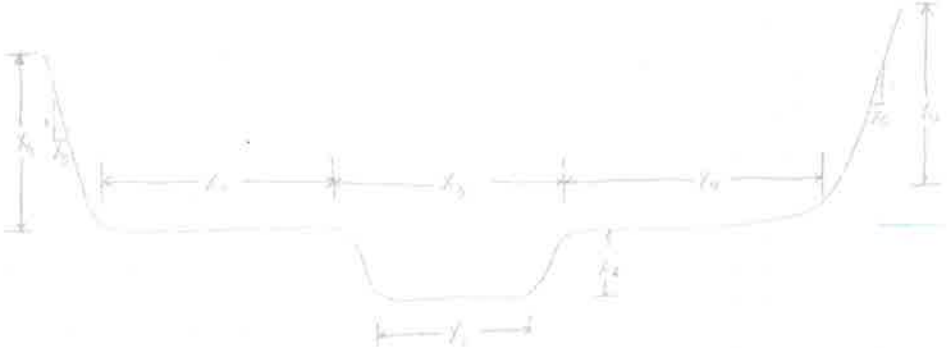
Date: 8/31/15

GPS Coordinates: N21°33'23.2" W158°06'02.9" SP or UTM

Photo #	Description
57 G1	water quality sample
57G2	upstream
57 G3	downstream
57 G4	left bank
57G5	right bank

Channel Geometry Sketch

no measurements taken,



INCLUDE
Dimensions
water level
vegetation

debris field
right bank cliff

Site Description

Stream Type

Water Present (Y/N)

Clarity

Depth

Velocity

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo)

Vegetation guinnea grass, haole koa, java plum, african tulip

Floodplain Description

Vegetation: types, canopy, understory

Deposition/Erosion

Field Data Sheet 6

Photo #5761- Water quality

Photo #5762- Upstream

Photo #5763- Downstream

Photo #5764- Left Bank

Photo #5765- Right bank

#7

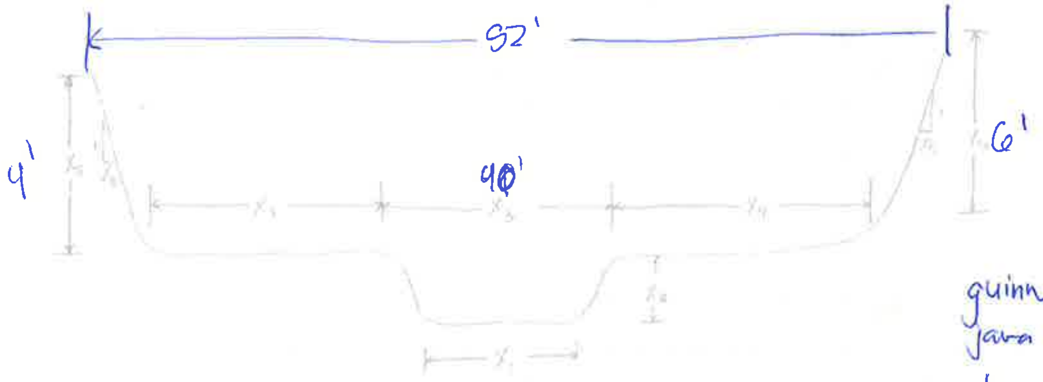
Stream Name: Poamoho

Date: 8/31/15

GPS Coordinates: 21°33'18.2" 158°06'01.2" SP or UTM

Photo #	Description
5766	Water quality
5767	upstream
5768	downstream
5769	right bank
5770	left bank

Channel Geometry Sketch



INCLUDE
Dimensions
water level
vegetation

guinnea grass
java plums
boulders

- upstream end of debris field
- multiple flow paths
- multiple level channels.

Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity

Depth

Velocity cascading areas.

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo) no signs of erosion.

Vegetation guinnea grass, javaplum.

Floodplain Description

Vegetation: types, canopy, understory

Deposition/Erosion

Field Data Sheet 7

Photo #5766- Water quality

Photo #5767- Upstream

Photo #5768- Downstream

Photo #5769- Right bank

Photo #5770- Left bank

#8

Stream Name: Poamoho

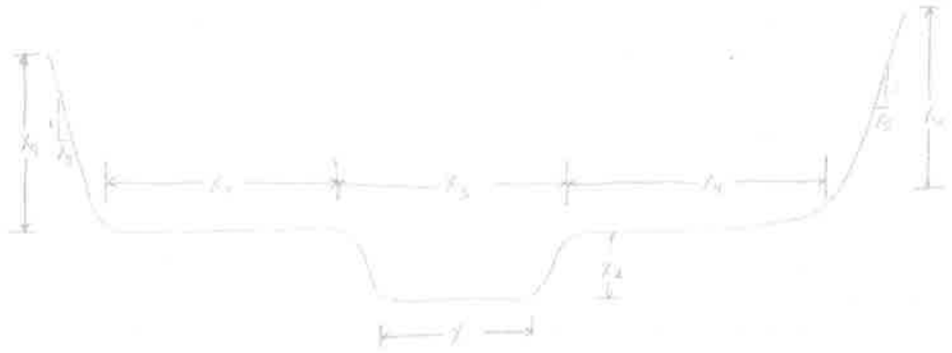
Date: 8/31/15

GPS Coordinates: 21° 33' 14.4" 158°05'52.7" SP or UTM

Photo #	Description
S777	water quality
S778	downstream
S779	upstream
S780	right bank
S781	left bank

Channel Geometry Sketch

no measurements



INCLUDE
Dimensions
water level
vegetation

right bank tall cliff.

Site Description

Stream Type

Water Present (Y/N)

Clarity

Depth

Velocity

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks boulders

Erosion (Photo)

Vegetation guinea grass, java plums, african tulip

Floodplain Description

Vegetation: types, canopy, understory

Deposition/Erosion

Field Data Sheet 8

Photo #5777- Water quality

Photo #5778- Downstream

Photo #5779- Upstream

Photo #5780- Right bank

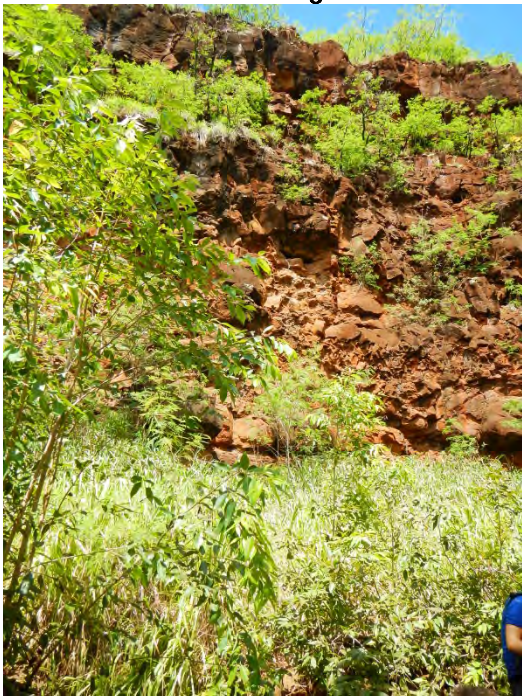


Photo #5781- Left bank

#9

Stream Name: Poamoho @ striker road

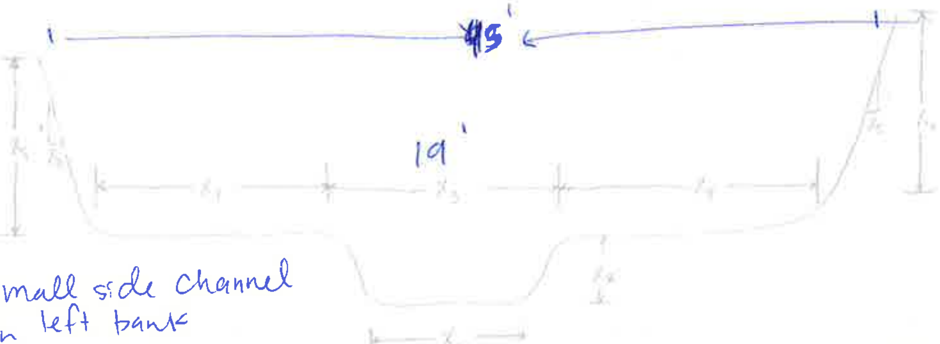
Date: 9/1/15

GPS Coordinates: 21°31'16.7" 158°02'50.5 SP or UTM

Photo #	Description	
5787	left bank	5795- car battery in stream
57 88	right bank	
57 89	down~~up~~stream	
57 90	upstream	
57 91	upstream	
57 92	water quality	
57 93	downstream	
5794	bank composition/historical	

Channel Geometry Sketch

INCLUDE
Dimensions
water level
vegetation



small side channel on left bank guinnea grass + large boulders

large boulders

Straight vertical w/ guinnea grass, weed delia, albizia

Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity

Depth

Velocity

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Migratory Barriers - Aquatic/terrestrial

site right down stream of four box culverts.

Streambanks photo 5794- shows historical bank composition

Erosion (Photo)

Vegetation albizia, guinnea grass, hau, weedelia

Floodplain Description no real flood plain on either side.

Vegetation: types, canopy, understory

Deposition/Erosion

Field Data Sheet 9

Photo #5778- Left Bank

Photo #5788- Right Bank

Photo #5789-Downstream

Photo #5790- Upstream

Photo #5791- Upstream

Photo #5792- Water quality

Photo #5793- Downstream

Photo #5794- Historical Bank Composition

k

Photo #5795- Car battery in stream

#10

Stream Name: Poamoho(?) upstream of Dole reservoir.

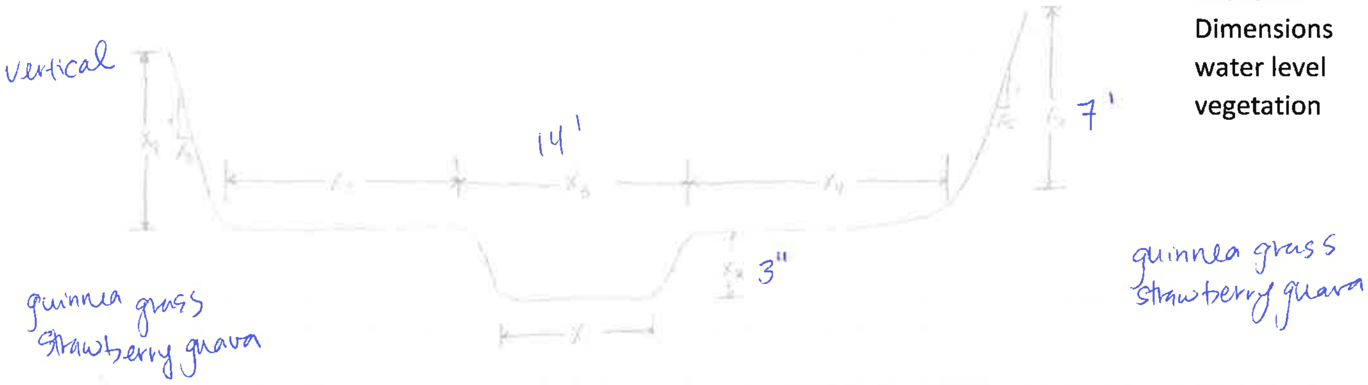
Date: 9/1/15

GPS Coordinates: 21° 31' 16.0" 158°01'35.9" SP or UTM

Photo #	Description
58 16	down stream
58 17	upstream
58 18	water quality.
58 20	downstream
58 21	right bank
58 22	left bank
58 23	stream bed / sediment
58 24/25	bed material
58 26	Woody debris/gravel bar down stream w/ car

Channel Geometry Sketch

INCLUDE
Dimensions
water level
vegetation



Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity

Depth 3"

Velocity 2 ft/sec.

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description: silt stone bed.

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo)

Vegetation albizia, guava, guinnea grass, fern

Floodplain Description

Vegetation: types, canopy, understory right flood plain 10'-20'

Deposition/Erosion left straight vertical.

Field Data Sheet 10

Photo #5816- Downstream

Photo #5817- Upstream

Photo #5818- Water quality

Photo #5820- Downstream

Photo #5821- Right bank

Photo #5822- Left bank

Photo #5823- Stream bed

Photo #5824- Bed material

Photo #5825- Bed material

Photo #5826- Woody Debris/ gravel bar with Car

#11

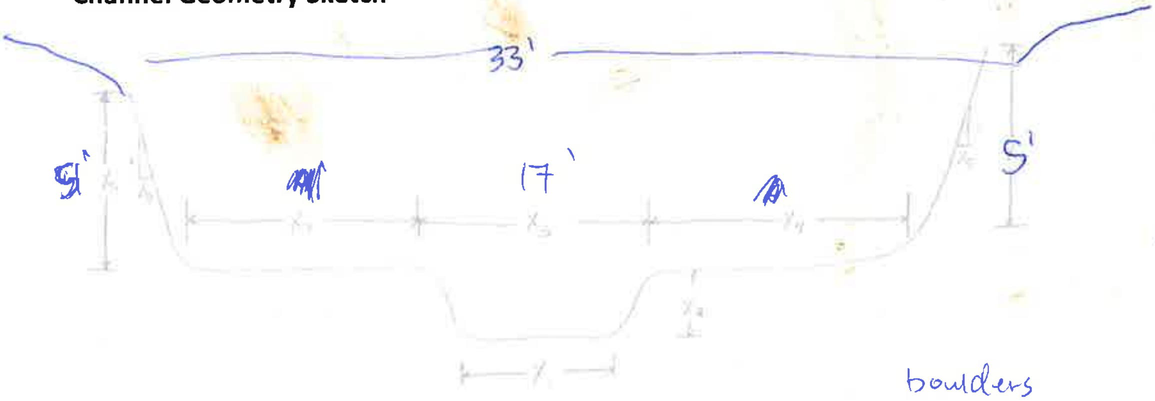
Stream Name: Poamoho

Date: 9/1/15

GPS Coordinates: 21°31'38.7" 158°01'00.6" SP or UTM

Photo #	Description
58 27	upstream
58 28	downstream
58 29	left bank
30	right bank
31	water quality
32	stream bed substrate
33	stream bed substrate
34	left bank

Channel Geometry Sketch



INCLUDE
Dimensions
water level
vegetation

cascading section.

boulders

Site Description

Stream Type

Water Present (Y/N)

Clarity

Depth

Velocity

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo) left bank photo 34

Vegetation albizia, strawberry guava, guinnea grass

Floodplain Description

Vegetation: types, canopy, understory same.

Deposition/Erosion

Field Data Sheet 11

Photo #5827- Upstream

Photo #5828- Downstream

Photo #5829- Left bank

Photo #5830- Right bank

Photo #5831- Water quality

Photo #5832- Stream bed substrate

Photo #5833-Stream bed substrate

Photo #5834- Left bank

#12

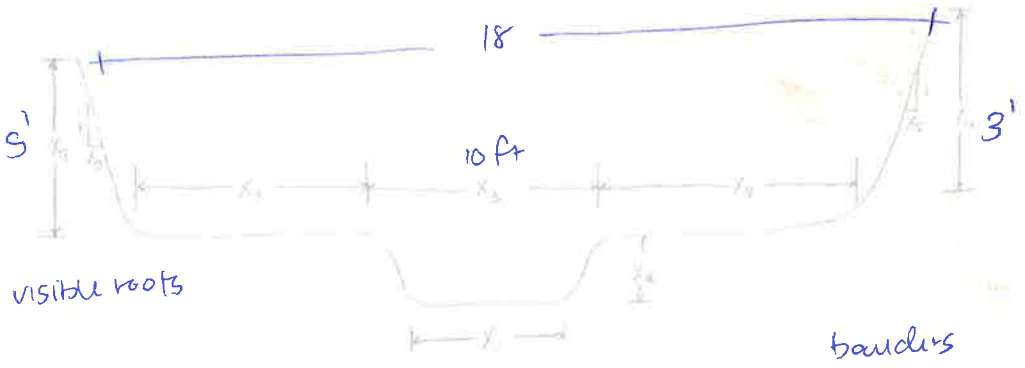
Stream Name: Poamoho

Date: 9/1/15

GPS Coordinates: 21°31'45.0" 158°00'48.9" SP or UTM

Photo #	Description
58 35	water quality
58 36	down
58 37	up
58 38	left bank
58 39	right bank
58 40	substrate/bed material

Channel Geometry Sketch



INCLUDE
Dimensions
water level
vegetation

Site Description

Stream Type

Water Present ([✓ Y]/N)

Clarity

Depth

Velocity

Migratory Barriers - Aquatic/terrestrial

Bed Material - include photo with scaleable object.

Description:

Color

Size

Surface Armor

Subsurface

Streambanks

Erosion (Photo)

Vegetation Christmas berry, strawberry guava

Floodplain Description

Vegetation: types, canopy, understory ten leaf, canopy healthy

Deposition/Erosion

Field Data Sheet 12

Photo #5835- Water quality

Photo #5836- Downstream

Photo #5837- Upstream

Photo #5838- Left bank

Photo #5839-Right bank

Photo #5840- Substrate/ Bed material

APPENDIX B. ADDENDUM TO THE KAIAKA BAY WATERSHED-BASED 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 Kaiaka Bay Watershed Based Plan to 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.

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.

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[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.

Management Practice	Description
	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.

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

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.

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 transported downstream by precipitation or runoff. The soil erodibility raster must be in units of t · h · ha / (ha · MJ · mm).	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 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.

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[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

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 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]
		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 3 shows the Borselli k Parameter by location.

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[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

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**	
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

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[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)

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 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

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[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.

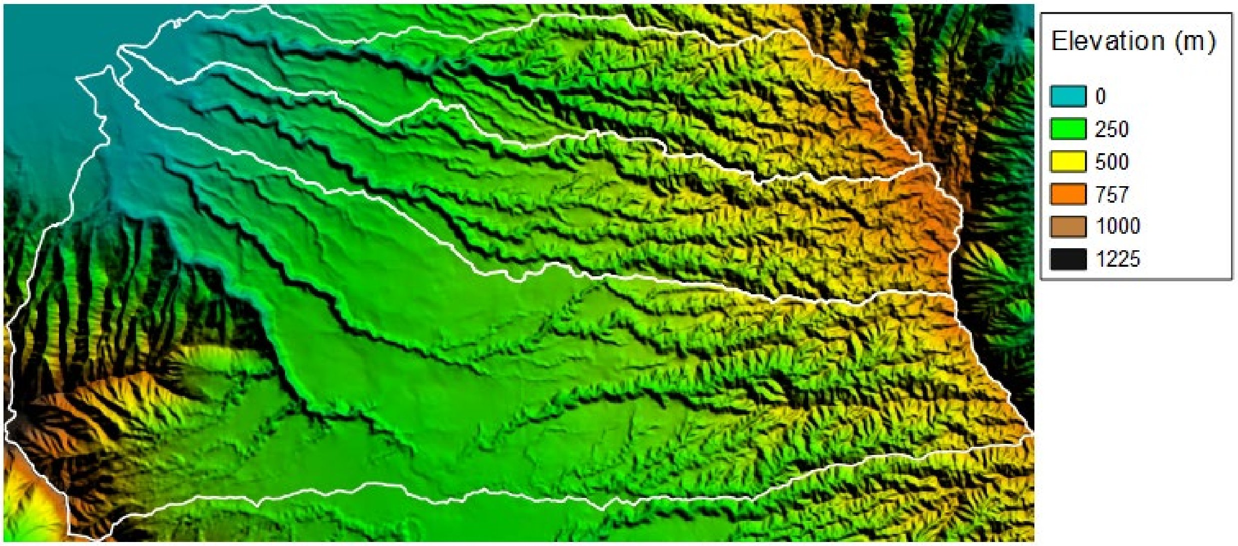
be changed to a type of forest cover if a best management practice would be to plant native species on non-vegetated land.

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.

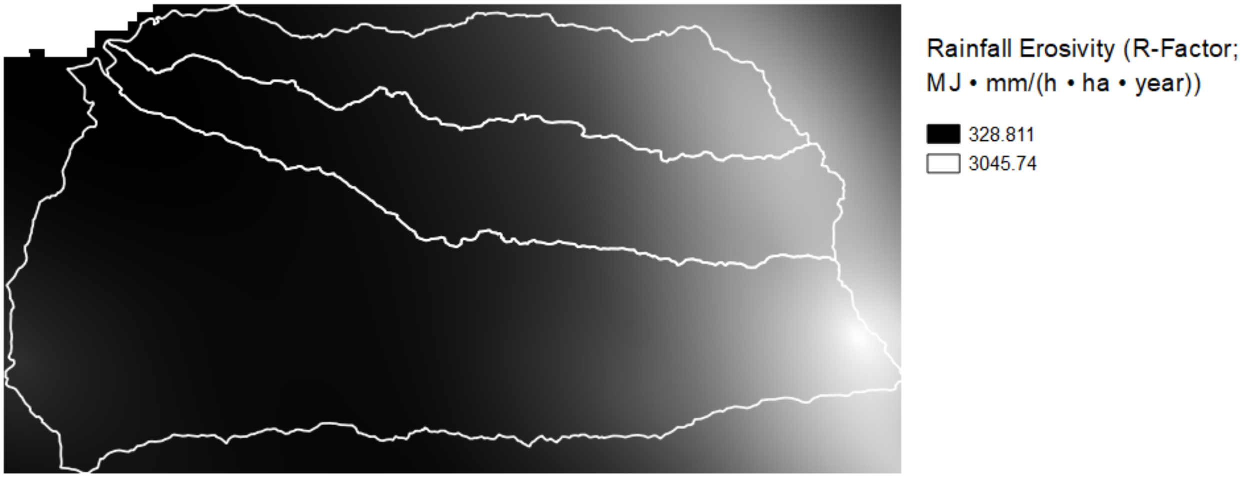
Example Use of the Procedure

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:

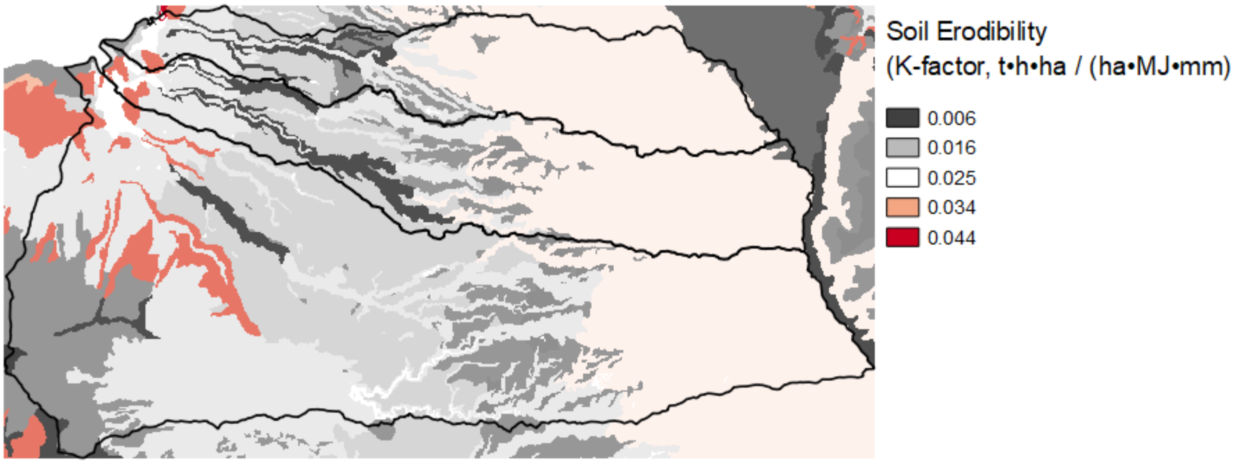
- Elevation Map: A DEM raster showing elevation in meters in the Kaiaka Bay and the surrounding area. This raster is a valid input for the InVEST model because the elevation is in meters and it extends beyond the Kaiaka Bay watershed boundary.



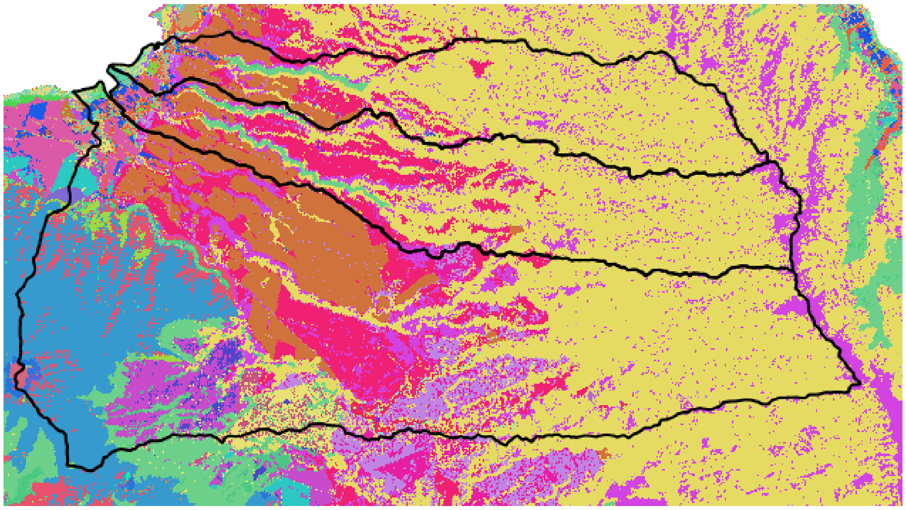
- Rainfall Erosivity: A rainfall erosivity map in raster format showing the rainfall erosivity throughout the Kaiaka Bay watershed in MJ • mm/(h • ha • year), the units required by the model.



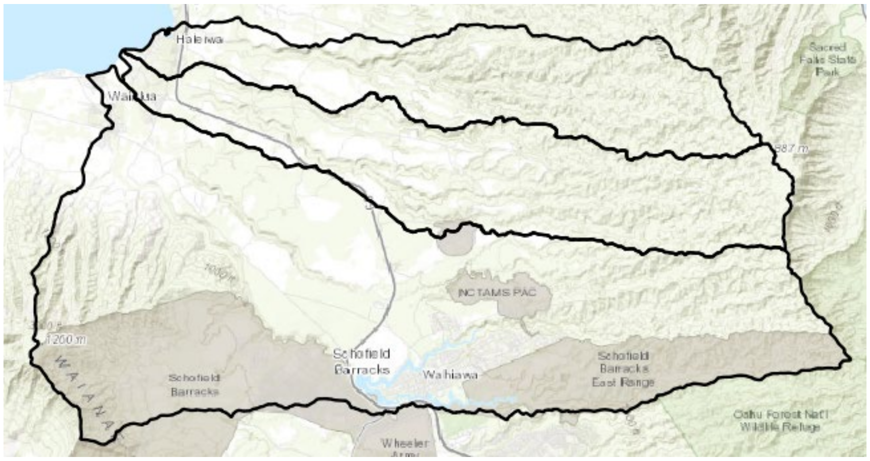
- Soil Erodibility: A map showing soil erodibility, or K factors, within the Kaiaka Bay watershed in raster format. The values in the raster format are in the proper units for the model, t • h • ha / (ha • MJ • mm).



- 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.

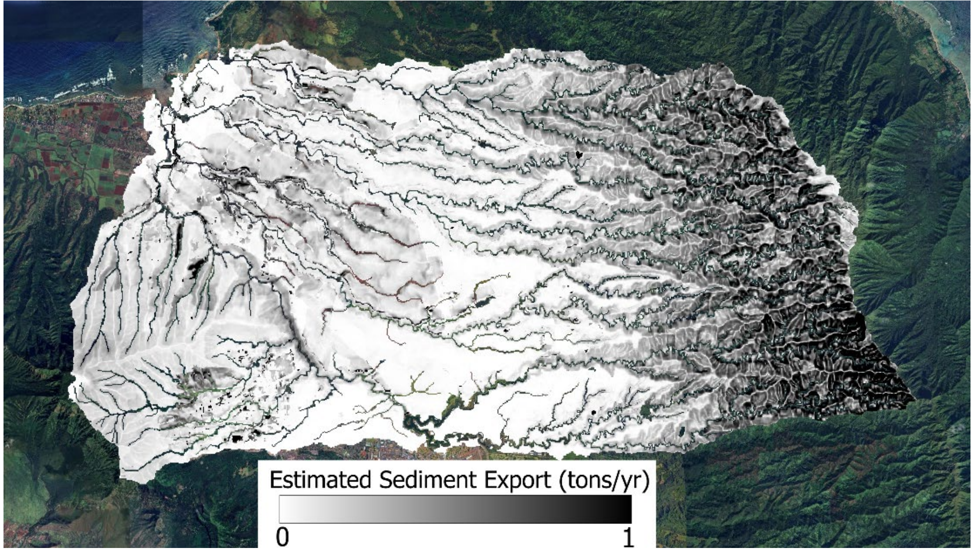
- Borselli k Parameter: The Borselli k parameter for this model run is 2.5, the value for all watersheds on Oahu.

- 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:



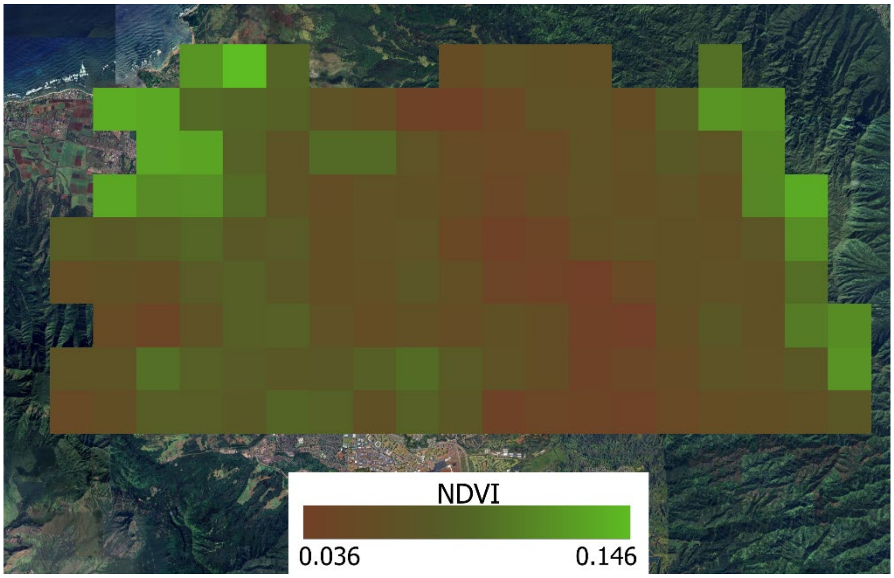
This raster indicates that the model expects the highest amount of sediment export to occur at the higher elevations of the watershed, but as discussed in the Step-by-Step Procedure section, the InVEST model tends to overestimate sediment export in high elevation areas. For this reason, multiple lines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

Class	Edge of Stream Sediment Load (lbs/acre/year)
Estuarine Forested Wetland	0.03
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 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

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United States Geological Survey (USGS). 2025. 1/3rd arc-second Digital Elevation Models (DEMs) - USGS National Map 3DEP Downloadable Data Collection. https://data.usgs.gov/datacatalog/data/USGS:3a81321b-c153-416f-98b7-cc8e5f0e17c3