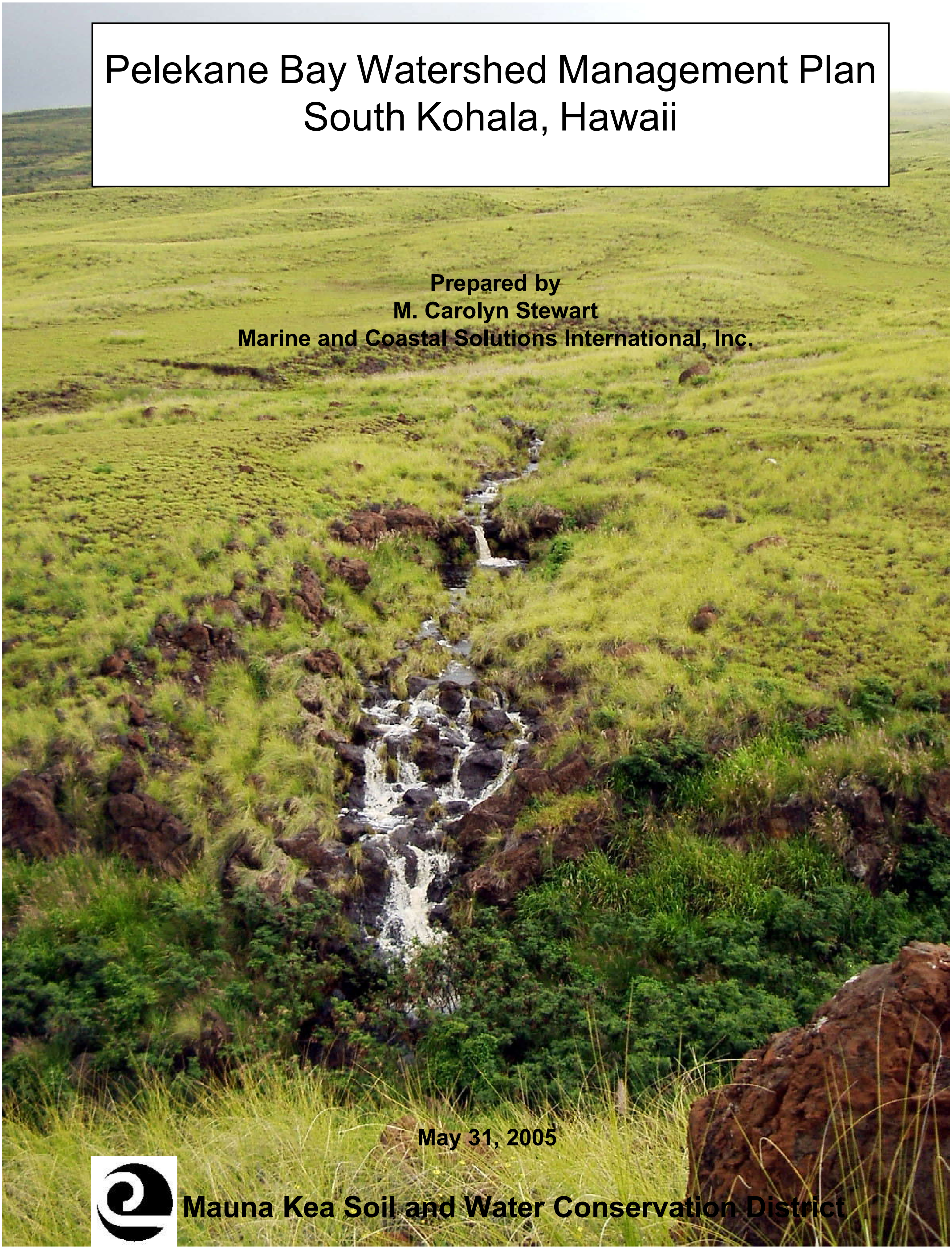

# Pelekane Bay Watershed Management Plan
# South Kohala, Hawaii


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**May 31, 2005**

**Mauna Kea Soil and Water Conservation District**

# Pelekane Bay Watershed Management Plan

## TABLE OF CONTENTS

APPENDICES

A. Photos of Breach of Berm
B. Vegetative Cover Monitoring Data
C. Stubble Height Monitoring Report 2001-2005
D. Addendum to the Pelekane Bay Watershed Management Plan

## LIST OF FIGURES



## LIST OF TABLES

# I. INTRODUCTION

The Pelekane Bay Watershed is located in South Kohala, on the northwest coast of Hawaii Island. The watershed is located on the slopes of Kohala Mountain, extending from the Kohala Forest Reserve at the top of the mountain down to Pelekane Bay, south of Kawaihae Harbor (Figure 1). It is approximately 12,225 acres in size. It is part of Hydrologic Unit Area (HUA) #20010000, which comprises the entire island of Hawaii.

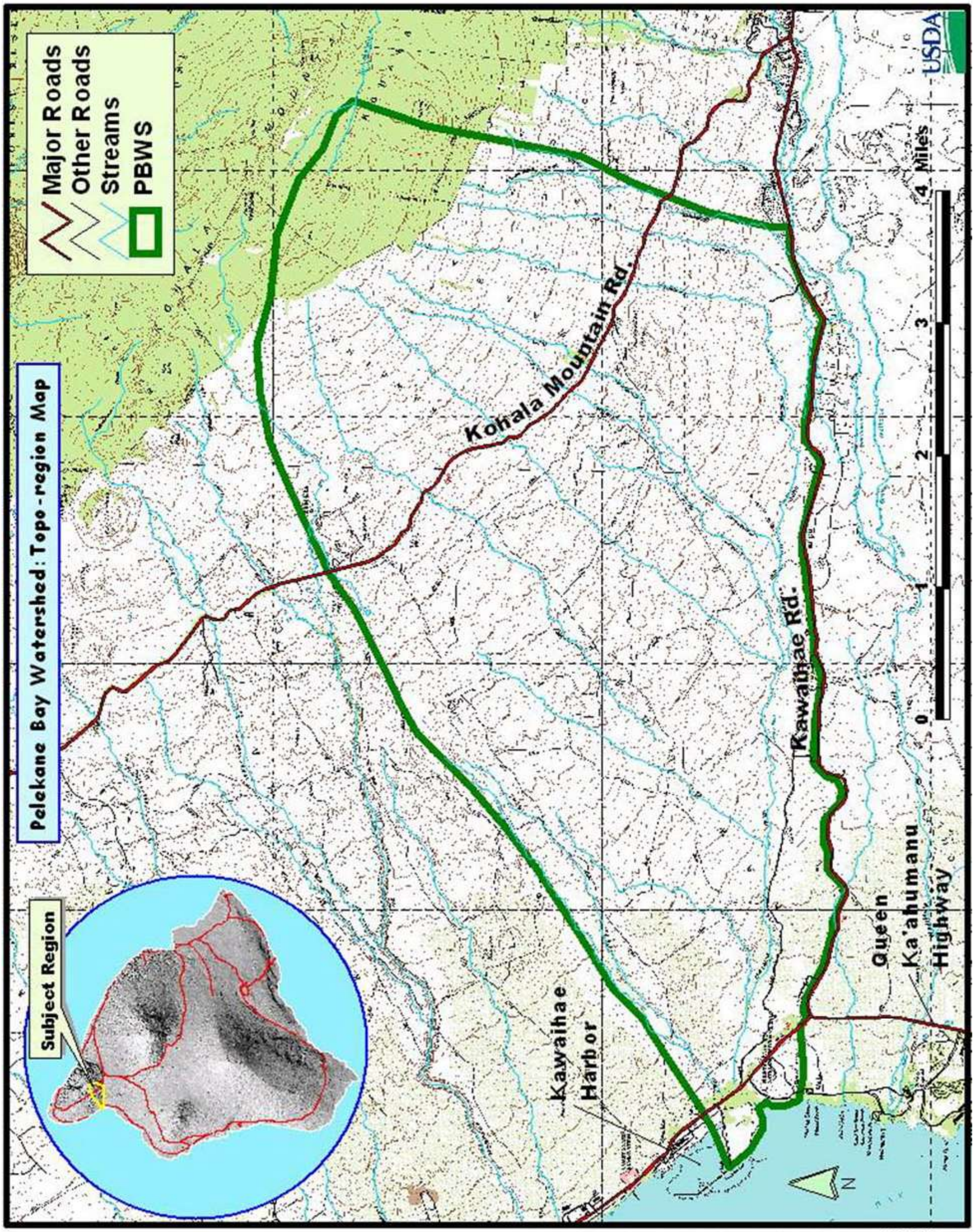
The Pelekane Bay watershed was identified in Hawaii's Unified Watershed Assessment as a Category I watershed: that is, one of the State's watersheds in most urgent need of restoration. Pelekane Bay is also on Department of Health's (DOH) 2004 Section 303(d) List of Impaired Waters. The reason for such designations is that soil erosion from the watershed has impaired the water quality of Pelekane Bay.

In 1998, the Clean Water Action Plan, initiated by the U.S. Environmental Protection Agency (EPA) and U.S. Department of Agriculture (USDA), asked each state to prepare a Watershed Restoration Action Strategy (WRAS) for the priority watersheds identified in their Unified Watershed Assessments. The Federal agencies stated that the WRAS should list specific water quality problems; identify sources of contaminants causing those problems; provide a schedule of action items that should be undertaken to address those sources; estimate the funding needs for those action items; and establish a monitoring program to assess effectiveness of conservation measures in addressing water quality problems. This updated management plan of the Pelekane Bay Watershed Management Project was initiated under these requirements.[1]

The Pelekane Bay Watershed Management Project was initiated in 1992, when staff from the Hawaii Department of Land and Natural Resources working on the Kawaihae Coral Reef Transplant Project alerted the Mauna Kea Soil and Water Conservation District (MKSWCD) that sediment from the watershed was polluting Pelekane Bay. The project began as a partnership among MKSWCD, land owner Queen Emma Foundation, lessee Parker Ranch, USDA's Natural Resources Conservation Service (NRCS), and University of Hawaii Cooperative Extension Service (CES) working to identify an effective erosion reduction strategy for the watershed.

The Mauna Kea Soil and Water Conservation District has received grant funds for the Pelekane Bay Watershed Management Project since 1994. The initial grants from the State Department of Health (DOH) in 1994 and 1998 funded the installation of best management practices to reduce polluted runoff potential. They also supported community education efforts to promote local stewardship of the watershed and the development of a monitoring plan. Two grants from USDA's Natural Resources Conservation Service (NRCS) supported the development of the Pelekane Bay Coordinated Resource Management Plan, a fire management plan, a native species revegetation plan, and a sediment management plan. The combined plans

[1] Since then, EPA has changed the program focus. In late 2001, EPA published supplemental guidelines for states in awarding grant funds for watershed management. The new focus is on Total Maximum Daily Loads (TMDLs) for nonpoint source pollutants, and watershed-based plans that describe the actions that are necessary to implement polluted runoff control activities in watersheds of Section 303(d)-listed waters. In watersheds without TMDLs, the plan must be designed to reduce nonpoint source pollution loadings that are contributing to non-attainment of water quality standards.




Prepared By: Orlando Smith; USDA-NRCS-Waimea Field Office

**Figure 1: Pelekane Bay Watershed**

provided a comprehensive watershed management program for the Pelekane Bay watershed.

At this time, the management plan for the watershed has been updated and compiled into one document: this 2005 Pelekane Bay Watershed Management Plan. As for all management plans, this plan is a work-in-progress and will continue to be updated periodically to reflect changing conditions, priorities, and management techniques.

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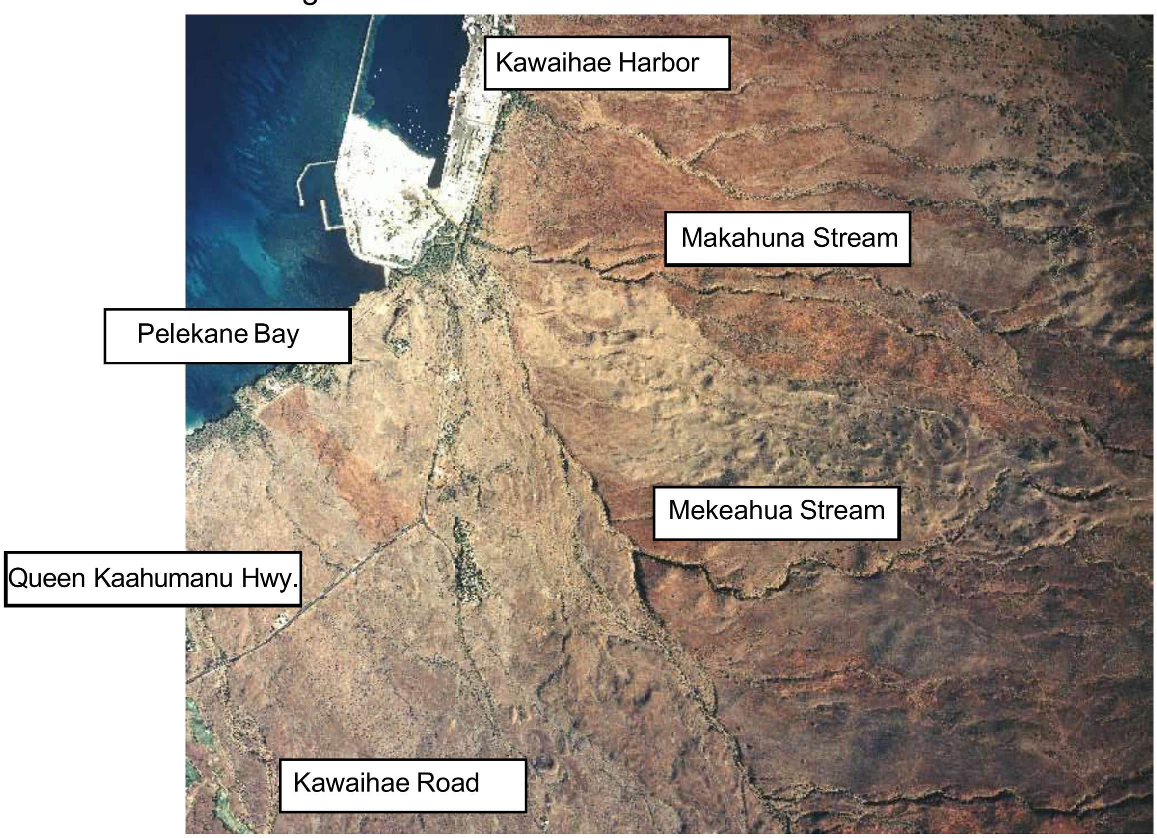
## II. WATERSHED ASSESSMENT and INVENTORY

The Pelekane Bay watershed is located on the slopes of Kohala Mountain, extending from the Kohala Forest Reserve at the top of the mountain (elevation 5,300 ft.) down to Pelekane Bay, just south of Kawaihae Harbor. It is approximately 12,225 acres in size. Makahuna Gulch is the watershed boundary to the northwest and Highway 19 (Kawaihae Road) to the southeast. While there are 6 named gulches within the watershed — Makahuna, Palihae, Luahine, Waiakamali, Makeahua, and Pauahi — there are no perennial streams, other than within the Kohala Forest Reserve. Streamflow is limited to flows in the gulches and overland during rainfall events in all but the highest parts of the watershed. Under normal conditions, there is a berm at the artificial mouth of the watershed, and no regular streamflow enters into the ocean.

Pelekane Bay, the current mouth of the watershed, lies between Puukohola Heiau to the south and the coral flats adjacent to Kawaihae Harbor to the north. The “coral flats” was created during the construction of Kawaihae Harbor in the late 1950s, when material (sand and coral) dredged from the nearshore waters was deposited to create a filled area. The original outlets of the watershed have been blocked by the creation of Kawaihae Harbor and channelization of the flows around the harbor facilities and coral flats.



## A. Topography and Soils

Rugged terrain, steep slopes, and gulches contribute to the erosion and fire potential of the area and make access difficult. The Pelekane watershed falls from 5,300 feet to sea-level in a distance of approximately 8 miles. The terrain is rough, bisected by deep, normally-dry gulches. Narrow, rough roads provide access into the watershed, and stony surfaces limit deviation from established routes.

A NRCS soil survey including the Pelekane Bay watershed was completed in 1982. NRCS is in the process of updating its soil maps for the Big Island, and the new maps should be completed within three years from 2005. While a new soils map has been started for the Pelekane Bay watershed and shows newly-identified soil types in the watershed, the map is preliminary and the data incomplete. Therefore, the following information must be considered in "draft" form.

Figure 2, still in draft form, delineates soil types in the Pelekane watershed. The descriptions of the soil types are as follows:

P1: Kawaihae silt loam, 6-12% slopes, extremely stony

This soil type is found on leeward, south Kohala Mountain in the elevation range of sea level to 1,000-ft. The surface and subsurface layers consist of silt loam, with 50-75% surface rock fragments. The parent material is volcanic ash over Pololu pahoehoe lava. The survey noted that this soil is extremely eroded in places, particularly within the Pelekane Bay watershed.

P2: Kawaihae2 silt loam, 6-20% slopes, very stony

This soil is limited to the Pelekane Bay watershed, in elevations between 1,000 and 2,300-ft. The surface and subsurface layers consist of silt loam, with 50-60% surface rock fragments. The parent material is volcanic ash over Pololu pahoehoe lava. The soil type P2(E) is similar to P2 but in an eroded phase.

P3: Kawaihae3 silt loam, 6-12%, very cobbly

This soil type is found on leeward, south Kohala Mountain in the elevation range of 2,300 to 3,500+-ft. The surface and subsurface layers consist of silt loam, with 20% cobbles. The parent material is volcanic ash over Pololu pahoehoe lava. There are no management concerns listed under this soil type.

MK1: Lalamilo-Waikui-Hapuna Complex

This soil type is found in leeward, north Mauna Kea, in the elevation range of sea level to 1,000-ft. and comprises three soil classifications: Lalamilo silt loam, with 5-25% cobbles and gravel; Waikui very gravelly silt loam with 50-60% surface fragments; and Hapuna cobbly silt loam with 50-60% surface fragments. The parent material of the Lalamilo-Waikui-Hapuna Complex is volcanic ash over Hamakua a'a. The soil type MK1-RW is similar to MK1 but located in the alluvial plain and influenced by river wash.

MK2: Puu Pa - Waikaloa Complex

This soil type is found in leeward, north Mauna Kea, in elevations between 1,000 and 2,500-ft. It comprises two soils: Puu Pa extremely stony, very fine, sandy loam; and Waikaloa very fine sandy loam. The parent material is volcanic ash over Hamakua a'a.

H1: Holikau-"Hapunalike" Complex

This soil type is found on leeward, south Kohala Mountain in the elevation range of sea level to 1,000-ft. It consists of Holikau very gravelly silt loam and "Hapunalike" very gravelly silt loam, with 50-75% surface fragments. Its parent material is volcanic ash over Hawi a`a.

H2: "Holikaulike" Complex

This soil type is found on leeward, south Kohala Mountain in elevations of 1,000 to 2,300-ft. It comprises "Holikaulike" extremely cobbly silt loam, with 70% cobbles, and "Holikaulike" gravelly silt loam, with 20% gravels. Its parent material is volcanic ash over Hawi a`a.

H3: Palapalai-Waimea Complex

This soil type is found on leeward, south Kohala Mountain in elevations ranging from 2,300 to 3,500+-ft. It comprises Palapalai very gravelly silt loam, with 50-60% cobbles and gravels, and Waimea silt loam, with 10-15% cobbles and gravels. Its parent material is volcanic ash over Hawi a'a.

Table 1, also in draft form, provides additional information about each of the soil types. The "depth class" is the normal depth of the soil; if the depth in the field is less, then the soil is eroded. The "Kf value" is the soil erodibility factor for the fine earth fraction or soil material less than 2.00 mm in diameter. The higher this number, the more erodible the soil. Amorphous clays in the soils keep the K values in Hawaii lower than on the Mainland. Sand, which is highly erodible, has a K value of 0.5 or 0.6. Hydrophobic soils repel water, and the water beads up rather than infiltrating the soil. Hydrophobic soils can occur naturally or as a result of intense heating from a fire. Water repellence may cause erosion of sloping land by contributing to surface runoff.

**Photo: Sediment movement in Paddock 4A**

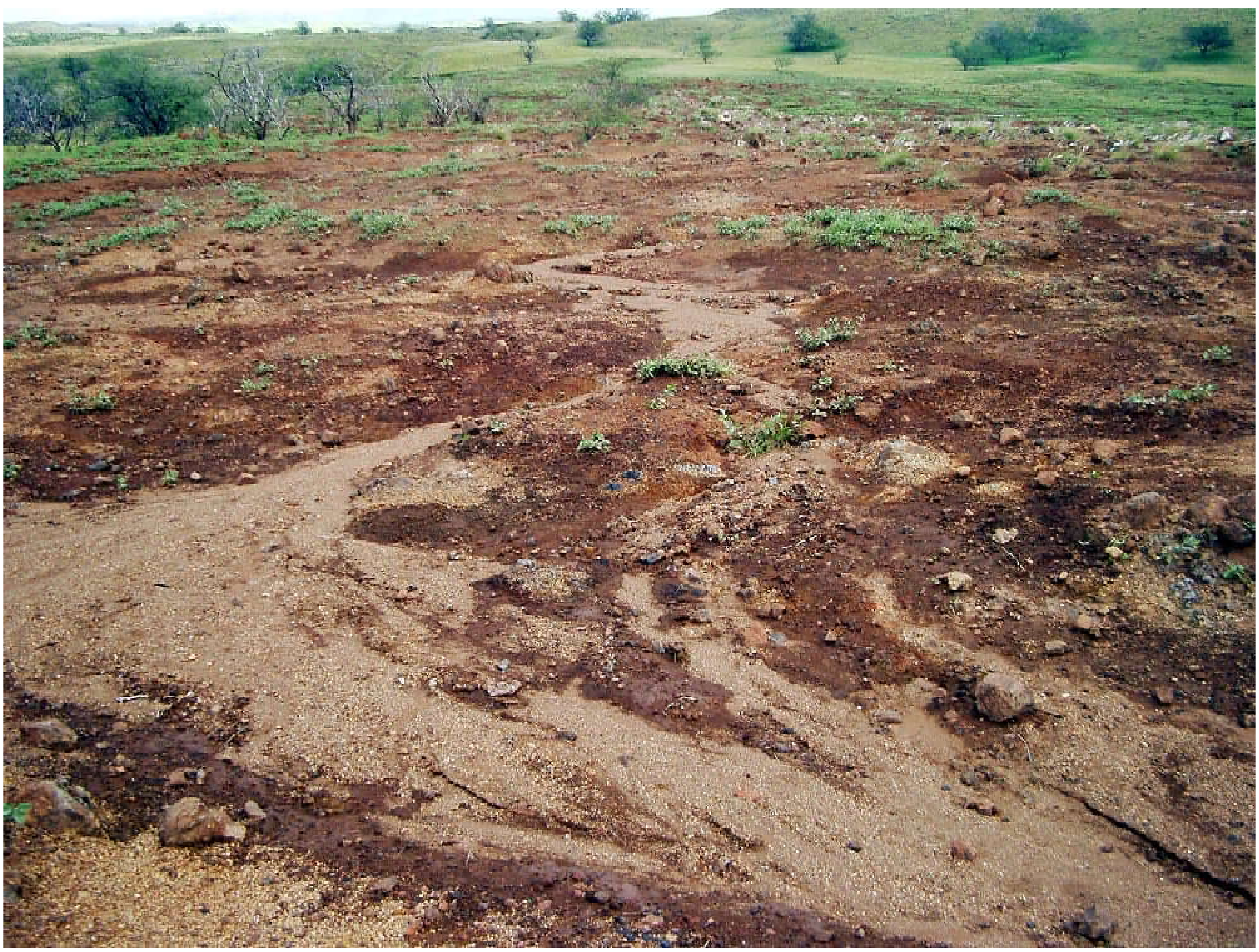
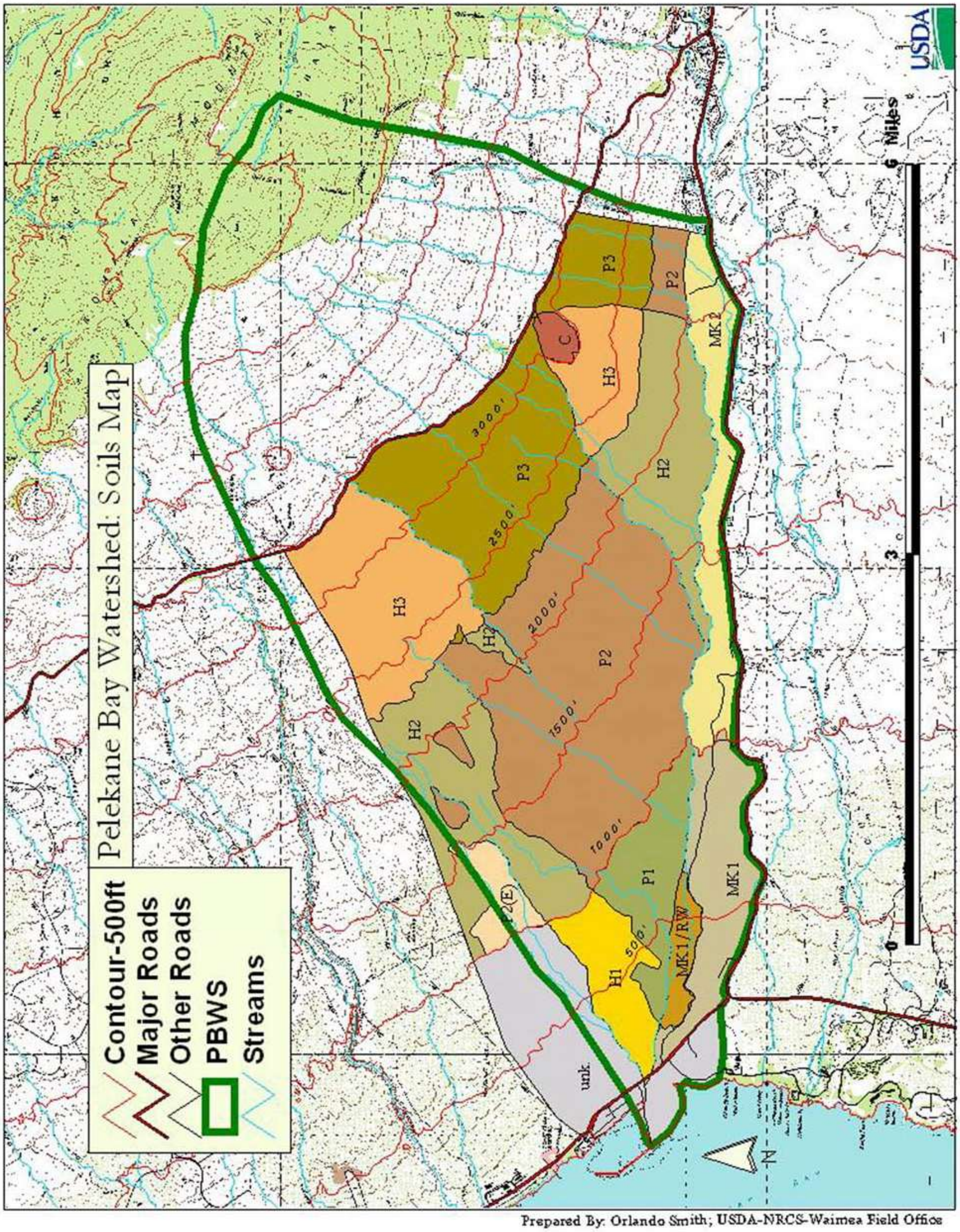


**Figure 2: DRAFT Soil Types in the Pelekane Bay Watershed**




Prepared By: Orlando Smith; USDA-NRCS-Waimea Field Office

**Table 1: DRAFT Characteristics of Soil Types in the Pelekane Watershed**

| Soil Type | Slope Range | Drainage Class | Current Vegetation | Depth Class | Precipitation/ Moisture Regime | Kf Value | hydro-phobic | Potential for Erosion |
|---|---|---|---|---|---|---|---|---|
| P1 | 6-12% | well-drained | buffelgrass, kiawe | moderately deep to pahoehoe lava | 7-9 inches; aridic | 0.28 | yes | high |
| P2 | 6-20% | | buffelgrass, fountaingrass, kiawe | moderately deep (20-40") | 9-22 inches; aridic | 0.28 | yes | high |
| P3 | 6-12% | well-drained | kikuyu, lantana, panini, koaia | deep (over 40") | 22-50 inches | 0.28 | no | low |
| MK1 | 2-12% | well-drained | | deep (Lalamilo) and moderately deep (Waikui and Hapuna) | 7-9 inches; aridic | 0.28 | yes | high |
| MK2 | 2-20% | well-drained | | moderately deep (Puu Pa) and deep (Waikaloa) | 9-22 inches; aridic | 0.32 PuuPa 0.17Waikaloa | yes | high |
| H1 | 6-12% | | buffelgrass, kiawe | deep (40-60" for Holikau) and moderately deep (Hapunalike) | 7-9 inches | 0.28 | yes | high |
| H2 | 2-20% | well-drained | kiawe, wiliwili, piligrass, kikuyu, buffelgrass | deep (over 40") | 9-22 inches | 0.28 | yes | high |
| H3 | 6-20% | well-drained | kikuyu, lantana, panini, koaia, sandalwood, aalii | deep (over 40") | 22-50 inches | 0.17 | yes | high |

## B. Vegetation

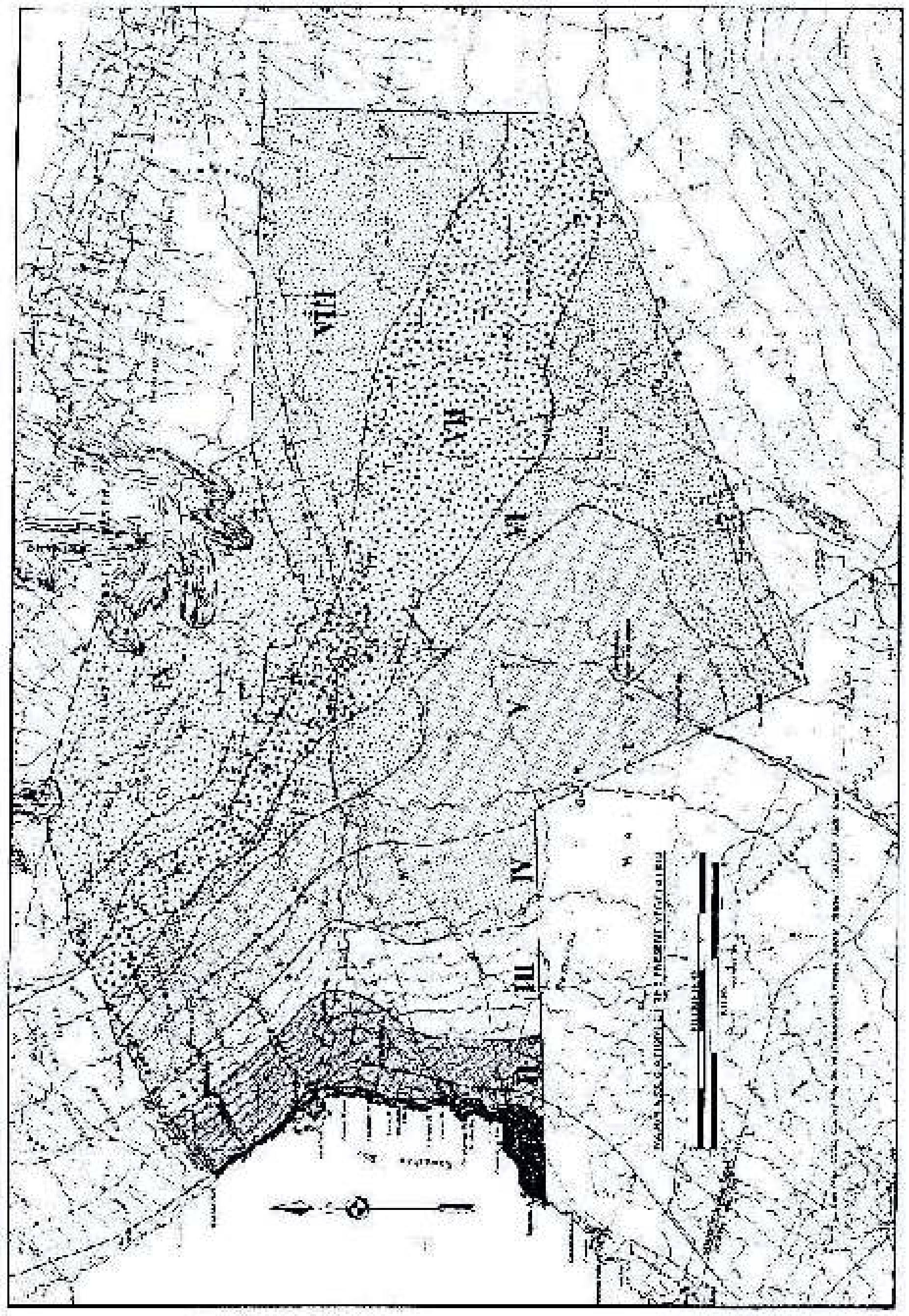
Both past and present vegetation communities in the watershed follow a climatic gradient resulting from elevation and rainfall patterns. Vegetation in the watershed includes native and introduced rangeland grass species, remnants of native plant communities, and invasive alien species of shrubs and trees.

McEldowney (1983) describes eight major plant communities that currently dominate the unforested sections of the region, most of them open grass or grass and shrub communities used for cattle grazing (see Table 2). Pang (1996) also describes existing vegetation in the Kawaihae 2 *ahupua'a*, which includes much of the Pelekane watershed, in a biological survey consisting of both ground reconnaissance and a literature review. According to McEldowney (1983), "[t]he present composition and structure of these communities primarily reflect the long-term cumulative effects of cattle grazing and ranching practices. Although these practices have varied since the cattle industry became more formalized in the second half of the 19th century..., the intentional and accidental introduction of grass and herb species, combined with continued grazing and browsing pressures from cattle, have contributed most significantly to the alteration" (p. 409).

**Table 2: Description of McEldowney's (1983) Zones of Current Major Plant Communities (from Pang 1996)**

| Zone | Distinguishing Characteristics | Elevation |
|---|---|---|
| I | Tall, closed canopy (60%) kiawe (*Prosopis pallida*) thickets interspersed with open stretches resembling Zone II. The understory also resembles Zone II. This area was not intensively surveyed. | 0-20 ft. |
| II | Slopes covered with an open-to-scattered canopy, medium stature (15-40%) cover) kiawe interspersed with closed-canopy kiawe thickets along intermittent stream channels. Grassland dominated by buffelgrass (*Cenchrus ciliaris*) mixed with pili (*Heteropogon contortus*). | 20-640 ft. |
| III | Open-to-closed canopy kiawe occurs almost continuously along stream channels and in scattered stands in flats and swales. Grassland on open slopes is dominated by buffelgrass, mixed with a larger proportion of pili than in Zone II. Abundance and diversity of shrubs is slightly greater than in Zone II. | 640-1,500 ft. |
| IV. | Predominantly a shrub and grassland interspersed with very scattered patches of kiawe. The abundance and diversity of native and exotic shrubs, exotic grasses, and exotic herbs is greater than Zone III. Fountain grass (*Pennisetum setaceum*) dominates the corridor and associated exotic grasses dominate most of the zone to the north. | 1,500-2,000 ft. |
| V. | A mixed shrub and grassland dominated by natal redtop, and Bermuda grass (*Cynodon dactylon*), interspersed with other exotic grasses, native and exotic shrubs, and exotic herbs. Abundance and diversity of exotic herbs is greater than in Zone IV. | 2,000-3,000 ft. |
| VI. | Contains the major characteristics of Zones V and VII. Knolls and exposed areas resemble Zone V and the swales and protected flats resemble Zone VII. Planted and adventive exotic tree species occur in scattered segments. | 3,000-3,600 ft. |
| VII. | Grassland dominated by Kikuyu grass (*Pennisetum clandestinum*) mixed with rattail grass (*Sporobolus africanus*). The abundance and diversity of shrubs, herbs, and other grasses are much less than Zones V and VI. Several areas are planted with exotic trees as windbreaks. | 3,600-4,000 ft. |
| VIII. | Grassland composed of mixed exotic grasses and exotic herbs. Species are more typical of wet pasture communities. Exotic trees are planted in rows or stands as windbreaks. | 4,000-5,000 ft. |

**Figure 3: Zone of Major Communities of Present Vegetation (McEldowney 1983)**



Based on her study, McEldowney (1983) was able to document relict vegetation patterns in the region. The term “relict vegetation” is defined as “...what remains of former communities, either as scattered individuals that are not reproducing regularly and will eventually disappear, or as members of isolated communities that are reproducing and maintaining themselves on a limited scale” (McEldowney 1983, p. 412).

She describes six vegetation zones of native plant species above 2,200-ft. elevation which, according to Pang (1996), can be divided into rainforest types (zones 1, 2 and 3) and dry forest types (zones 4, 5 and 6). Tomich and Barclay (1989) describe the historical vegetation of the area as follows: “.... koaia, iliahi, wiliwili, naio, and mamane predominated in the lower areas, and ... this complex gradually gave way to a mixed forest of olopua, kolea, ohia, and hapuu in the higher, wetter regions (p.4)."

Based on these studies, it is possible to get an idea of what types of native plant species were found in the watershed historically. These species are described in the MKSWCD's *Native Species Revegetation Plan for the Pelekane Bay Watershed Management Project* (October 2001). Obviously, it is difficult to know exactly how human pressures altered the distribution and composition of the native plant communities. But, generally, historical accounts document a series of human impacts on the environment of the watershed. The early Hawaiians altered the lands by developing large, irrigated agricultural systems, mostly for taro and sweet potato. The sandalwood (*Santalum paniculatum* or iliahi) trade of 1791-1856 drastically altered the landscape as the slopes were denuded of sandalwood trees. With the arrival of European settlers and whaling ships, the cattle industry was born, and cattle grazed down shrub and tree species and the land was fenced for livestock. Trees were also harvested for firewood. Whereas the streams in the watershed had once been perennial, providing the water supplies for the Hawaiian settlements on the coast, over time and with the changes in landscape, the streams now flow only in times of extreme or continuous rainfall events.

Fire is a major threat to restoring and maintaining a healthy ecosystem in the watershed, and the changing composition of vegetation in the watershed has contributed to an increased fire hazard. Fire contributes to the erosion problem by stripping the land of vegetation. Because grass species now dominate the watershed, it is also possible to describe the watershed's range of vegetation types by elevation in terms of their contribution to the fire hazard.

<u>Lower Elevation: Buffel and pili grassland with kiawe trees (0-1,500 ft. elevation)</u>: The lower zone of the watershed is the driest and hottest, with 5-20 inches of rainfall per year (Shade 1995). Salt tolerant and shoreline species are found near the coast. Further *mauka*, the area is predominantly buffelgrass (*Cenchrus ciliaris*) and pili grass (*Heteropogon contortus*) with scattered kiawe trees (*Prosopis pallida*).

Pili grass is a native species. It is a bunch grass growing up to 3 feet in height. It has bluish-green leaves and narrow flower spikes. Each spikelet is tipped with a twisted reddish-brown awn or bristle about 4 inches long. Pili is not well-adapted to grazing pressure. Buffelgrass, an introduced African species, is adaptable; it grows well in heavy, limestone, and sand soils, can tolerate low pH, and is drought tolerant. It can also withstand heavy grazing. Studies on Oahu show that pili grass communities are declining and have been replaced by communities dominated by one of three African grasses: *Cenchrus ciliaris* (buffel grass), *Pennisetum setaceum* (fountain grass), or *Panicum maximum* (Guinea grass) (Daehler and Carino 1998).

According to Daehler (pers. comm.), both buffel grass and pili grass are well-adapted to fire. While the adults of both species would be killed in a high-intensity fire, the grasses can come back from seedlings, provided live seeds are present. "Seedlings of pili grass tolerate low water conditions better than seedlings of buffel grass, so pili grass (not buffel grass) is likely to become established in the driest areas, assuming seeds are present" (Daehler, pers. comm.). However, "a fire in a *C. ciliaris* community would be expected to spread faster and farther than in pili grasslands, where frequent open rock outcrops had provided barriers to the spread of fire" (Daehler and Carino 1998 citing Mueller-Dombois 1981).

More research is needed on the responses to fire of both pili grass and buffel grass and the long-term effects of fire on these species in the watershed.

The kiawe tree *(Prosopis pallida)* is an introduced species. It can desiccate an area by using all available water by tapping groundwater with its deep root system. This species is generally killed by intense fires, although a small proportion of the trees will survive if the bases are partially protected.

<u>Central Elevation: buffel, guinea, and bermuda grassland with koaia, wiliwili and sandalwood (1,500-3,000 ft. elevation)</u>: In this range, pili grassland grades into mixed grasses and shrubs dominated by buffel, guinea, natal redtop and bermuda grass. Some native and exotic shrubs and herbs are found within this range. Koaia (*Acacia koaia*), sandalwood (*Santalum paniculatum* or iliahi) and wiliwili (*Erythrina sandwicensis*) are found primarily within ungrazed or lightly grazed ravine pockets and protected exclosures.

Fountaingrass is beginning to dominate in elevations between 1,500-2,500 ft. “Fountain grass *(Pennisetum setaceum*), an escaped ornamental introduced in 1926, has spread rapidly ... over large portions of North Kona and South Kohala[, as well as many other dry areas]. ... Usually avoided by cattle [and even feral goats], this stiff-bladed bunch grass increases in dominance following periodic fires” (McEldowney 1983, p. 409). It has the ability to form monotypic stands which increase the fire fuel load of dry lowland regions and, when dry, are highly flammable. The plant is extremely fire-resilient, benefiting from fire at the expense of more palatable, non-fire-hardy grasses.

<u>Upper Elevation: kikuyu grassland with koaia and ohia trees (3,000-5,000 ft. elevation)</u>: Along and *mauka* of the Kohala Mountain Road (Hwy 250) lies an area of temperate, moist, and cool grasslands consisting primarily of the introduced kikuyu grass (*Pennisetum clandestinum*). Kikuyu grows as a dense mat; therefore, it provides better protection against soil erosion. There are scattered pockets of native tree species, primarily in inaccessible gulch areas. Because this part of the watershed normally receives greater amounts of annual rainfall, it is less susceptible to fire. However, the combination of a dry mat of kikuyu, the prevalence of wind, and the access provided by the Kohala Mountain Road has led to numerous small fires along the highway corridor. A fire burned approximately 250 acres in the upper watershed in November 2003.

## C. Precipitation

The average annual rainfall in Pelekane Bay, adjacent to Kawaihae Harbor, is about 5 inches a year, while up to 150 inches a year fall at the summit of Kohala Mountain. Figure 4 delineates average annual rainfall amounts in the watershed. Heavy windward blow-over during the winter months (November to March) normally accounts for most of the annual precipitation in the *mauka* areas. *Kona* storms and localized convection events on the leeward side of the mountain account for much of the moisture in the *makai* areas. Drought conditions in the watershed in recent years have exacerbated the dry conditions in the lower watershed. According to DLNR’s Commission on Water Resources Management, severe drought conditions affected North Hawaii or Kohala in 1996, 1998-1999, and 2002-2003.

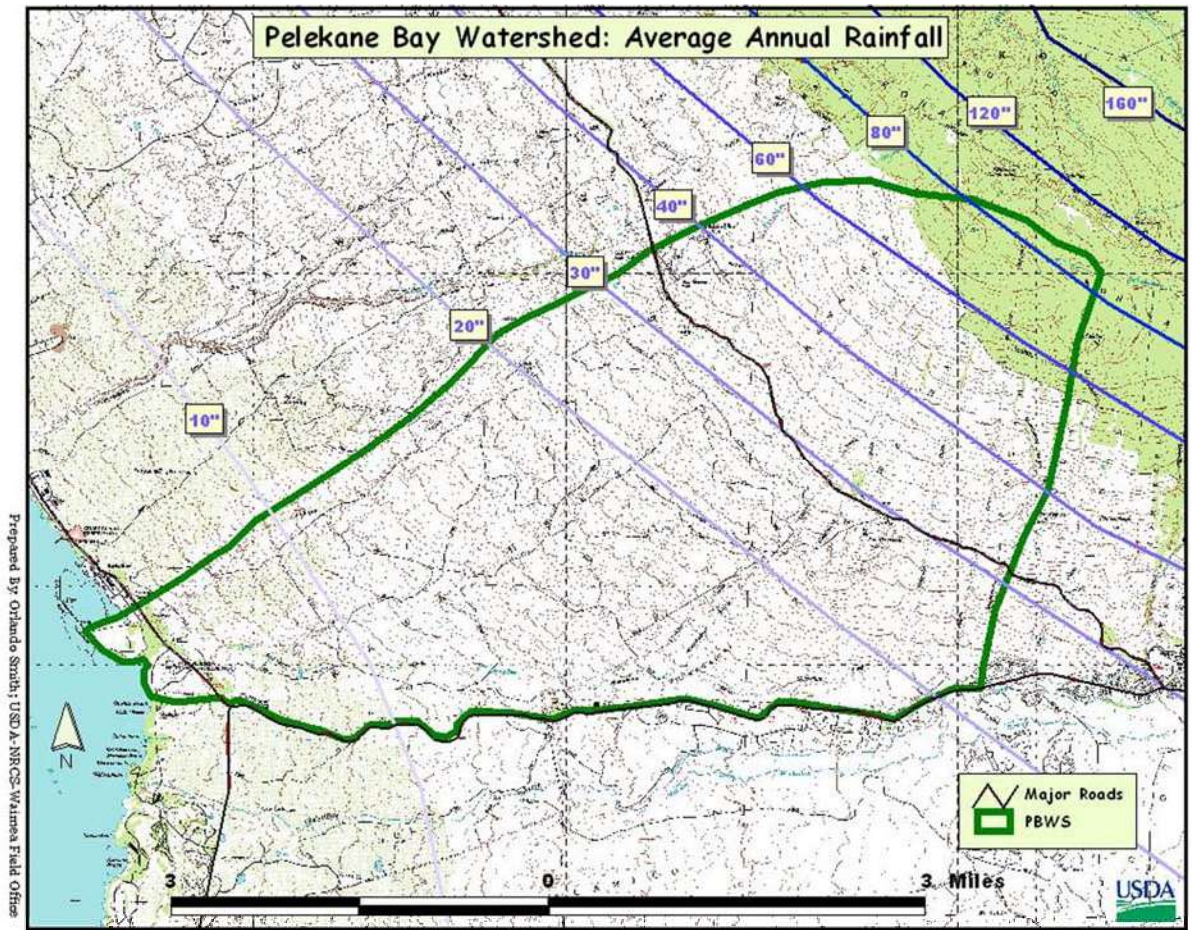



**Figure 4: Average Annual Rainfall (in inches)**

In addition, the Pelekane watershed is typically affected by heavy trade winds, which blow from the northeast down the leeward slope of Kohala Mountain. The strong winds at Kawaihae are sometimes referred to as “mumuku.”

There are four rain gauges located in the Pelekane watershed. One is located at 140-ft elevation at Puukohola Heiau National Historic Site and has been in operation since at least the 1980s. Rainfall data is recorded daily by park personnel.

Two tipping bucket rain gauges with data loggers were installed in the watershed in November 2002. The upper gauge is located just below Highway 250 at 3,300-ft. elevation on the Kohala side of the watershed. The lower gauge is situated one-half mile north of Kawaihae Road at 1,268-ft. elevation. The data loggers record the amount of rainfall every hour and can accumulate over one year of data.

There is a rain gauge at Parker Ranch’s Puu Iki Corral just off of Kawaihae Road at approximately 2,300-ft. elevation. It is read regularly by Parker Ranch cowboys.

In addition to the rain gauges located within the watershed, there are two gauges located on nearby ranches, which provide data relevant to this project. There is a National Weather Service rain gauge located at 3,250-ft. elevation at Kahua Ranch, located about four miles from the watershed. There is also a rain gauge at the 1,390-ft. elevation at Ponoholo Ranch (middlepen), from which rainfall data has been recorded since the 1930s. This gauge is located 4-5 miles north of the watershed, just north of the Kohala Ranch subdivision.

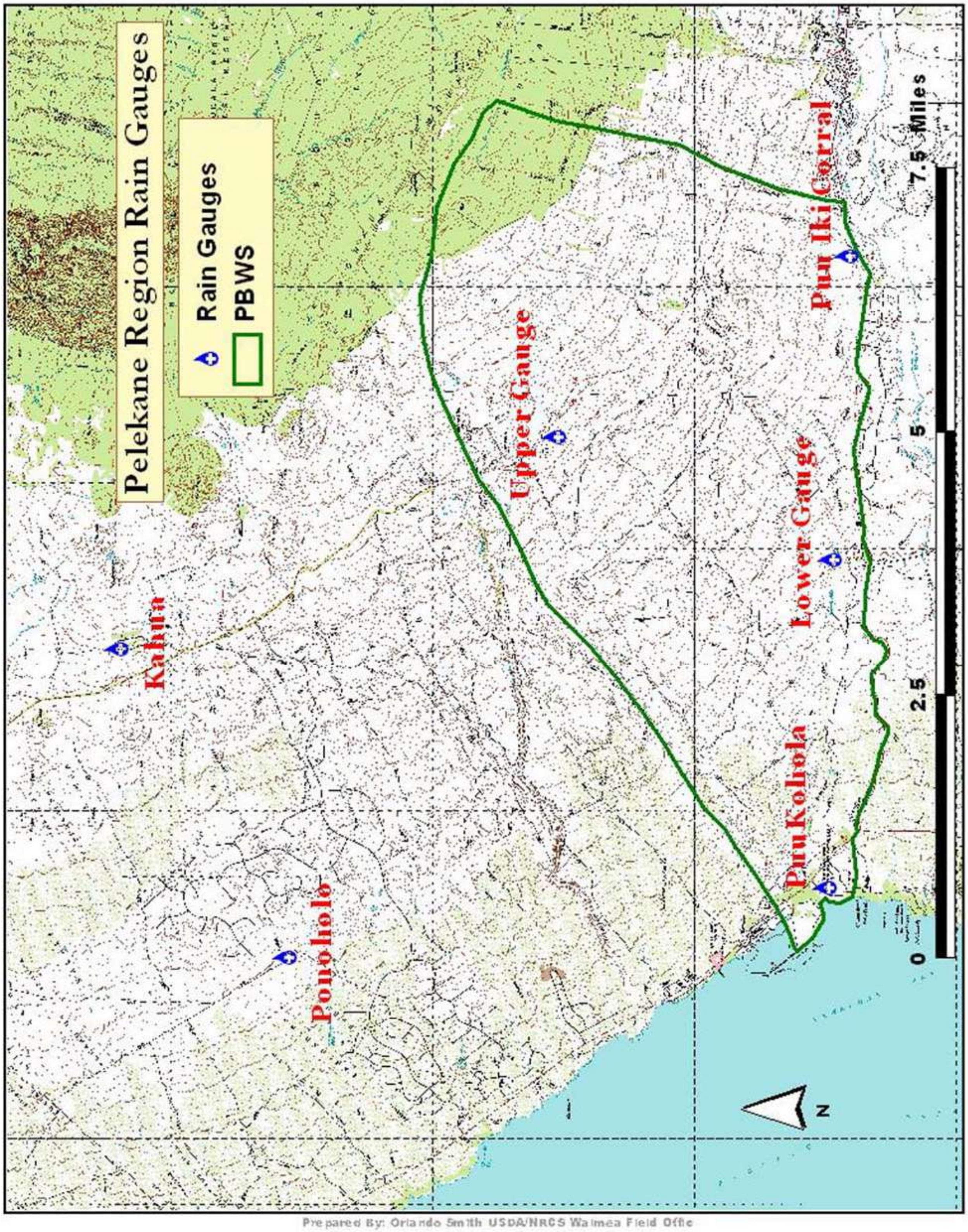



**Figure 5: Locations of Regional Rain Gauges**

Figure 5 maps the locations of these six regional rain gauges. Table 3 summarizes monthly rainfall data from these six gauges between September 2002 and February 2005. Figure 6 charts these monthly rainfall data from January 2003 through December 2004. It is interesting to note that while the monthly rainfall amounts vary by gauge, all generally experience "peaks" in rainfall at the same time.

**Table 3: Monthly Rainfall In and Adjacent to Pelekane Bay Watershed**

| Month | Puukohola Heiau NHP | Lower Gauge Pelekane | Ponoholo Ranch Middle Pen | Puu Iki Corral | Upper Gauge Pelekane | Kahua Ranch |
|---|---|---|---|---|---|---|
| | 140-ft. | 1,268-ft. | 1,390-ft. | 2,300-ft. | 3,300-ft. | 3,250-ft. |
| Feb 05 | 0.81 | 0.01 | 1.15 | 1.75 | 1.07 | 2.61 |
| Jan 05 | 3.94 | 0.00 | 6.73 | 7.00 | 8.47 | 8.48 |
| Dec 04 | 0.15 | 0.04 | 0.75 | 0.00 | 1.02 | 3.24 |
| Nov 04 | 0.20 | 0.08 | 0.00 | 0.50 | 1.75 | 6.50 |
| Oct 04 | | 0.53 | 1.94 | 2.75 | 3.31 | 3.29 |
| Sept 04 | | 0.01 | 0.00 | 0.00 | 0.10 | 0.73 |
| Aug 04 | 2.87 | 0.04 | 1.75 | 0.55 | 2.05 | 3.54 |
| July 04 | 0.00 | 0.02 | 0.00 | 0.00 | 0.20 | 1.23 |
| June 04 | 0.51 | 1.94 | 1.10 | 0.00 | 0.87 | 1.40 |
| May 04 | 0.87 | 4.73 | 3.66 | 2.75 | 5.93 | 5.90 |
| April 04 | 1.06 | 1.69 | 0.60 | 0.00 | 1.99 | 9.08 |
| Mar 04 | 4.60 | 6.99 | 6.67 | 11.25 | 9.04 | 19.39 |
| Feb 04 | 3.31 | 5.27 | 4.01 | 0.00 | 4.75 | 5.66 |
| Jan 04 | 3.07 | 4.78 | 5.05 | 5.10 | insuf data | 4.15 |
| Dec 03 | 1.63 | 2.02 | 2.60 | 1.50 | no data | 2.71 |
| Nov 03 | 0.58 | 0.34 | 0.40 | 0.00 | no data | 1.31 |
| Oct 03 | 0.34 | 0.29 | 0.35 | 0.00 | no data | 0.03 |
| Sept 03 | 0.02 | 0.17 | 1.33 | 0.80 | no data | 1.67 |
| Aug 03 | 0.24 | 0.15 | 0.00 | 0.00 | no data | |
| July 03 | 0.00 | 0.03 | 0.00 | 0.00 | 0.54 | 1.47 |
| June 03 | 0.83 | 1.24 | 3.75 | 0.50 | 1.81 | 1.55 |
| May 03 | 0.02 | 0.02 | 0.00 | 0.00 | 0.04 | 0.06 |
| April 03 | 0.14 | 1.15 | 0.80 | 0.00 | 0.76 | 0.33 |
| Mar 03 | 1.21 | 2.60 | 0.80 | 0.40 | 2.67 | 2.43 |
| Feb 03 | 0.69 | 1.17 | 0.95 | 1.30 | 1.90 | 4.79 |
| Jan 03 | 1.052 | 2.01 | 2.17 | 2.65 | 3.39 | 3.38 |
| Dec 02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.20 | 1.59 |
| Nov 02 | 0.00 | | 0.00 | 0.00 | | 0.36 |
| Oct 02 | 1.32 | | 0.90 | 0.00 | | 0.87 |
| Sept 02 | 0.37 | | 1.29 | 0.00 | | 0.94 |

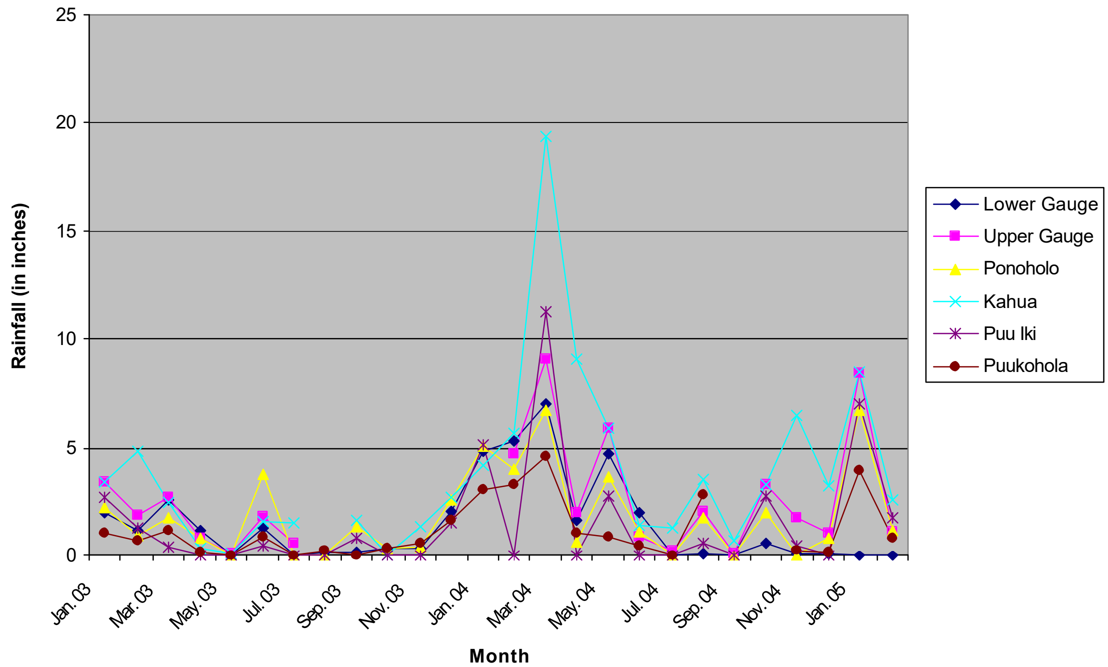



**Figure 6: Monthly Rainfall (in inches) at Six Rain Gauges**

## D. Drainage

Because the island is so young, geologically-speaking, there are few well-formed drainageways in the watershed. Instead, there are many small, braided channels throughout the watershed, which eventually drain into the six named gulches within the watershed — Makahuna, Palihae, Luahine, Waiakamali, Makeahua, and Pauahi. These gulches join above Highway 270 and outlet at two shoreline locations. Makahuna and Palihae join above Highway 270 at about 300 feet elevation and are directed into Kawaihae Harbor as Makahuna Gulch. Makeahua, Luahine, Waiakamali, and Pauahi join at about 1,200 feet elevation and outlet into Pelekane Bay as Makeahua Gulch. Four additional drainageways outlet into Makeahua Gulch at various locations below 1,200 feet elevation. Makeahua Gulch drains approximately 85% of the watershed.

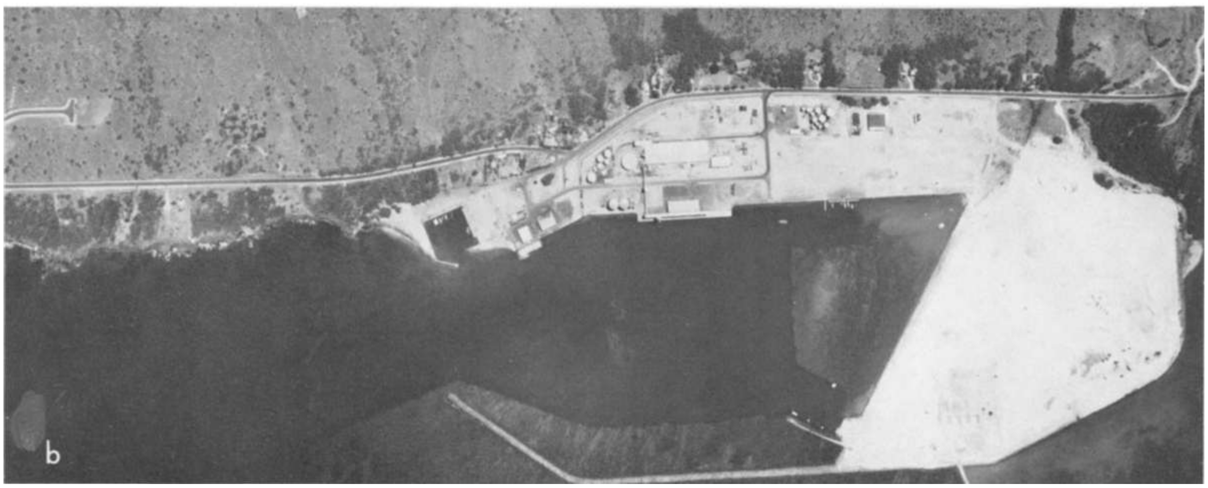
There are no perennial streams on leeward Kohala. Some streams are perennial in the upper reaches, but intermittent at lower elevations. Streamflow is generally limited to flows in the gulches and overland during rainfall events. Localized heavy rainfall and storms cause flooding, called freshets or spates, which contribute to the flashy characteristic of Hawaiian streams. The photos in Appendix A provide a classic illustration of this flashy characteristic.

Under normal conditions, there is a berm at the mouth of the watershed and no streamflow into the ocean. Pelekane Bay, the current mouth of the watershed, lies between Puukohola Heiau to the south and the coral flats adjacent to Kawaihae Harbor to the north. The original outlets of the watershed have been blocked by the creation of Kawaihae Harbor and channelization of the flows around it.

Experts have noted that much of the sediment retention in Pelekane Bay may be attributable to the lack of nearshore circulation caused by the construction of Kawaihae Harbor in 1959. In fact, Jokiel "considers the loss of the littoral drift current carrying sediment out of Pelekane Bay to be the major reason for the present siltation of the bay" (MKSWCD 1998). The virtual absence of consistent circulation means that the sediments in the bay are rarely "flushed" out but rather resuspended each time there is heavy weather.

**Photos: Stream channel in normal dry condition (top) and following storm event (below)**


**Photos: Kawaihae Bay before (top) and after (bottom) construction of Kawaihae Harbor in 1959**



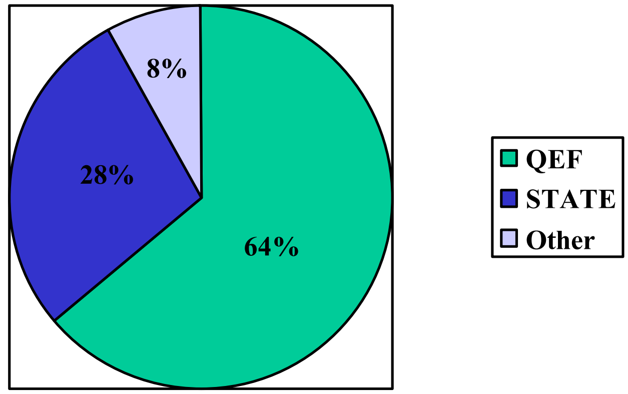

## E. Cultural Resources in Pelekane Bay

In the past, Pelekane Bay was a historical and cultural center of native Hawaiians. Puukohola Heiau sits atop the “Hill of the Whale”, overlooking Pelekane Bay. This heiau is considered the most important structure associated with the founding of the kingdom of Hawaii by Kamehameha. Mailekini Heiau is situated below Puukohola Heiau halfway down the hill, while Hawaiian oral tradition and early local informants suggest another temple, Hale o Kapuni, existed underwater just offshore in Pelekane Bay. Though this submerged heiau has never been located or documented through underwater archeology, local lore relates that it was dedicated to the shark gods. Tidal wave activity and the silting resulting from harbor construction activities have covered any features in this area. The Bay is one of the few places in Hawaii where the black tip reef shark is common and can be seen from shore. The three heiau are now part of the Puukohola National Historic Site of the National Park Service.

**Photo: Looking across Pelekane Bay to Puukohola and Mailekini heiaus**

## F. Land Ownership in the Watershed

There are few land owners within the Pelekane Bay watershed. Queen Emma Foundation, a nonprofit organization dedicated to supporting and advancing health care in Hawaii, owns 7,828 acres, or 64%, of the watershed. It leases most of this land to Parker Ranch. The State of Hawaii, through the departments of Land and Natural Resources (DLNR) and Hawaiian Home Lands (DHHL), is the second largest land owner with 3,376 acres, or 28%, of the watershed. Parker Ranch is the lessee of the DLNR land, and Thelma Kaniho leases the DHHL land. The remaining lands are held by a number of smaller landowners.




## G. Land Use in the Watershed

Parker Ranch is the primary user of the Pelekane watershed. The Ranch uses lands leased from Queen Emma Foundation and the State of Hawaii for cattle grazing. These account for approximately 85% of the watershed.

Other land users include a DHHL lessee ranch, a private poultry operation, an agricultural subdivision, a small residential subdivision, private properties along Kawaihae Road, and Catholic Charities' transitional housing for the homeless.

**III. WATER QUALITY PROBLEM**

The water quality of Pelekane Bay is impaired almost exclusively by sediment and the resulting turbidity. According to Kam (1998) as cited in the Pelekane Bay Coordinated Resource Management Plan (CRMP), soil erosion from sheet and rill erosion in the 1990s varied from 0.6 tons/ acre/year (t/a/y) in the kikuyu grass areas above the Kohala Mountain Road to about 2.5 t/a/y in the middle elevations to 9 t/a/y in the lower watershed with low rainfall and areas damaged by past wildfires. The area below 1,600 ft. elevation produced the most sediment, but excessive erosion was common up to 2,500 ft. Pedestaling around the base of grass plants caused by water and wind erosion was evident and soil surface crusting was present. Vegetative cover was 50% or less in the lower elevations during this time (Kam 1998). These soils are hydrophobic[2], which in desert conditions increases runoff potential. The dry conditions create a capped soil that the seeds cannot penetrate without hoof action or mechanical crushing of the crust. Soil loss has been exacerbated by years of drought conditions in the watershed. The current condition of the watershed is much improved as a result of on-the-ground management measures and increased rainfall over the past 2 years.

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[2] Said of materials and surfaces that have little or no affinity for water molecules. Hydrophobic soils resist hydration, falling water beads on the surface and tends to run off when sloping.

## IV. WATER QUALITY GOALS

The primary purpose of the Pelekane Bay Watershed Management Project is to reduce soil erosion in the watershed by improving land management practices and restoring vegetative ground cover.

The goals of the project are:

- to increase groundcover density and quality in the watershed;
- to minimize the number of fires within and adjacent to the watershed;
- to restore damaged groundcover and areas of bare soil in the watershed, as practicable;
- to reduce sediment deposits into Pelekane Bay from upland watershed areas; and
- to measure the success and effectiveness of watershed restoration and protection activities.

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## V. MANAGEMENT PROGRAM

Outlined in this chapter are recommended actions to implement the major goals of the Pelekane Bay watershed management project. For each recommended action, responsible parties, relative cost, and level of priority are identified. This information will be useful in determining specific projects for which to pursue funding and the sequence in which to focus resources. While the management program outlines a wide range of proposed activities and projects, these will not be implemented until specific funding is secured. In addition, specific actions may need to be further refined through the management process, as new information is obtained and circumstances evolve.

**Management Goal 1: <u>Increase Groundcover Density and Quality.</u>**

Healthy groundcover is essential to holding soil in place. Both overgrazing and fire have a detrimental effect on the viability of groundcover. Therefore, a key aspect of preserving groundcover is to ensure that proper grazing techniques are used and to reduce the fire hazard in the watershed.

When the watershed management project began in 1994, the 11,125 acres grazed by Parker Ranch was divided into four large paddocks: two above Kohala Mountain Road (Hwy. 250) and two below. The size of the paddocks made it difficult to graze the paddocks evenly and efficiently, with the cattle concentrating on the most palatable species near water sources. The size of the paddocks also made it difficult to get water throughout the area. The first grant from the Department of Health in 1994, along with some EQIP funding from NRCS, funded 7 miles of fencing and installation of water lines, tanks, and troughs to increase the number of paddocks in the lower watershed (below Kohala Mountain Road) from 2 to 9. This enabled Parker Ranch to begin rotational grazing, thereby allowing the lands to be grazed more efficiently, rested for a greater portion of time, and maintained in a healthier condition. Rotational grazing can “be an effective tool to reduce fuel loads and to stimulate healthy ground cover on bare soils” (MKSWCD 1998, p.22).

In early 2000, a one-million gallon reservoir was installed at Kawaihae Uka I. Parker Ranch provided the excavation work and purchased the sub-liner, while the District used grant funds to purchase the pond liner. The installation of this *mauka* reservoir provided a consistent source of water to the watershed, also enhancing Parker Ranch’s ability to rotate cattle through numerous paddocks.

In 2001, the Natural Resources Conservation Service (NRCS) established general guidelines for judging proper grazing use on grass pasture as part of its Standards and Specifications for Prescribed Grazing (528A) (see Table 4). Use of these guidelines and removing cattle before minimum heights are exceeded aids in plant vigor, increases cover for erosion prevention, and helps provide drought reserve. Since 2001, the District, in partnership with NRCS, has conducted semi-annual stubble height monitoring to assess proper grazing and grass heights. The monitoring program is described under Management Goal 5.

In 2002-2003, the District used grant funds to fence the lower boundary of the watershed, from the Kohala side of the watershed along Kawaihae Road *mauka* to just below Waiemi subdivision. This 27,000-ft. *makai* boundary fence restricts access into the watershed from the adjacent roadways, thereby reducing the potential for accidental and intentional fire starts, and enables cattle grazing to reduce fine fuel loads adjacent to residential areas. In 2005, Parker Ranch installed water troughs in this area and began grazing cattle.

Because of higher rainfall, the watershed area *mauka* of Kohala Mountain Road (Hwy. 250) tends to be more productive in terms of feed. In addition, the kikuyu grass can be grazed sustainably to shorter heights. In 2004, the District funded the installation of 5.5

**Table 4: General Guidelines for Judging Proper Grazing Use on Grass Pasture**

| Key Grass Species | Minimum Height to Begin Grazing (inches)[3] | Minimum Height to Remove Livestock (inches)[4] | Recovery Period (days)[5] |
|---|---|---|---|
| Giant Bermuda grass | 4 - 6 | 2 | 18-40 |
| Buffel grass | 8 | 3 | 30-60 |
| California grass[6] | 6 | 2 - 4 | 18-40 |
| Dallis grass | 8 | 3 | 30-60 |
| Green panic grass | 12 | 4 | 45-60 |
| Guinea grass | 12 | 4 - 5 | 45-60 |
| Kikuyu grass | 3 - 9 | 1 - 2[7] | 18-40 |
| Limpo grass | 6 | 3 | 30-60 |
| Napier grass | 12 - 18 | 5 - 7 | 45-60 |
| Orchard grass | 8 | 3 | 30-60 |
| Pangola grass | 4 - 6 | 3 | 30-60 |

[3] For many species, height to begin grazing is not as important as the stage of growth. When possible, begin grazing between the boot stage (when the seed heads begin to emerge from the sheath) and early flower stage.
[4] Remove livestock before minimum height is reached on the majority of the forage.
[5] Recovery period will vary according to the climatic conditions, soil moisture and fertility, and amount of leaf area remaining after grazing.
[6] Manage for grass when interseeded with a legume. Exception is when grass is interseeded with tropical legumes such as glycine and desmodium.
[7] Includes the height of the mat.

established by NRCS. Figure 7 demarcates the fence lines in the watershed, indicating original fences and the subsequent additions funded under the watershed management project.

An unanticipated problem exacerbated by the increased water development in the lower watershed is the proliferation of feral goats attracted by the water. The goat population in this area likely numbers in the thousands, and, without hunting pressure, the population will only increase. These browsing ungulates are having a significant impact of the groundcover in these lower paddocks. A control program needs to be devised to address this problem.

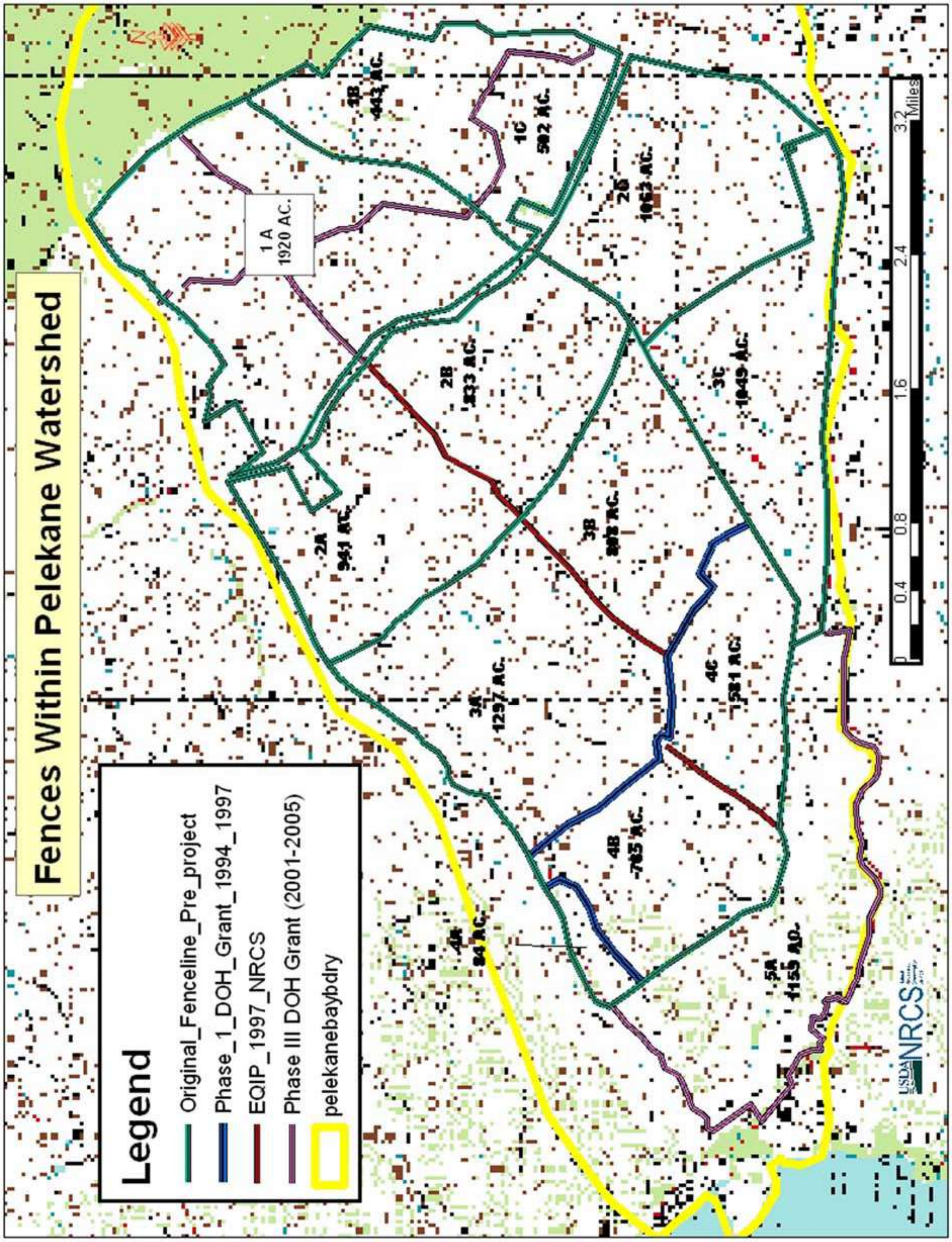
*Recommendations for preserving groundcover:*

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Encourage land users who graze livestock in the watershed to continue to implement grazing management plans, with technical assistance from NRCS and incorporating the Standards and Specifications for Prescribed Grazing, to help maintain healthy groundcover. | MKSWCD, NRCS | Low | High |
| Install additional fencing and water to further subdivide the watershed, as feasible, to reduce paddock size and increase the areas of the watershed accessible to cattle. | MKSWCD, Parker Ranch | High | High |
| Continue to develop water in the lower watershed to enable cattle grazing to reduce fine fuel loads adjacent to Waiemi subdivision, Kawaihae Village, and Catholic Charities transitional housing. | MKSWCD, Parker Ranch | Medium | High |
| Assess techniques for eliminating feral goats in the watershed and evaluate their feasibility. Initiative goat eradication program. | MKSWCD, Parker Ranch, QEF | Medium | High |

**Management Goal 2: <u>Minimize Fires Within and Adjacent to the Watershed.</u>**
Fire is a major threat to maintaining healthy groundcover in the watershed. It contributes to the erosion problem by stripping the land of vegetation. Access roads and fire breaks can further contribute to erosion if not carefully planned and properly restored following a fire.

In November 2003, a fire accidentally started by private forestry workers burned 250 acres of grasslands in the watershed at Puu Loa, *mauka* of Kohala Mountain Road. Only the construction of a fire break around the burn area and tied into the Kohala Mountain Road prevented the spread of the fire into the forested watershed. Following the fire, there was concern that the fire break would be prone to both wind and water erosion because it was wide, bare, and steep and the soils hydrophobic in places. Fortunately, there were some light rains in the weeks following the burn, which allowed the area to green up without significant loss of soil. By January, the grass cover in the burned area had been restored.

**Figure 7: Fences Within the Pelekane Bay Watershed**



In September 2004, a fire of a suspicious nature started along the south side of Kawaihae Road, across from the Pelekane watershed. The fire burned approximately 1,500 acres and caused the evacuation of several neighborhoods. Fortunately, the Hawaii Fire Department was able to control the fire and prevent it from jumping the road into the Pelekane watershed.

For a list of other fires in and around the watershed, see the District's *Fire Management Plan for the Pelekane Bay Watershed Management Project* (October 2001).

**Photo: November 2003 Fire in the Upper Watershed**

**i. Fire Prevention**: Fire prevention is critical to maintaining groundcover density and quality. "Fire prevention includes those activities intended to reduce the number and/or severity of fires. Since the cost of preventing a wildfire is almost certainly less than the cost of suppressing it, fire prevention is one of the most cost-effective fire management activities available..." (U.S. Army 2000, p. 4-1). Fire prevention activities in the Pelekane watershed include education, fuels management, controlling access, and pre-suppression planning.

a. <u>Education</u>: Education is important to help establish awareness among residents and users of the watershed of its fire potential, especially in the lower areas. Some public education has occurred in the past and is most pronounced immediately following a fire. Regular education is needed to remind people about the ongoing fire hazard and the detrimental impacts of fire on watershed resources. In addition, fire suppression personnel need to be educated regarding resource values in the watershed, access points and roads for use in fire suppression, and available water resources.

The not-for-profit West Hawaii Wildfire Management Organization (WHWMO), established in 2002 to protect, conserve and enhance resource values in West Hawaii by reducing wildfire frequency and size, has initiated public education and outreach activities. The organization's goals are to develop and implement fuels management activities, to provide educational opportunities about wildfire, to conduct fuels management research, to promote the protection of native ecosystems from the effects of wildfire, and to promote and facilitate a multi-faceted approach to wildfire prevention and management. Participating agencies and organizations include Hawaii Department of Land and Natural Resources (DLNR), Hawaii County Fire Department, NRCS, U.S. Fish and Wildlife Service (USFWS), U.S. Army, U.S. Forest Service, University of Hawaii Cooperative Extension Service (CES), MKSWCD, and affected landowners and communities. The organization has received Federal Wildland-Urban Interface grant funds to conduct community outreach about the wildland fire hazard and build fuel breaks around selected high-risk communities.

<u>*Recommendations for education:*</u>

| **Activity** | **Responsible Person(s)** | **Cost** | **Level of Priority** |
|---|---|---|---|
| Install signage, as appropriate and permissible, along the highways adjacent to the watershed warning of the fire hazard. Consider including fire danger rating information as part of signage. | DLNR-DOFAW, WHWMO | Low | Low |
| Develop (or use brochure already developed by the Wildland-Urban Interface Hui) and distribute brochure to all residents within the watershed on how to protect structures from wildfire and, conversely, to prevent a structure fire from igniting wildlands. | MKSWCD, WHWMO, DLNR, County Fire Dept. | Low | Medium |
| Institute an annual presentation series focusing on fire prevention and landscaping with fire resistant plants. | B.I. Landscape Assoc, WHWMO | Low | Low |
| Develop public service announcements on radio about fire prevention, and warnings about open fire barbeques and cigarette butts. | WHWMO, County Fire Dept., DLNR | Low | Medium |
| Educate fire suppression personnel about resource values in the watershed, access points and roads for use in fire suppression, and available water resources. | MKSWCD to coordinate with BIWCG, WHWMO, County Fire Dept. | Low | High |

b. <u>Fuel Management</u>: Fuel management is a major component of fire behavior and erosion control, and includes modification of the size, arrangement, and kind of vegetative fuels. “This modification reduces the ignition potential, flame length, and the heat output of a fire” (LA County 1998, p. 3).

Fuel modification can take several forms: changing the vegetation type (to fire resistant plants); reducing fuel volume (by prescribed burning and grazing); and changing the distribution and loading of fuels (mowing or grazing) within a vegetation type (U.S. Army 2000). Typically, a combination of techniques, and perhaps additional techniques, will be needed. The goal is to maintain a fuel condition that makes fire easier to control. Within the Pelekane watershed, two of these forms of fuel modification are most appropriate for implementation: grazing and changing vegetation type.

*Grazing*, or the use of livestock to reduce the amount of vegetation, is one form of fuel modification. While much of the Pelekane watershed is used for grazing cattle, parts of the watershed have historically remained ungrazed because they had not been fenced and there has been no water available for cattle. These areas are closest to the residential communities in the lower watershed and to Kawaihae Road. This has created a situation where the greatest and most flammable vegetative fuel load is closest to areas of the watershed most easily accessible to accidental or intentional fire starts.

As part of the Pelekane watershed management project, the perimeter of this lower area was fenced to restrict access into the watershed from the adjacent roadways and enable cattle grazing to reduce fine fuel loads adjacent to residential areas. The District, partnering with the Hawaii Fire Department, County Department of Water Supply, and Parker Ranch, worked to facilitate access to water in this lower area. In 2005, Parker Ranch installed water troughs and began grazing cattle, using water to move the cattle to critical areas within the lower watershed. Additional fencing and water sources may also be developed in the future to further assist cattle grazing.

*Recommendations for grazing to modify fuel loads:*

| **Activity** | **Responsible Person(s)** | **Cost** | **Level of Priority** |
|---|---|---|---|
| Install cross fencing to divide the lower watershed into the appropriate number of paddocks for impact control and plant health. | Parker Ranch | Medium | High |
| Install a water tank, pipelines, and troughs to provide water for cattle in these paddocks and a source for helicopter water-bucket operations (relates to water resources for fire-fighting, see below). | Parker Ranch | Medium | High |
| Amend the grazing management plan for Parker Ranch to include the lower “new” paddocks to be managed for the purposes of fuel reduction and erosion control. | NRCS | Low | High |

*Changing the vegetative type* may be another form of fuel modification appropriate to the Pelekane watershed. Fountain grass (*Pennisetum setaceum*), an introduced species, is an aggressive invader which is spreading rapidly up the watershed. Because of its flammability, reducing the spread of fountain grass and replacing it with other, more manageable species will help minimize the threat of fires.

*Recommendation for changing the vegetative types:*

| **Activity** | **Responsible Person(s)** | **Cost** | **Level of Priority** |
|---|---|---|---|
| Research the most effective way to control fountain grass in the watershed. | WHWMO, NRCS, CES | Medium | High |
| Implement small-scale experimental fountain grass control project, which can be expanded over time if results are promising. | Parker Ranch, NRCS, WHWMO | Medium | High |

The construction of fuel breaks or fire breaks is another component of fuel management. Fuel breaks are defined as “a strategically located block or strip on which a cover of vegetation has been manipulated to reduce fuel volume or flammability as an aid to fire control” (U.S. Army 2000, p. 4-7). The appropriate width of a fuel break is site-specific and dependent on fuel type, terrain features, and expected fire weather conditions, especially wind direction and speed. Fire breaks tend to be narrower strips cleared or grazed to stubble height, which are potential fire control lines. While these can be created and maintained before the threat of a fire, they are more frequently made during fire control. Both are a buffer or anchor point from which to fight a fire.

Historically, pili grass was found in greater abundance in the lower watershed. Because pili grass has a lower tolerance to grazing pressure, buffel grass (*Cenchrus ciliaris*) has become the more dominant species. While both pili grass and buffel grass are well-adapted to fire, more comparative research is needed on how they each behave in a fire and whether any difference is significant enough to influence the choice of fuel break vegetation in the watershed.

Fuel breaks can also be created by bulldozing a strip of a specific width to remove vegetation that would otherwise burn in a fire. This type of fuel break must be constructed with care to avoid wind and soil erosion and dust problems. In addition, it must be maintained regularly to keep it clear. Such fuel breaks have been created behind Catholic Charities’ Transitional Housing and adjacent to Kawaihae Village.

*Recommendations for construction and maintenance of fuel breaks:*

| **Activity** | **Responsible Person(s)** | **Cost** | **Level of Priority** |
|---|---|---|---|
| Study the expected responses of pili grass and buffel grass to fire to determine if one will be more effective than the other for use as a vegetative fuel break outside of paddock areas. | National Park Service, Univ. of Hawaii, CES | Medium | Low |
| Continue to create fuel breaks around the residential and commercial areas of the watershed. Depending on the results of the above study, this buffer strip could be seeded with pili grass with cattle excluded (a green belt) or seeded with buffel grass and grazed to maintain a short stubble height. | Parker Ranch, Queen Emma Foundation | Low | High |
| Plant a strip of fire-resistant vegetation, the selection of which will be made upon consultation with experts, and provide irrigation using drip lines from the agricultural water system. | Parker Ranch, Queen Emma Foundation | Low | Low |
| Create a fuel break around the scenic lookout on the Kohala Mountain Road. | Parker Ranch, Queen Emma Foundation, in cooperation with adjacent land owner(s) | Low | High |
| Maintain fuel breaks, as necessary, by mowing, grazing, weed-whacking, or other techniques. | land user, adjacent community members | Low | High |

**Photo: Fire Break Construction**

c. Controlling Access: Most fires in the Pelekane watershed are started by people, whether accidentally or intentionally. Until recently, the lower part of the watershed was easily accessible, as evidenced by the trash that has been dumped there. The construction of the perimeter fence, with locked gates, has restricted access to the watershed and reduces the threat of fire.

d. Pre-Suppression Planning: Effective pre-suppression planning enables firefighters and land managers to more easily and effectively control a fire. "Pre-suppression planning focuses on identifying and acquiring the resources needed to suppress anticipated fires once they start ... [and is] done before fire occurrence to ensure timely and effective suppression" (U.S. Army 2000, p. 4-4). Knowing the location in the watershed of water resources, access points, and roads/trails and the types of equipment available from land users for fire suppression will enable a quick and effective initial attack against fire outbreaks.

**ii. Water Resources**: Availability of water is critical to the suppression of fire. Therefore, water sources, such as water tanks, must be placed strategically within the watershed to allow access by fire trucks and/or located within a range that allows a two-minute turn-around time for helicopter water drop operations. While wildfires are less likely in the wetter *mauka* areas of the watershed, more water resources are available. In the *makai* part of the watershed, water is available from the ocean, provided the fire is close enough. In the heart of the watershed, water storage resources are primarily used by 4WD fire trucks and for aerial water bucket operations.

Measures implemented as part of the Pelekane watershed management project have enhanced Hawaii Fire Department access to water in the watershed. In 2002, the Hawaii County Department of Water Supply (DWS), partnering with the District, installed two standpipes (see photo below) on the county water line within the watershed to increase availability and access to water in the watershed for fire-fighting purposes. These standpipes will enable the Fire Department to attach hoses to fill tanker trucks and dip "frog" ponds for aerial fire control. In addition, DWS has recently agreed to allow Parker Ranch to draw water from these standpipes to supply troughs so that cattle can graze down the surrounding fuel load to enhance fire-fighter access and safety.

**Photo: Standpipe on County waterline**

The District has also coordinated the installation of fittings on some pressure-breaking tanks within the watershed - at Puu Kawaiwai on Kohala Mountain Road, below Waiemi subdivision, and within a centrally-located corral within the lower watershed - to enhance fire-fighting capabilities within the watershed. With the fittings, the Hawaii Fire Department can readily access water to fill tanker trucks and dip ponds. Figure 8 shows water resources within the watershed.

*Recommendations for increasing water resources for fire suppression:*

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Install a water tank with 2.5" gate valve outlet for fire fighting access, pipelines, and troughs to provide water for cattle in lower paddocks. (This recommendation under Fuel Management will provide an additional water resource for fire suppression.) | Parker Ranch | Medium | High |
| Develop MOUs with land users within and adjacent to the watershed for use of water for fire fighting purposes. | MKSWCD to coordinate | Low | Medium |

**iii. Vehicular Access for Fire Suppression**: Access into and within the watershed is another important element of successful fire-fighting. Firefighters must be able to get to where the fire is burning and around the fire to prevent its spread. Access roads are also safety features that should enable firefighters to quickly move out of an area that is no longer safe. Access roads may also be used to break up contiguous fuel loads and provide a line of defense from which fire-fighting actions can be effectively executed.

There are access points into the Pelekane watershed from the Kohala Mountain Road and Kawaihae Road. Some of these access points are locked gates requiring a key for entry. Numerous unpaved roads crisscross the watershed; most require high clearance and 4-wheel drive, and some are no longer passable because of ruts, deep dips or unstable substrate. One of the biggest obstacles to effective fire-fighting in the watershed is the state of disrepair of many of the access roads in the watershed. Parker Ranch has recently repaired many roads within the watershed to make them more passable.

*Recommendations for improving vehicular access for fire suppression:*

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Assess the condition of all access roads and trails within the Pelekane watershed. Determine, in order of priority, the repairs that must be done to restore these roads for use in the event of a fire. | MKSWCD, Fire Dept., NRCS, Parker Ranch | Low | High |
| Meet with all land users and partner agencies to discuss repair priorities and schedule, funding sources, and responsibility for regular road maintenance. Discuss with personnel from Pohakuloa Training Area their availability to assist with repairs. | MKSWCD to coordinate | Low | High |

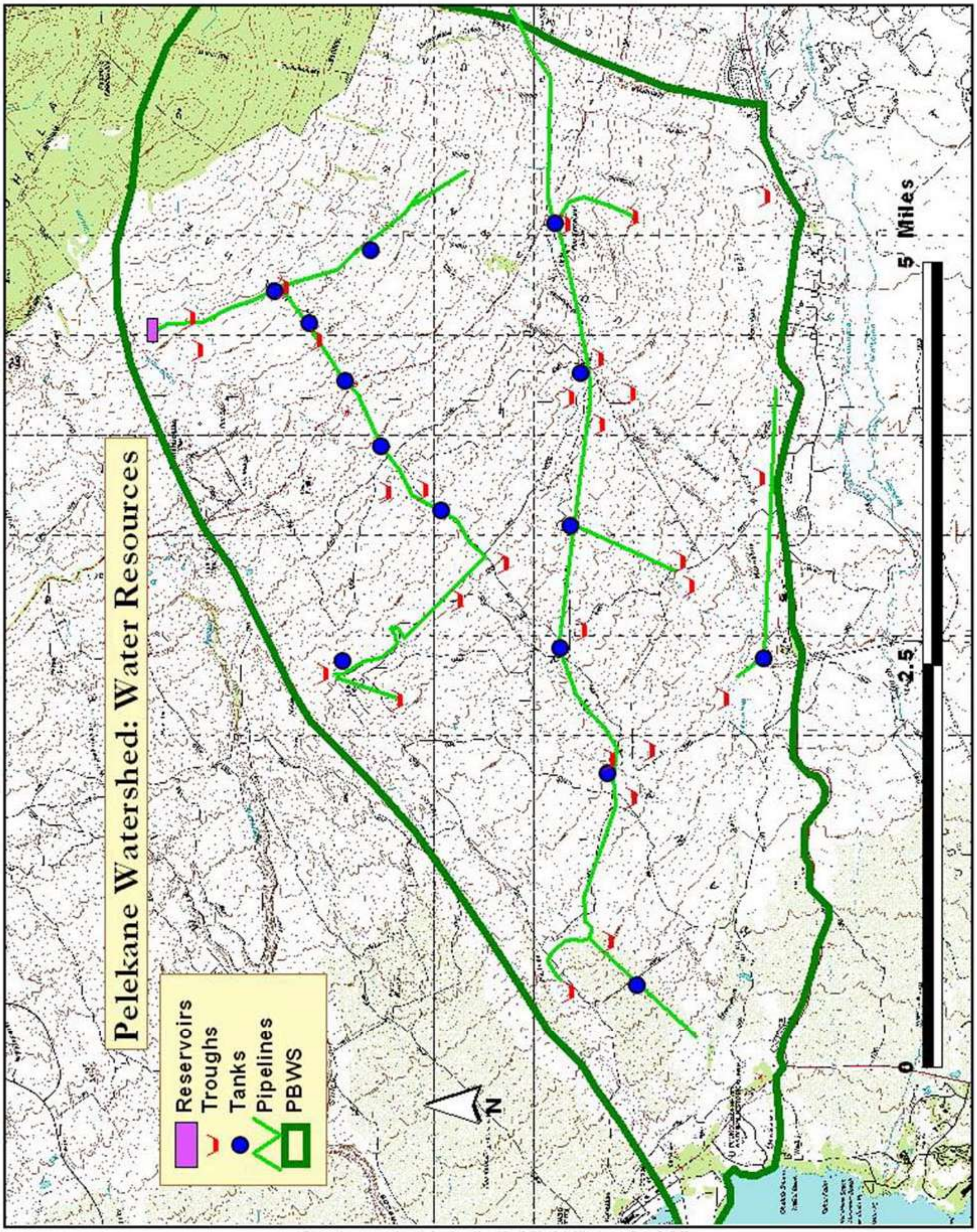



**Figure 8: Water Resources in the Pelekane Watershed**

*Recommendations for improving vehicular access for fire suppression (continued):*

| Activity (continued) | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Repair and maintain access roads, particularly the Tank Trail down to the historic Carriage Trail in the lower section and the HELCO access road. | to be determined | depends on work needed, but likely high | High |
| Assess the need for additional access roads to ensure adequate access into all parts of the watershed. | MKSWCD to coordinate | Low | Medium |
| Investigate feasibility of installing Knox boxes on potentially "high-use" gates or having cut-able links on gate chains. | land users in cooperation with Fire Dept. | Low | High |

**iv. Fire Response Protocol**: As part of pre-suppression planning, it is important for land owners/users and resource and fire suppression agencies to consider how aggressively firefighters should respond to a fire. This is especially important in areas with significant natural and cultural resources or high economic value. Obviously, in areas where fire presents a real and immediate threat to human safety and inhabited property, fires would be aggressively suppressed, even if there is a resulting detrimental effect on the environment. But, unless significant natural, cultural and economic resources are identified and mapped beforehand, these areas requiring special protection will be less obvious to firefighters at the scene. There is a need "to consider land and resource objectives and to decide the appropriate suppression response and tactics which result in minimum costs and resource damage" (U.S. Army 2000, p.5-5). Having such a protocol in place before a fire occurs will ensure that the appropriate agencies are notified immediately following a report of fire (such as DLNR for fires spreading to more remote but valuable parts of the watershed) so that significant resources are protected.

In developing and implementing a fire response protocol, the Mauna Kea Soil and Water Conservation District will work with the Big Island Wildfire Coordinating Group (BIWCG). This is a multi-agency group of wildfire program managers, including representatives from Hawaii Volcanoes National Park, DLNR Division of Forestry and Wildlife, U.S. Army, Hawaii County Fire Department, Hawaii County Civil Defense Agency, and U.S. Fish and Wildlife Service. The purposes of the group are to coordinate training for all levels of wildfire management, and coordinate suppression resources such as communications, access, water and equipment.

In the event of a fire, it is important for the Fire Department and land users to be able to contact adjacent land users and others who can provide assistance in containing the fire. As part of a fire response protocol, a notification and equipment list that is updated regularly is critical.

Recommendations for developing a fire response protocol:

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Draft fire response protocol describing actions to be taken to protect resource values and importance of multi-agency response. Draft and execute an agreement among land owners/users, resource management agencies, and fire response agencies. | MKSWCD to coordinate with BIWCG, DLNR-DOFAW, Fire Dept., National Park Service, U.S. Army | Low | High |
| Develop and maintain a notification and equipment list. | MKSWCD to coordinate | Low | High |
| Identify and map significant natural, cultural and economic resources in the watershed to be a focus of protection in the event of a fire. This activity should involve all primary land users and land owners in the watershed, resource management agencies, and fire response agencies. | MKSWCD to coordinate | Medium | Medium |

**Management Goal 3: <u>Restore Groundcover in the Watershed.</u>**
Sometimes, areas that have been overgrazed, experienced fires, or suffered severe erosion remain bare for long periods of time, exacerbating their erosion potential. This can occur for a number of reasons: absence of seeds in the soil, poor or depleted soil quality, capping of the soil making seed penetration difficult, and lack of rainfall or other form of irrigation. Sometimes, opportunistic species of grasses and plants introduced into an area are less effective for erosion control and create a greater fire hazard (*e.g.*, fountaingrass). In these situations, there may be need for human assistance in revegetating erosion-prone areas.

**Photo: Bare ground in Paddock 4A**

*Recommendations for restoring groundcover:*

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Implement measures identified in the District's *Native Species Revegetation Plan for the Pelekane Bay Watershed* (October 2001). | land owners/ users | variable | Low |
| Restore Paddock 4A, as a demonstration project regarding effectiveness of post-fire revegetation of erosion-prone area, using innovative techniques. | MKSWCD, Parker Ranch, NRCS, QEF | High | High |
| Monitor the effectiveness of this restoration project, with respect to stubble height, percentage vegetative cover, and soil loss before, during and after restoration. | MKSWCD, NRCS, CES | Low | High |
| Based on outcomes of Paddock 4A demonstration project, restore other critical bare areas of the watershed. | MKSWCD to coordinate | High | Medium |
| Assess pili grass' erosion control potential compared to buffel grass and fountain grass. | Puukohola National Historic Site, QEF, USFWS, MKSWCD, NRCS | Medium | Medium |
| Research the most effective way to control fountain grass in the watershed. | Parker Ranch, NRCS, WHWMO | Medium | High |
| Implement small-scale experimental fountain grass control project, which can be expanded over time if results are promising. | Parker Ranch, NRCS, WHWMO | Medium | High |

Not only does fire itself damage the natural environment, but the process of fighting the fire also affects the resources of a watershed. Fire removes vegetation and increases the potential for soil loss. This has occurred in the Pelekane watershed, most graphically in Paddock 4A. Construction of fire breaks during a fire can create channels for future erosion. Therefore, it is critical that post-fire assessments be performed and restoration activities undertaken, preferably before available heavy equipment are released from the site following a fire.

A post-fire assessment of the burned area helps to determine effects of the fire on vegetation and other resource values, and effectiveness of pre-suppression and suppression measures. It also helps assess the damage to fuel breaks and access roads so the repair can occur quickly. Large fires may require post-fire restoration, rehabilitation or revegetation of areas severely impacted by wildfires. There is currently little data available on successful revegetation of burned areas in Hawaii; therefore, studies are needed.

*Recommendations for post-fire assessment and restoration:*

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Develop post-fire assessment process to determine effects of the fire on vegetation and other resource values, and effectiveness of pre-suppression and suppression measures, and to assess damage to fuel breaks, and necessary restoration of fire breaks and access roads. | MKSWCD to coordinate with land owners/ users and Fire Dept. | Low | High |
| Implement post-fire assessment after all major fires. | Fire Dept. to coordinate | Low | High |
| Repair fuel breaks and access roads, as necessary, following a fire, and restore fire breaks. | Land user | depends on work needed | High |
| Conduct post-fire restoration, rehabilitation, or revegetation, as needed, following all major fires. | Land user | depends on work needed | High |

**Management Goal 4: Reduce Sedimentation in Pelekane Bay.**

While implementation of erosion-control measures within the watershed will reduce the potential for soil loss from the watershed, the sedimentation problem in Pelekane Bay may remain for numerous reasons. It is unrealistic to imagine that management measures will be implemented in all parts of the watershed immediately. The gulches and smaller drainage channels may already contain sediments that will be flushed downstream during future large rainfall events. Because of reduced nearshore circulation within Pelekane Bay, current sediments may be resuspended during large swell events but not flushed out of the bay.

Until 1959, Pelekane Bay was part of a large embayment at Kawaihae with a long sandy beach. The building of Kawaihae Harbor in 1959 and the deposition of the dredge spoils on the coral flats has limited ocean circulation in Pelekane Bay, contributing to the turbidity problem. In fact, Jokiel "considers the loss of the littoral drift current carrying sediment out of Pelekane Bay to be the major reason for the present siltation of the bay" (MKSWCD 1998).

Over the years, a number of ideas have circulated about how to reduce the sedimentation in Pelekane Bay, including: dredging the bay to remove existing sediment depositions, building a sediment basin to "catch" and settle sediments before they can be deposited into the bay, and creating a channel or canal through the coral flats to restore some of the circulation and natural flushing of the bay. These ideas would all entail large expenditures of monies and require multi-agency collaboration. Therefore, it is important that studies are undertaken to determine which, if any, of these ideas warrants further attention.

In 2002, the District agreed to be the local sponsor for a U.S. Army Corps of Engineers' study under Section 1135, Water Resource Development Act of 1986, Environmental Restoration. The purpose of the Pelekane Bay Ecosystem Restoration Project is to reverse degradation to the coral reef ecosystem and improve water quality in Pelekane Bay to conditions that prevailed prior to the development of the Kawaihae Deep Draft Harbor area. Restoration features being evaluated include sediment retention facilities and erosion control measures. Unfortunately, no funds have been provided since 2004, due to funding constraints.

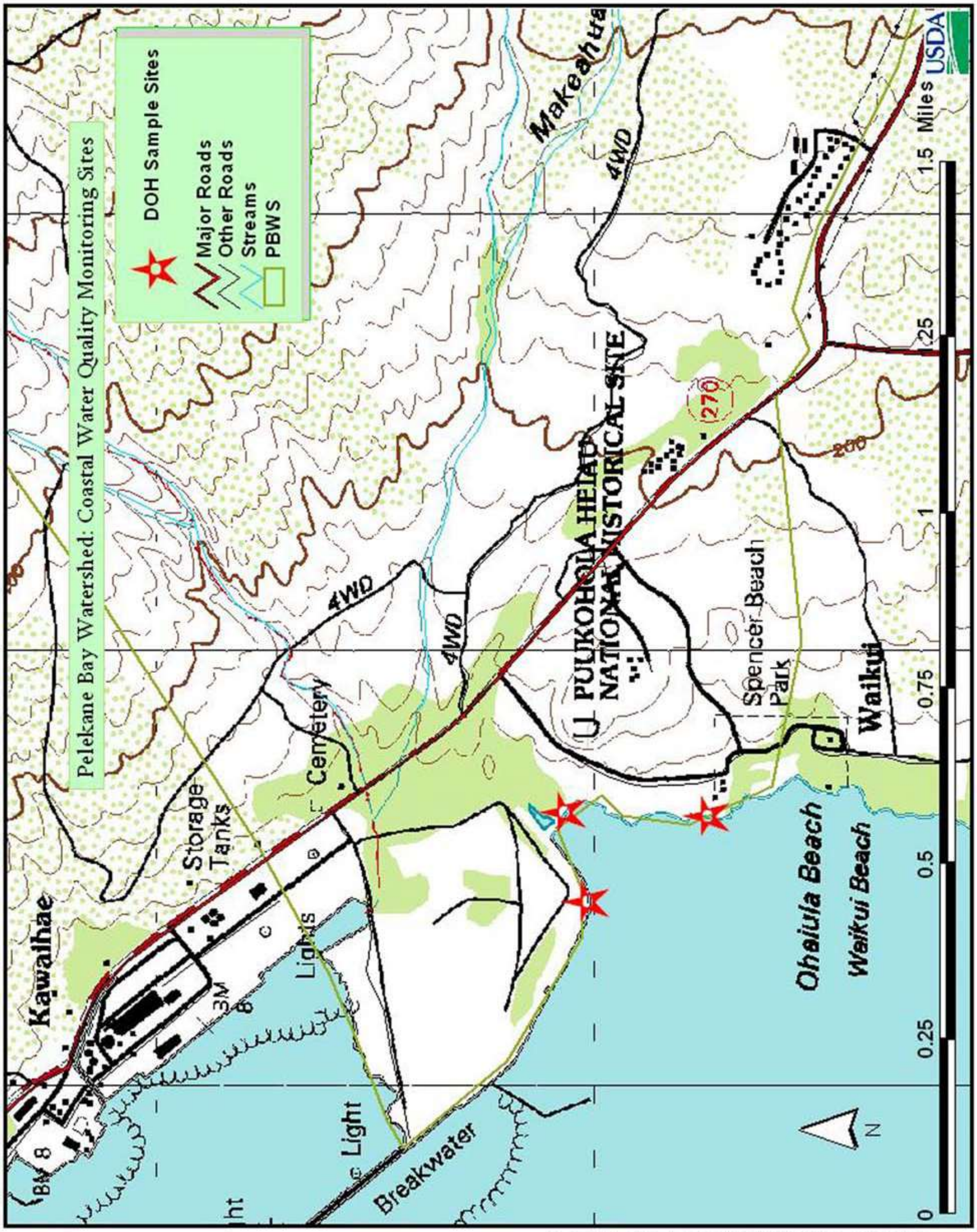
*Recommendations for reducing sedimentation in Pelekane Bay:*

| **Activity** | **Responsible Person(s)** | **Cost** | **Level of Priority** |
|---|---|---|---|
| Request Congressional funding for continued feasibility studies as part of the Pelekane Bay Ecosystem Restoration Project. | MKSWCD | Low | High |
| Explore the feasibility and cost-effectiveness of creating a catchment basin and/or sediment basin in the old quarry and/or on the coral flats adjacent to Pelekane Bay. | U.S. Army Corps of Engineers | depends on needed studies | High |
| Explore the feasibility and cost-effectiveness of dredging the bay in a manner as to preserve any remaining historic sites within the bay (*i.e.*, the submerged shark heiau Hale o Kapuni). | U.S. Army Corps of Engineers | depends on needed studies | High |
| Explore the feasibility and cost-effectiveness of creating a channel or canal through the coral flats to restore circulation and natural flushing of the bay. | U.S. Army Corps of Engineers | depends on needed studies | High |
| Explore other ideas for reducing the sedimentation in Pelekane Bay. | U.S. Army Corps of Engineers | Low | High |
| Implement most feasible and cost effective solution, if any, to reduce sedimentation of Pelekane Bay, provided funding is available and inter-agency and public support widespread. | depends on which solution is selected | High | High |

**Management Goal 5: <u>Measure the Success and Effectiveness of Watershed Restoration and Protection Activities.</u>**

The water quality of Pelekane Bay is impaired almost exclusively by sediment and the resulting turbidity. On November 2, 2003, DOH conducted a one-time water quality sampling in Pelekane Bay. Samples were collected from three sites (Figure 9): at the north end of the bay near the coral flats (N 20° 01’ 38.9", W 155° 49’ 20.8"), near the middle of Pelekane beach (N 20° 01’ 40.8", W 155° 49’ 23.7"), and at the south end of the bay near Spencer Park (N 20° 01’ 30.1", W 155° 49’ 23.9"). Table 5 summarizes monitoring results.

**Figure 9: Coastal Water Quality Monitoring Sites**




Prepared By: Orlando Smith USDA/NRCS Waimea Field Office

**Table 5: Pelekane Coastal Water Quality Monitoring Results (November 2003)**

| Sample Site | Hach Turbidity | Nitrate mg/L | Total N mg/L | Total P mg/L | Filtered Silica mg/L Si | Chlorophyll A ug/L |
|---|---|---|---|---|---|---|
| Pelekane Beach | 26.5 | 0.203 | 0.348 | 0.041 | 3.05 | 3.19 |
| Pelekane N | 9.15 | 0.088 | 0.234 | 0.020 | 1.56 | 3.76 |
| Pelekane S | 3.18 | 0.068 | 0.137 | 0.010 | 1.65 | 0.85 |

Because of its salinity of less than 32 parts per thousand (ppt), the sampling site at Pelekane Beach is considered estuary waters. The samples from this site were out of compliance according to the State water quality standards for estuarine waters for turbidity (26.5 vs. 1.5 standard), Nitrates or inorganic nitrogen (0.203 mg/L vs. 0.008 mg/L standard), Total Nitrogen (0.348 mg/L vs. 0.200 mg/L standard), Total Phosphorus (0.041 mg/L vs. 0.025 mg/L standard) and Chlorophyll A (3.19 ug/L vs. 2 ug/L standard). High nitrates are often found in nearshore waters in coastal areas such as Pelekane where kiawe trees are predominant, because they are a leguminous, nitrogen-fixing plant. Turbidity in the Pelekane Beach sample was almost 18 times the allowable water quality standard.

Pelekane North and Pelekane South are both considered embayment waters, according to DOH personnel. The water quality standards for embayment waters are more stringent than for estuary waters.

Water samples from Pelekane North and South were not in compliance with State water quality standards for turbidity and nitrates. Pelekane North also exceeded water quality standards for Total Nitrogen and Total Phosphorus. Water quality at Pelekane South was generally better than elsewhere, probably because it is an area that receives greater flushing.

**Table 6: Hawaii Water Quality Standards for Embayment Waters**

| Parameter | Standard | Geomean[8] | 10%[9] | 2%[10] |
|---|---|---|---|---|
| TN mg/l | Wet Season | 0.200 | 0.350 | 0.500 |
| | Dry Season | 0.150 | 0.250 | 0.350 |
| $NH_4$-N mg/L | Wet | 0.006 | 0.013 | 0.020 |
| | Dry | 0.0035 | 0.085 | 0.015 |
| $NO_3$+$NO_2$-N mg/L | Wet | 0.008 | 0.020 | 0.035 |
| | Dry | 0.005 | 0.014 | 0.025 |
| TP mg/L | Wet | 0.025 | 0.050 | 0.075 |
| | Dry | 0.020 | 0.040 | 0.060 |
| Chlorophyll a ug/L | Wet | 1.5 | 4.5 | 8.5 |
| | Dry | 0.5 | 1.5 | 3.0 |
| Turb NTU | Wet | 1.5 | 3 | 5 |
| | Dry | 0.4 | 1 | 1.5 |

[8] The geomean is a function of a minimum of 3 samplings. Desired water quality should be this number or less.
[9] 10% of samples can exceed value given (requires minimum of 10 samples).
[10] 2% of samples can exceed value given (requires minimum of 50 samples).

Monitoring is an important element of the Pelekane Bay watershed management project. Monitoring will enable the District to measure the success and effectiveness of watershed restoration and protection activities. Each future activity will have a monitoring component that is based on the intended outcomes of the specific activity and the overall goals of the broader watershed management project. Other monitoring stations established and monitored over the life of the Pelekane Bay Watershed Management Project will provide information on overall watershed health.

Documenting that water quality changes at a watershed scale were caused by implementation of best management practices (BMPs) is difficult. Usually, a strong causal relationship between changes in land treatments and changes in nearshore water quality must be established. However, water quality changes may also be affected by other variables within the watershed. This is particularly true in the Pelekane Bay watershed, as noted below, and poses a challenge for the project's monitoring program in establishing such a causal relationship:

1. While the lower part of the watershed receives little rain in a normal year, drought conditions in 1996, 1998-1999, and 2002-2003 exacerbated dry conditions. This led to the subsequent removal of cattle in the watershed, so that land treatments could not be monitored under "normal" conditions.

2. Weather conditions are extremely localized within the watershed, creating situations where one area receives rainfall and the adjacent area at the same elevation does not. Without a clear picture of this rainfall variability, under both normal weather and drought conditions, it is difficult to establish causal relationships.

3. The intermittent streams discharging into Pelekane Bay must flow with enough intensity to breach the sand berm at the mouth of the watershed for sediment delivery into nearshore waters. The breach of the sand berm occurs irregularly and intermittently, preventing any real measurement of the direct causal relationship between changes in the watershed and changes in coastal water quality.

4. There are six named gulches in the watershed. In the lower reaches, these flow for a limited time only during times of major storm events, of which there have been relatively few over the last decade. There are many smaller, braided channels throughout the watershed, which are normally dry, except during storm events. All these gulches and channels likely contain large amounts of stored sediments. Because of the size of the watershed and number of poorly-defined channels, there is little existing information on the volume of stored sediment throughout the watershed.

5. Because of poor ocean circulation within Pelekane Bay, there are sediments that have settled to the bottom of the bay and are rarely flushed out into deeper waters. In heavy weather (whether storm-related or caused by high surf), these sediments are resuspended in the water column.

Because of these variables, this monitoring program does not rely on coastal water quality measurements to determine the effectiveness of the watershed management project. Rather, the primary focus of the monitoring program is on changes in groundcover quantity and quality and soil loss to measure how well pollution control measures are working.

**i. Previous Studies in the Pelekane Bay Watershed**

Some relevant studies have been undertaken in Pelekane Bay and its watershed, both under the auspices of the Pelekane Bay Watershed Management Project and as part of other planning and management efforts within the watershed. Some of these studies provide limited baseline data and are summarized below. Anecdotal information also suggests a change in water transparency/clarity since the construction of Kawaihae Harbor.

Draft Sediment Management Plan, Pelekane Bay Watershed, Island of Hawaii, by Paula Haight, MKSWCD contractor (December 1998): This document describes available information about soil erosion and water quality in Pelekane Bay and its watershed.

Baseline survey of Makeahua Gulch watershed (May 1999): Dr. Michaud and her classes at the University of Hawaii at Hilo conducted field surveys in January and March 1999. The main purpose of the study was to estimate the volume of sediment currently stored in Makeahua Gulch and its tributaries. These data will be useful in the future as a benchmark for comparison, to determine how the watershed is changing over time and the effectiveness of various watershed management practices.

Preliminary discharge rates for Pelekane Bay watershed, by D. Kubo (internal NRCS memo.-no date): Preliminary estimates for peak runoff discharge from the Pelekane Bay watershed were determined for 2-year to 500-year frequency storms using five discrete methods of analysis. Results show considerable variation in the discharges predicted by the five methods. The results are deemed appropriate only for sediment control planning. The memorandum recommends further data collection and evaluation of specific watershed characteristics.

Water Quality Monitoring Program, Kawaihae Small Boat Harbor, by Marine Research Consultants for Dutra Construction Co. (1996): The purpose of the monitoring program was to determine if construction of the breakwaters for the Kawaihae small boat harbor resulted in changes in water quality. It involved a methodological approach consisting of repetitive sampling of several water chemistry constituents (temperature, chlorophyll a, turbidity, salinity, total suspended solids) at five stations (surface and bottom samples) in the vicinity of the project site on a monthly basis during construction and for three months following completion of construction. It included sampling following heavy rainfall (Sept. 1997) which resulted in high levels of runoff and extreme turbidity in nearshore waters. A pre-construction baseline was collected by the U.S. Army Corps of Engineers in October 1995-January 1996. The monitoring program concluded that the effects of storm-generated runoff had substantially more impact on water quality than the construction activity. Figures 1 and 2 in the document show the locations of sampling stations.

Changes in the Marine Habitat and Biota of Pelekane Bay, Hawaii over a 20-Year Period, by Brian Tissot, University of Hawaii at Hilo (March 1998): This study involved quantitative sampling of three 50-ft. transects on patch reefs in Pelekane Bay in 1996. A list of species and relative abundance of all species was compiled for all habitats within the bay. The study found a striking decrease in abundance of all plants and animals, associated with major changes in species diversity and composition since the 1976 surveys. Tissot attributes the changes to long-term sedimentation stress due to chronic terrestrial runoff and reduced ocean circulation in Pelekane Bay associated with massive historical deforestation in the Pelekane watershed and construction of the Kawaihae Harbor revetment.

**ii. Monitoring Objectives**

The objectives of the project's monitoring program are:

- To evaluate the change in groundcover quantity and quality due to the implementation of management measures;
- To develop watershed-specific rainfall-runoff relationships;
- To assess the changes in soil loss resulting from installation of specific BMPs;
- To determine changes in suspended-sediment transport at a watershed scale;
- To determine the changes and trends in turbidity and water chemistry in Mekeahua Stream due to the implementation of management measures in the watershed; and
- To assess measurable changes in land treatment practices throughout the watershed.

**iii. Monitoring Activities**

While MacDonald (1991) identifies seven types of monitoring, this monitoring program focuses on three: trend, implementation, and effectiveness monitoring. The recommended monitoring program will describe status and trends in water quality, soil loss, and ground cover; track management measure implementation; and, based on the data from the trend and implementation monitoring, evaluate the effectiveness of BMPs with respect to pollution control. Every effort will be made to include these and other data in the project's Geographic Information System (GIS) to facilitate long-term monitoring and analyses.

Over the years, a number of experts have made recommendations regarding monitoring techniques that could be used in the Pelekane Bay watershed. Taken together, they provide a comprehensive monitoring program for soil loss, sediment transport, and coastal water quality. Unfortunately, many of these techniques are cost-prohibitive for this project, do not account for variables described earlier, and/or require baseline data not readily available. Therefore, a recommended monitoring program is described below, which is considered a "first step" that can be expanded upon as resources and data become available.

a. Erosion Monitoring: Erosion monitoring is undertaken to monitor soil loss. The purpose of this monitoring is to obtain basic data on the amount of sediment being eroded from hillsides and transported out of zero-order streams (smallest tributaries).

Dr. Jene Michaud of the University of Hawaii at Hilo designed a check dam on a small, representative tributary in the watershed to help measure soil loss. On April 12, 2003, students from the Hawaii Preparatory Academy (HPA) and University of Hawaii at Hilo assisted in the construction of the check dam. A student from HPA prepared a short video about the project. After conducting surveys, Dr. Michaud submitted to the District a report that describes check dam construction, data collection methods, and topography and sediment depths of the sub-watershed (a baseline survey of the area immediately above the check dam). Periodically, and following major storm events in the watershed, the depth of soil trapped behind the check dam is measured. Data obtained from the check dam, along with information from the rain gauges and automatic water sampler will help the District to gain a better picture of soil loss in the watershed.

The sediment trap dam provides a very low-cost estimate of the sediment yield over a 18 acre sub-watershed. While this is an unconventional way to monitor sediment, it provided a first order measurement of the amount of erosion during a specific time period. Insofar as alternative methods of measuring or estimating sediment yields are either very expensive (conventional sediment measurements) or are of questionable accuracy (RUSLE equation), the use of sediment trap dams appears to have merit and is recommended for future monitoring programs.

**Photo: At the end of the work day building the check dam**

**Photo: Rain Gauge in Pelekane Watershed**

In November 2002, Dr. Michaud also installed two automatic rain gauges and data loggers in the watershed. These rain gauges enable the District to begin to make correlations between changes on the landscape and rainfall amounts. Over the long-term, they will help the District to obtain an understanding of the relationship between rainfall, runoff events, and sedimentation events in Pelekane Bay. Data from these rain gauges is downloaded periodically; data from September 2002 to February 2005 are summarized in Table 3 and in Figure 6.

Figure 10 identifies the locations of the rain gauges and check dam.

As additional resources become available, and provided the benefits to the project can justify the higher costs, more sophisticated monitoring techniques may be pursued, including:

- spatially-distributed and instrumented runoff plots to detect soil loss and movement of sediment sources within watershed;
- gauging stations to monitor suspended-sediment transport;
- sediment-budget approach; and
- measurements of concentrations of radionuclides in soils.

*Recommendations for Erosion Monitoring:*

| **Activity** | **Responsible Person(s)** | **Cost** | **Level of Priority** |
|---|---|---|---|
| Continue downloading rainfall data from rain gauges in the watershed. | MKSWCD, Univ. of Hawaii | Low | High |
| As land management practices and other management activities are implemented in the watershed, construct check dams below each site to measure changes in soil loss from the area before, during and following management measure implementation. | MKSWCD, Univ. of Hawaii | Low | Medium |

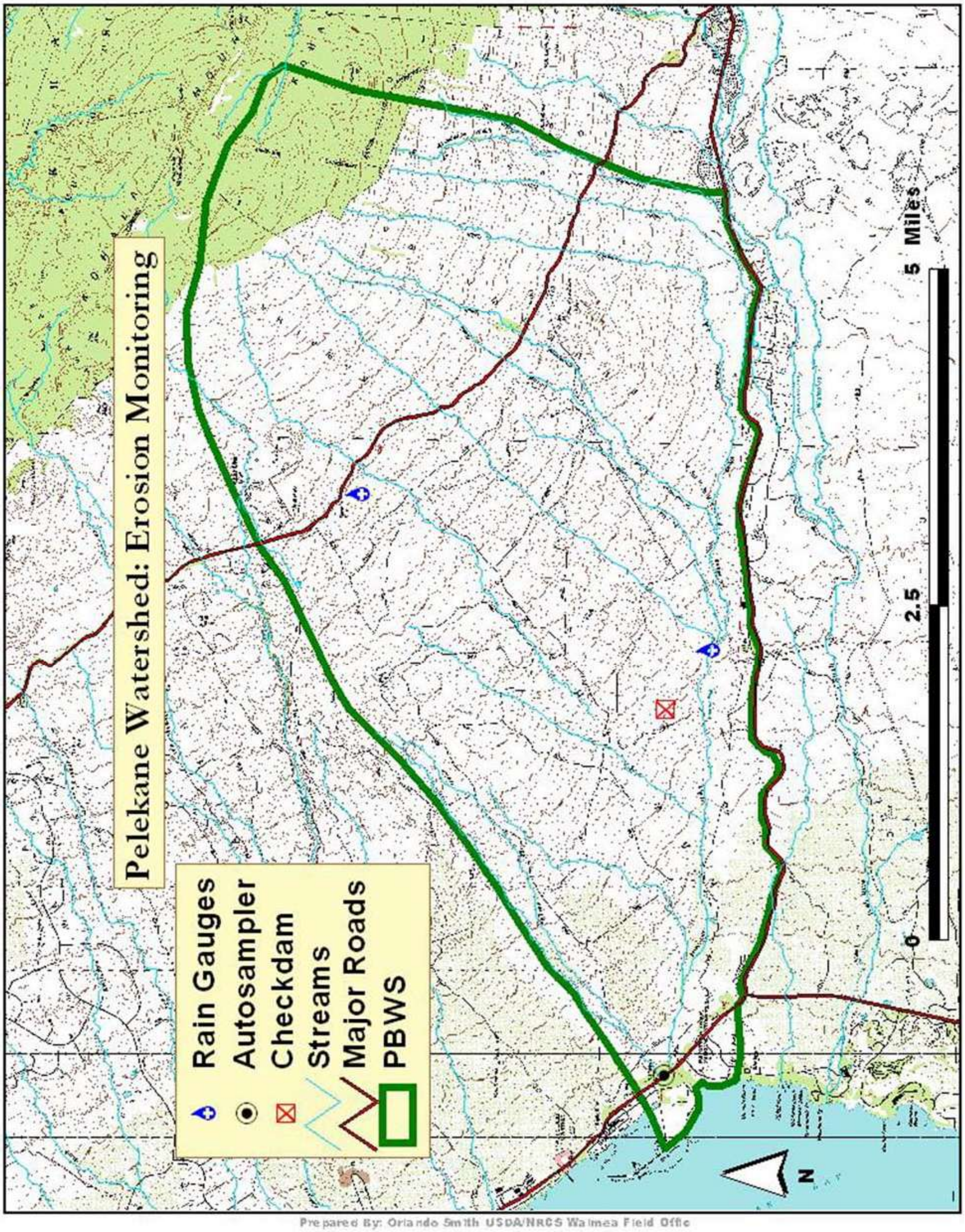



**Figure 10: Erosion Monitoring Sites**

b. Vegetative Cover Monitoring: The purpose of vegetative cover monitoring is to determine percent and composition of groundcover in the watershed, as an overall indication of watershed health. Dr. Burt Smith (retired), of the University of Hawaii Cooperative Extension Service, established transects in the mid-1990s and initiated monitoring using two techniques: line intervals and pace transects. Visual estimates are also made of the dry matter fuel loading at each site.

**Photo: Vegetative Cover Monitoring Transect**

A linear interval transect is used to monitor vegetational changes over intervals of time on a fixed line or location. A 100-ft. tape is stretched between two point and a 1-ft. interval used. A vegetational hit is recorded if all or part of the basal component of a plant lies totally or partially within that 1-ft. interval, directly under the tape. Bare ground, rock and litter are also recorded if they are at least one square-inch in area. To provide further precision, the 100-ft. line is subdivided into 20-ft. sections with subtotals calculated for each section. This helps more clearly define where changes in vegetation are actually occurring along the 100-ft. line.

Pace transects are used to determine the percent frequency of occurrence of both vegetation and unused areas (bare ground, rocks and litter) at the time the transects are taken. The pace transects allow a generalized comparison to be made with other areas and, if subsequent transects are made, rough comparisons over time for areas larger than possible with the line intervals. The pace transects are conducted starting at an end-marker for the line interval transect. A hit is recorded if bare ground, rock, litter or the basal area of vegetation occurs directly at a mark at the toe of the observer's boot at each step or pace. The observer proceeds in one direction until 150 or more hits have been recorded. Then, the observer turns 90 degrees and proceeds, again, in a line until approximately 150 hits have been recorded. This continues until the observer has formed a box (*i.e.*, returned to the starting point). Pace transects are recorded as hits and then later converted to percent frequency.

Two critical areas, representative of the watershed environment, are currently being monitored. The upper critical area is north of the chicken farm along Kawaihae Road at an approximate elevation of 1,200-1,500-feet. The lower critical area is in the *makai* portion of the watershed (Paddocks 5A and 5B). There are four stations located in the Pelekane watershed study area. Each station has two paired monitoring sites, each site consisting of one line interval and one pace transect. The locations of these transects are listed in Table 7. Monitoring of these sites began in December 1995.

This type of monitoring is extremely time-consuming and requires personnel who can distinguish among all the species of grasses and other groundcovers, making it difficult to involve volunteers or laypeople in this effort. As a result, regular monitoring has not been conducted over the life of the watershed management project. Data are available from December 1995 and December 1996, as well as partial data from August 2002 and March 2003. These data are included in Appendix B.

**Table 7: Locations of Line Transects**

| SITE | LATITUDE | LONGITUDE |
|---|---|---|
| A-Upper | N 20°02’28.04” | W 155°46’57.27” |
| A-Lower | N 20°02’27.66” | W 155°46’58.27” |
| B-Upper | N 20°02’23.47” | W 155°46’48.49” |
| B-Lower | N 20°02’22.38” | W 155°46’48.82” |
| C-Upper | N 20°02’05.84” | W 155°46’08.89” |
| C-Lower | N 20°02’04.85” | W 155°46’08.89” |
| D-Upper | N 20°02’00.09” | W 155°46’02.17” |
| D-Lower | N 20°01’59.13” | W 155°46’03.02” |
| E-Upper | N 20°02’39.16” | W 155°48’38.18” |
| E-Lower | N 20°02’38.50” | W 155°48’39.24” |
| F-Upper | N 20°02’37.90” | W 155°48’39.73” |
| F-Lower | N 20°02’37.18” | W 155°48’40.43” |
| G-Upper | N 20°02’58.34” | W 155°48’08.87” |
| G-Lower | N 20°02’57.80” | W 155°48’09.81” |
| H-Upper | N 20°03’01.21” | W 155°48’10.11” |
| H-Lower | N 20°03’00.64” | W 155°48’10.91” |

* Each end of the transect is marked with a metal bar driven into the ground. Recovery of the locations is use of GPS and a metal detector to aid in “pin-pointing” the actual start and stop of the 100-ft. transect.

** Line transects established in December 1995 by Dr. Burt Smith, University of Hawaii Cooperative Extension Service; Jerry Williams, NRCS; and Gary Kam, NRCS.

*Recommendations for Vegetative Cover Monitoring:*

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Reinstitute vegetative cover monitoring on an annual or semi-annual basis. | NRCS, CES | Low | High |
| Explore remote sensing as a tool for vegetative cover monitoring. | NRCS, CES | Medium | High |

c. Stubble Height Monitoring: Monitoring stubble height of key forage species in key grazing areas in each paddock in the watershed is undertaken semi-annually with NRCS assistance. Regular stubble height monitoring can be used as a management tool to determine when cattle should be rotated out of paddocks, based on the minimum heights established under NRCS's Standards and Specifications for Prescribed Grazing, 528A (see page 21 above), and as a monitoring tool to ensure that paddocks are not being over-grazed.

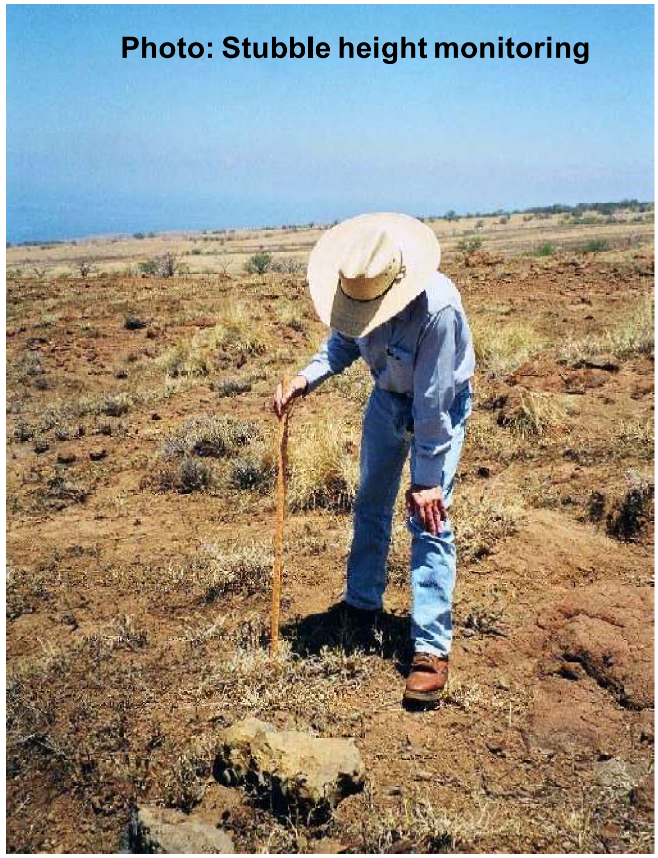
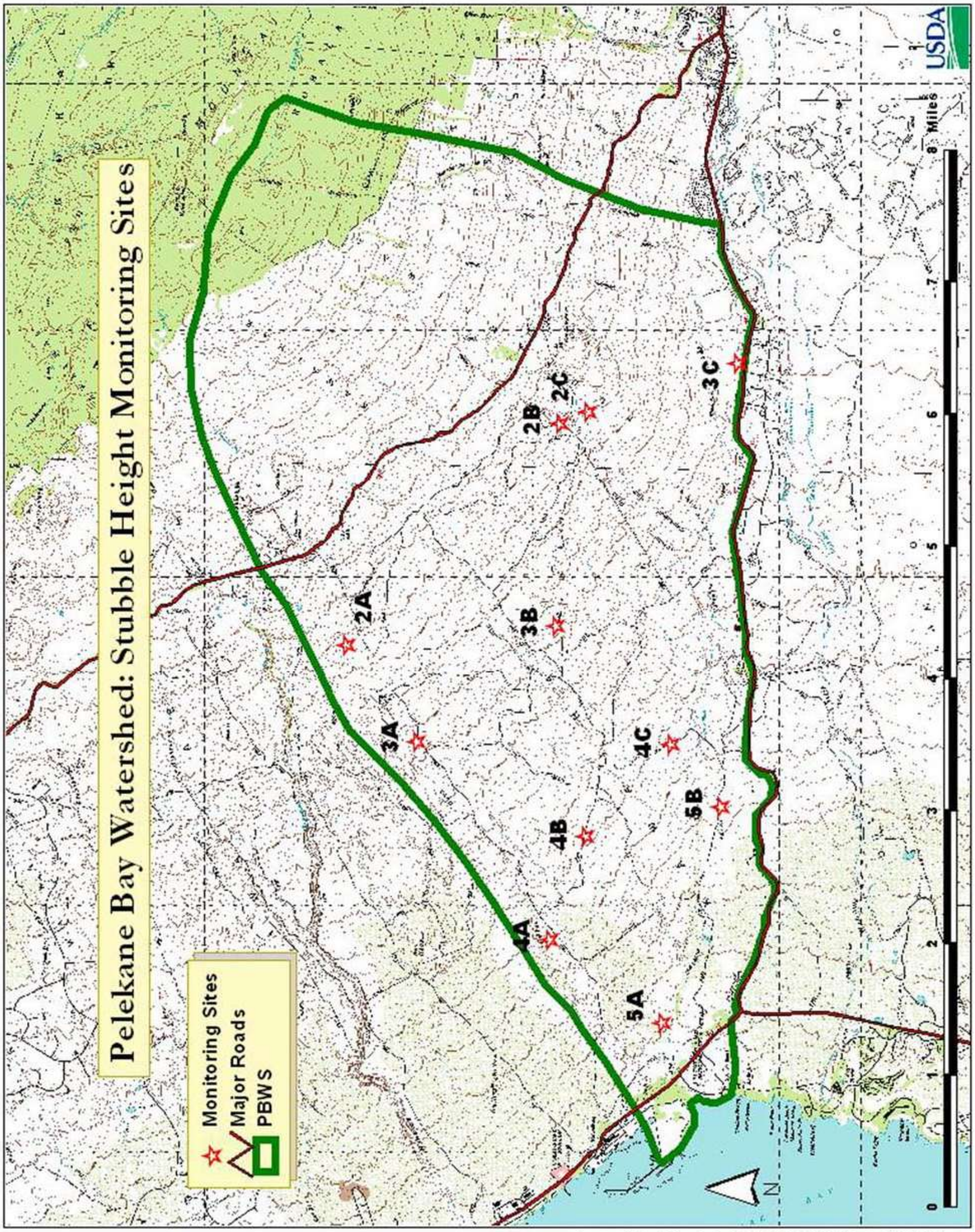


**Photo: Stubble height monitoring**

Eleven monitoring sites have been established in the watershed below the Kohala Mountain Road (Figure 11). Other sites will be established above the Kohala Mountain Road at a later time. These key grazing areas are identified in each paddock by their latitudinal and longitudinal coordinates. The key forage plant, subject to monitoring, was identified for each key area. The monitoring consists of measuring the average height of grasses within the vicinity of each key area. Stubble height monitoring began in early 2001. Monitoring sites in Paddocks 5A and 5B, which have never been grazed, were established in September 2004. Monitoring results are provided in Table 8 below. Photo documentation of the changes in stubble heights between 2001 and 2005 is attached as Appendix C.

**Table 8: Stubble Height Monitoring Results(stubble heights in inches)**

| Paddock Number | March 2001 | August 2002 | February 2003 | October 2003 | March 2004 | Sept. 2004 | February 2005 |
|---|---|---|---|---|---|---|---|
| **2A** **(guinea)** | 6.30 | 18.5 | 9.35 | 7.30 | 32.50 | 28.1 | 18.0 |
| **2B** **(buffel)** | 1.725 | 10.5 | 11.50 | 3.05 | 10.15 | 13.2 | 10.6 |
| **2C** **(buffel)** | 2.35 | 10.5 | 14.40 | 3.65 | 9.75 | 9.5 | 5.3 |
| **3A** **(buffel)** | 2.30 | not sampled | 4.10 | 6.75 | 9.90 | 11.6 | 5.0 |
| **3B** **(buffel)** | 0.875 | 6.0 | 9.20 | 9.05 | not sampled | 12.0 | 13.1 |
| **3C** **(buffel)** | 2.00 | not sampled | 3.20 | 1.65 | 6.70 | 4.65 | 11.2 |
| **4A** **(buffel)** | 1.90 | 2.0 | 2.25 | 2.00 | 2.90 | 6.65 | 5.0 |
| **4B** **(buffel)** | 1.90 | 4.5 | 3.10 | 1.85 | 8.65 | 6.35 | 7.0 |
| **4C** **(buffel)** | not sampled | not sampled | 6.95 | 5.45 | 11.05 | 10.5 | 10.0 |
| **5A** **(buffel)** | | | | | | 9.8 | 12.2 |
| **5B** **(buffel)** | | | | | | 10.6 | 12.2 |




Prepared By: Orlando Smith USDA/NRCS Waimea Field Office

**Figure 11: Stubble Height Monitoring Sites**

In 2005, the groundcover in the watershed is denser and healthier than at the start of the watershed management project. Some of this can be attributed to more effective rotational grazing by Parker Ranch resulting from the greater number of paddocks in the watershed, thereby allowing the lands to be grazed more efficiently, rested for a greater portion of time, and maintained in a healthier condition.

The increase in groundcover can also be attributed to an increase in rainfall. Comparing the stubble height data with the rainfall data illustrates this connection: when rainfall was higher, stubble heights increased; when rainfall amounts decreased, so did stubble heights. For much of the life of this watershed management project, the region experienced drought conditions. These drought years severely affected the Pelekane watershed, causing Parker Ranch to finally reduce the size of its herd within the watershed.

The reduction in herd size posed a problem once the rains resumed in 2004. The unusually high rainfall amounts that year stimulated a great deal of forage growth. Parker Ranch no longer had the number of cattle in the watershed needed to graze down the stubble height. As the grass dries out, this stubble height has created a fire hazard. This is particularly a concern near residential communities within the watershed (*e.g.*, Waiemi subdivision, Kawaihae Village, Catholic Charities' Transitional Housing).

*Recommendations for stubble height monitoring:*

| **Activity** | **Responsible Person(s)** | **Cost** | **Level of Priority** |
|---|---|---|---|
| Continue stubble height monitoring on a semi-annual basis. | MKSWCD, NRCS | Low | High |
| Establish monitoring sites in the paddocks above Kohala Mountain Road. | MKSWCD, NRCS | Low | Medium |

d. Instream Water Quality Monitoring: Initially, the District recommended that a limited amount of coastal water quality monitoring take place, primarily for turbidity and water chemistry. The monitoring would be undertaken on a monthly basis and during or immediately following major storm events. The parameters envisaged to be monitored included: turbidity, chlorophyll a, temperature, salinity, and pH.

In 2003, as our water quality monitoring contractor further explored monitoring techniques applicable to a situation such as Pelekane Bay and discussed the proposed monitoring program with other water quality professionals, it became clear that in-the-bay monitoring would not provide an objective and useful measure of the effectiveness of conservation measures in the watershed in reducing soil runoff into the bay. As a result, the District requested and received approval from DOH to change this aspect of its monitoring program to instream water quality monitoring.

There may be a time when coastal water quality monitoring will provide useful data. At that time, every efforts will be made to use the parameters and procedures recommended in West Hawaii Coastal Monitoring Task Force (1992). Monitoring stations and transects will be selected in consultation with researchers who have previously conducted sampling in the area. The number of stations monitored will depend, in part, on available resources. As the monitoring program progresses, other parameters may be added and monitoring frequency increased, as recommended in Teytaud (2000).[11]

Measuring in-stream flow and turbidity provides data useful in calculating soil loss and developing the watershed-specific rainfall-runoff relationship. The District decided to initiate instream water quality monitoring in Makeahua Stream, which drains approximately 85% of the watershed. A qualified consultant with expertise in monitoring, quality assurance/quality control (QA/QC) procedures, and data analysis was contracted to undertake the instream water quality monitoring.

In May 2004, after waiting seven months for permission from the State Department of Transportation (DOT), an ISCO 6712C Compact Sampler, with flow module, was installed on a high ledge under the bridge over Makeahua Stream and secured to a concrete post. Figure 10 identifies the location of the autosampler. A pipe attached to the face of the bridge support contains the suction tubing and other wires. A cage at the bottom of the pipe contains and protects the water intake tubing. The flow meter is attached to the bottom of the cage. The sampler collects stormwater samples and flow rate data during times of stream flow.

**Photo: Installing the Instream Auto-Sampler**

Unfortunately, the delay by DOT in issuing the permit caused the District to miss 6-7 sampling opportunities during the 2004 winter season, which was the wettest in 20 years. (It is unusual to have one sampling opportunity during a "normal" year, so 2004 was exceptional.) As a result, no water samples have been collected to date.

*Recommendations for instream water quality monitoring:*

| Activity | Responsible Person(s) | Cost | Level of Priority |
|---|---|---|---|
| Continue instream water quality monitoring in Makeahua Stream. | MKSWCD | Low | High |
| Install an automatic sampler in Makahuna Stream, which drains the remainder of the watershed. | MKSWCD | Medium | Medium |

[11] Teytaud (2000) recommends including water transparency, total suspended solids, dissolved oxygen, and nutrients as parameters and conducting a one-time collection of sediment samples for nutrients and pesticides analysis. He recommends a monitoring frequency of two times per month over a minimum of 2-yr period and during unusual or episodic events including high surf, high winds, or periods of unusually calm weather and clear water in order to document the range of variability.

e. Implementation Tracking: Tracking of BMP implementation provides the necessary information to determine whether pollution controls have been implemented, operated, and maintained adequately and as required under the watershed management plan. Without this information, the project will not be able to fully interpret its other monitoring data. According to Spooner *et al.* (1995), "quantitative monitoring of BMP implementation facilitates documentation of land treatment trends and is a necessary step in linking water quality to land treatment" (p. 3).

The District will use two tracking methods - expert evaluations and self-evaluations - as described in EPA (1997).

f. Geographic Information System (GIS): A GIS is a computerized tool that links and relates geographic data — the locations of sampling stations, shorelines, stream corridors, forest lands, fences, water resources, or other lines, points, and areas — with descriptive or qualifying numerical data. The data can then be analyzed and presented in a variety of scales and formats, including maps. Two Cornell University students developed a GIS data set and maps for the Pelekane Bay watershed in 2004 as part of an internship program. This GIS will facilitate long-term monitoring and analyses.

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## VI. CONCLUSIONS

Many management measures have been implemented in the Pelekane Bay watershed since 1994, as part of the watershed management project. Great strides have been made in increasing groundcover density and quality, as reflected in increased stubble heights and groundcover throughout most of the watershed. The fencing and grazing of Paddocks 5A and 5B help minimize soil loss by reducing the risk of fires within the watershed. The firebreak constructed by Parker Ranch protects neighboring communities from fire and provides a line of defense against fire starts. Monitoring of instream water quality, stubble height, vegetative cover, and soil erosion has been initiated in the Pelekane watershed. Even with these accomplishments, the recommended actions contained in this management plan include many more activities needed to reduce soil loss and provide ongoing comprehensive monitoring to measure trends and changes over time.

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# Appendix A

# Pelekane Bay Watershed Management Project

**9 March**

Stormwater flow into Pelekane


# Appendix B

# APPENDIX B

## VEGETATIVE COVER MONITORING
## (Line Transects)

### Line Transect Locations

Line transects established in December 1995 by Dr. Burt Smith, University of Hawaii Cooperative Extension Service; Jerry Williams, NRCS; and Gary Kam, NRCS.

Each end of the transect is marked with metal bars driven into the ground.  Planned recovery of the locations is use of GPS and a metal detector to aid in “pin-pointing” the actual start and stop of the 100-ft. transect.

| SITE | LATITUDE | LONGITUDE |
|---|---|---|
| A-Upper | N 20º02’28.04” | W 155º46’57.27” |
| A-Lower | N 20º02’27.66” | W 155º46’58.27” |
| B-Upper | N 20º02’23.47” | W 155º46’48.49” |
| B-Lower | N 20º02’22.38” | W 155º46’48.82” |
| C-Upper | N 20º02’05.84” | W 155º46’08.89” |
| C-Lower | N 20º02’04.85” | W 155º46’08.89” |
| D-Upper | N 20º02’00.09” | W 155º46’02.17” |
| D-Lower | N 20º01’59.13” | W 155º46’03.02” |
| E-Upper | N 20º02’39.16” | W 155º48’38.18” |
| E-Lower | N 20º02’38.50” | W 155º48’39.24” |
| F-Upper | N 20º02’37.90” | W 155º48’39.73” |
| F-Lower | N 20º02’37.18” | W 155º48’40.43” |
| G-Upper | N 20º02’58.34” | W 155º48’08.87” |
| G-Lower | N 20º02’57.80” | W 155º48’09.81” |
| H-Upper | N 20º03’01.21” | W 155º48’10.11” |
| H-Lower | N 20º03’00.64” | W 155º48’10.91” |

**Summary of Available Data**

The first number in each column represents the number of "hits" of each species or ground type and the second number represents the percentage of these hits of the total.

N 20º02'28.04" W 155º46'57.27" --------> N 20º02'27.66" W 155º46'58.27"

| **Site A** | 1995 (Dec 27-28) | 1996 (Dec 18-19) | 2003 (Mar 3) |
|---|---|---|---|
| Bare ground | 95 (49%) | 92 (41%) | 88 (88%) |
| Rock | 10 ( 5%) | 25 (11%) | |
| Litter | 32 (17%) | 48 (22%) | 7 ( 7%) |
| Aalii | | | |
| Akuli kuli | | | |
| Buffel | | 7 ( 3%) | |
| Ekoa | | | |
| Fountain grass | | | |
| Ilima | 1 ( 1%) | 2 ( 1%) | |
| Japanese tea | 1 ( 1%) | 4 ( 2%) | |
| Joee | | 2 ( 1%) | |
| Kiawe | | | |
| Pili | 14 ( 7%) | 10 ( 5%) | 1 ( 1%) |
| Waltheria | 39 (20%) | 32 (14%) | 4 ( 4%) |
| TOTAL | 192 (100%) | 222 (100%) | 100 (100%) |

N 20º02'23.47" W 155º46'48.49" --------> N 20º02'22.38" W 155º46'48.82"

| **Site B** | 1995 (Dec 27-28) | 1996 (Dec 18-19) | 2003 (Mar 3) |
|---|---|---|---|
| Bare ground | 99 (43%) | 80 (29%) | No Data. |
| Rock | 44 (19%) | 46 (17%) | |
| Litter | 27 (12%) | 59 (22%) | |
| Aalii | | | |
| Akuli kuli | | | |
| Buffel | | | |
| Ekoa | | | |
| Fountain grass | | | |
| Ilima | | 3 ( 1%) | |
| Japanese tea | | | |
| Joee | | | |
| Kiawe | | | |
| Pili | 15 ( 6%) | 27 (10%) | |
| Waltheria | 44 (19%) | 58 (21%) | |
| Unknown | 3 ( 1%) | | |
| TOTAL | 232 (100%) | 273 (100%) | |

N 20°02'05.84"  W 155°46'08.89" --------> N 20°02'04.85"  W 155°46'08.89"

| **Site C** | 1995 (Dec 27-28) | 1996 (Dec 18-19) | 2002 (July 31) | 2003 (Mar 3) |
|---|---|---|---|---|
| Bare ground | 77 (30%) | 83 (28%) | 28 (28%) | 20 (20%) |
| Rock | 35 (14%) | 47 (16%) | 16 (16%) | 7 ( 7%) |
| Litter | 72 (28%) | 57 (19%) | 29 (29%) | 25 (25%) |
| Aalii | | | | |
| Akuli kuli | | | | |
| Buffel | 4 ( 2%) | | | |
| Ekoa | | | | |
| Fountain grass | 3 ( 1%) | 3 ( 1%) | | 2 ( 2%) |
| Ilima | 5 ( 2%) | 6 ( 2%) | 3 ( 3%) | 2 ( 2%) |
| Japanese tea | | | | |
| Joee | 1 ( 0%) | | | |
| Kiawe | | | | |
| Pili | 28 (11%) | 52 (17%) | 2 ( 2%) | 5 ( 5%) |
| Waltheria | 33 (13%) | 50 (17%) | 22 (22%) | 39 (39%) |
| TOTAL | 258 (101%) | 298 (100%) | 100 (100%) | 100 (100%) |

N 20°02'00.09"  W 155°46'02.17" --------> N 20°01'59.13"  W 155°46'03.02"

| **Site D** | 1995 (Dec 27-28) | 1996 (Dec 18-19) | 2002 (Aug 1) | 2003 (Mar 3) |
|---|---|---|---|---|
| Bare ground | 100 (59%) | 94 (39%) | 74 (74%) | 91 (91%) |
| Rock | 5 ( 3%) | 46 (19%) | 9 ( 9%) | |
| Litter | 25 (15%) | 46 (19%) | 14 (14%) | 5 ( 5%) |
| Aalii | | 2 ( 1%) | | |
| Akuli kuli | | | | |
| Buffel | | | | |
| Ekoa | | | | |
| Fountain grass | 3 ( 2%) | 2 ( 1%) | | 1 ( 1%) |
| Ilima | | | | |
| Japanese tea | 1 ( 1%) | | | |
| Joee | | | | |
| Kiawe | | | | |
| Pili | 8 ( 5%) | 7 ( 3%) | | |
| Waltheria | 27 (16%) | 47 (19%) | 3 ( 3%) | 3 ( 3%) |
| TOTAL | 169 (101%) | 244 (101%) | 100 (100%) | 100 (100%) |

N 20º02'39.16" W 155º48'38.18" --------> N 20º02'38.50" W 155º48'39.24"

| **Site E** | 1995 (Dec 27-28) | 1996 (Dec 18-19) | 2002 (Jul 31) | 2003 (Mar 3) |
|---|---|---|---|---|
| Bare ground | 88 (68%) | 77 (42%) | 74 (74%) (soil capped) | No Data. |
| Rock | 8 ( 6%) | 36 (20%) | 1 ( 1%) | |
| Litter | 31 (24%) | 30 (16%) | 22 (22%) | |
| Aalii | | | | |
| Akuli kuli | | | | |
| Buffel | | 25 (14%) | 1 ( 1%) | |
| Ekoa | | | | |
| Fountain grass | | | | |
| Ilima | | | | |
| Japanese tea | | | | |
| Joee | | | | |
| Kiawe | 1 ( 1%) | 1 ( 1%) | 2 ( 2%) | |
| Pili | | | | |
| Waltheria | 2 ( 2%) | 13 ( 7%) | | |
| TOTAL | 130 (101%) | 182 (100%) | 100 (100%) | |

N 20º02'37.90" W 155º48'39.73" --------> N 20º02'37.18" W 155º48'40.43"

| **Site F** | 1995 (Dec 27-28) | 1996 (Dec 18-19) | 2002 (Jul 31) | 2003 (Mar 3) |
|---|---|---|---|---|
| Bare ground | 95 (63%) | 90 (62%) | 82 (82%) (soil capped) | No Data. |
| Rock | 16 (11%) | 13 ( 9%) | 3 ( 3%) | |
| Litter | 22 (15%) | 29 (20%) | 9 ( 9%) | |
| Aalii | | | | |
| Akuli kuli | | | | |
| Buffel | 17 (11%) | 10 ( 7%) | 6 ( 6%) | |
| Ekoa | | | | |
| Fountain grass | | | | |
| Ilima | | | | |
| Japanese tea | | | | |
| Joee | | | | |
| Kiawe | | | | |
| Pili | | | | |
| Waltheria | 1 ( 1%) | 4 ( 3%) | | |
| TOTAL | 151 (101%) | 146 (101%) | 100 (100%) | |

N 20°02’58.34”  W 155°48’08.87” --------> N 20°02’57.80”  W 155°48’09.81”

| **Site G** | 1995 (Dec 27-28) | 1996 (Dec 18-19) | 2003 (Mar 3) |
|---|---|---|---|
| Bare ground | 93 (43%) | 95 (39%) | No Data. |
| Rock | 16 ( 7%) | 33 (13%) | |
| Litter | 54 (25%) | 57 (23%) | |
| Aalii | | | |
| Akuli kuli | | | |
| Buffel | 13 ( 6%) | 22 ( 9%) | |
| Ekoa | | | |
| Fountain grass | | | |
| Ilima | 1 ( 0%) | | |
| Japanese tea | 1 ( 0%) | | |
| Joee | | | |
| Kiawe | | | |
| Pili | 10 ( 5%) | 3 ( 1%) | |
| Waltheria | 27 (13%) | 35 (14%) | |
| TOTAL | 215 (99+%) | 245 (99+%) | |

N 20°03’91,21”  W 155°48’10.11” --------> N 20°03’00.64”  W 155°48’10.91”

| **Site H** | 1995<br>(Dec 27-28) | 1996<br>(Dec 18-19) | 2002<br>(Aug 1) | 2003<br>(Mar 3) |
|---|---|---|---|---|
| Bare ground | 66 (37%) | 61 (25%) | 60 (60%) | No Data. |
| Rock | 25 (14%) | 28 (12%) | 7 (7%) | |
| Litter | 45 (25%) | 70 (29%) | 4 (4%) | |
| Aalii | | | | |
| Akuli kuli | | 1 ( 0%) | | |
| Buffel | 30 (17%) | 50 (21%) | 29 (29%) | |
| Ekoa | 3 ( 2%) | 3 ( 1%) | | |
| Fountain grass | | | | |
| Ilima | 1 ( 1%) | | | |
| Japanese tea | | | | |
| Joee | | | | |
| Kiawe | | | | |
| Pili | | 7 ( 3%) | | |
| Waltheria | 9 ( 5%) | 21 ( 9%) | | |
| TOTAL | 179 (101%) | 241 (100%) | 100 (100%) | |

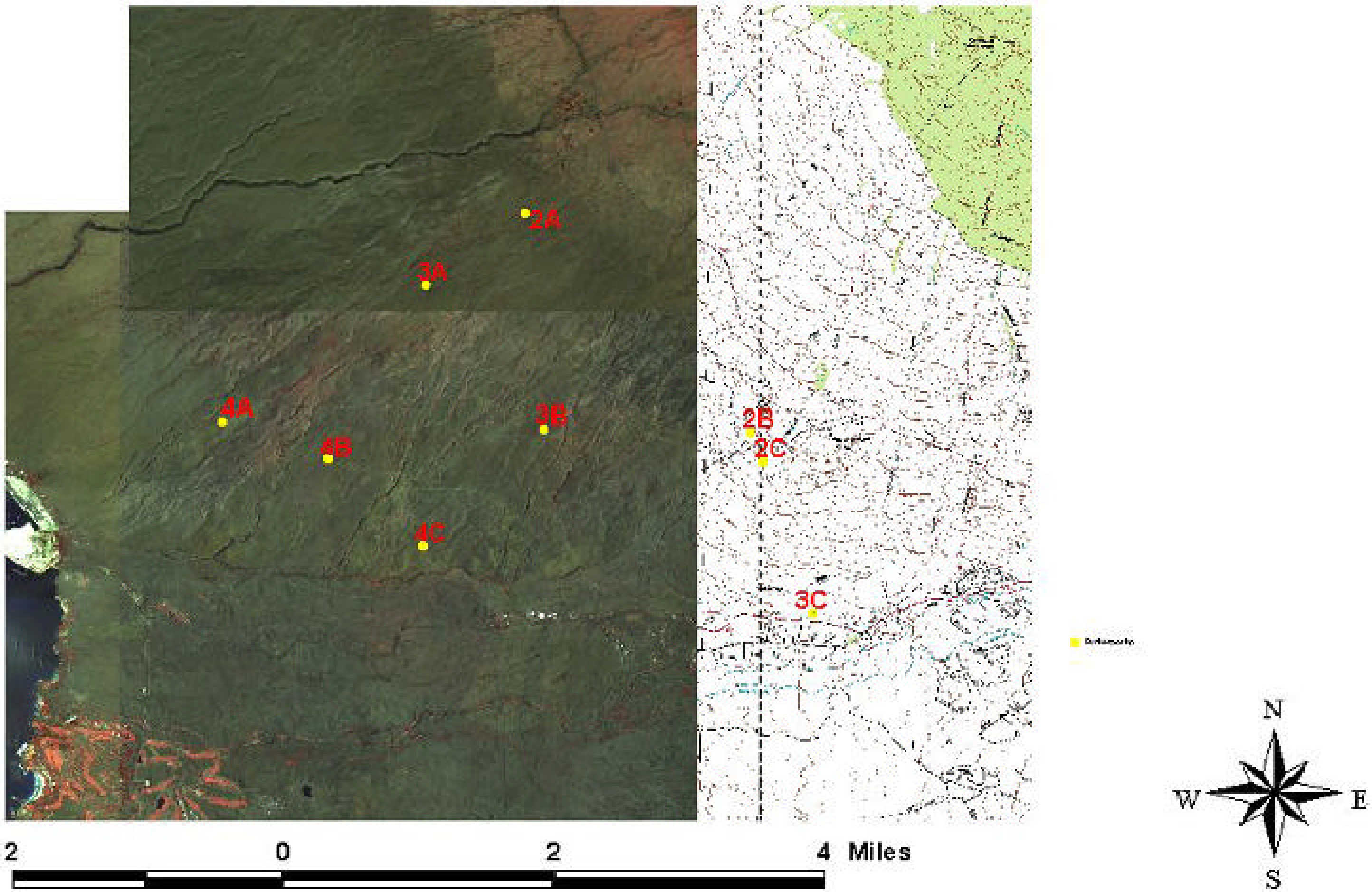
# Appendix C

# Mauna Kea Soil and Water Conservation District

Pelekane Bay Watershed Management Project

Stubble Height Monitoring 2001-2005

# Map of Monitoring Stations



# Paddock 2A
# Key Forage Species: Guinea

March 2001
Average stubble height 6.3”

August 2002

February 2003
Average stubble height 9.35”

March 2004
Average stubble height 32.5”

February 2005
Average stubble height 18.0”

# Paddock 2B
# Key Forage Species: Buffel

March 2001
Average stubble height 1.725”

August 2002

February 2003
Average stubble height 11.5”

March 2004
Average stubble height 10.15”

September 2004
Average stubble height 13.2”

February 2005
Average stubble height 10.6”

# Paddock 2C
# Key Forage Species: Buffel

March 2001
Average stubble height 2.35”

August 2002

February 2003
Average stubble height 14.4”

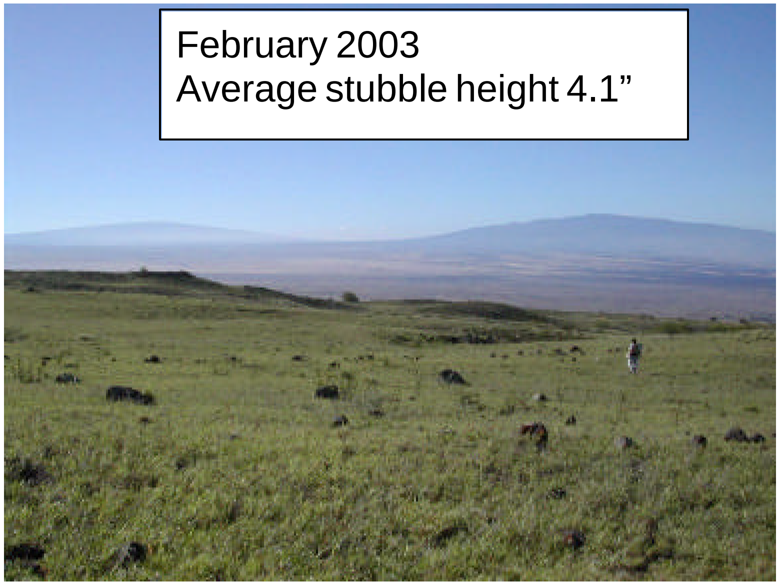
September 2004
Average stubble height 9.5”

February 2005
Average stubble height 5.3”

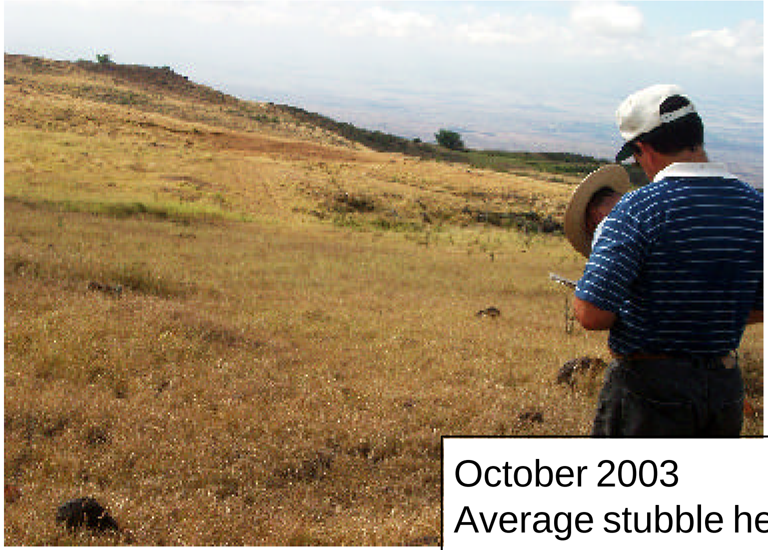
March 2004
Average stubble height 9.75”

# Paddock 3A
# Key Forage Species: Buffel

February 2001
Average stubble height 2.3”



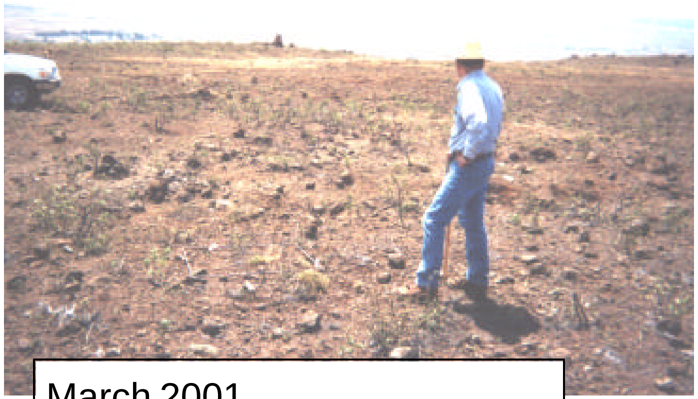
February 2003
Average stubble height 4.1”



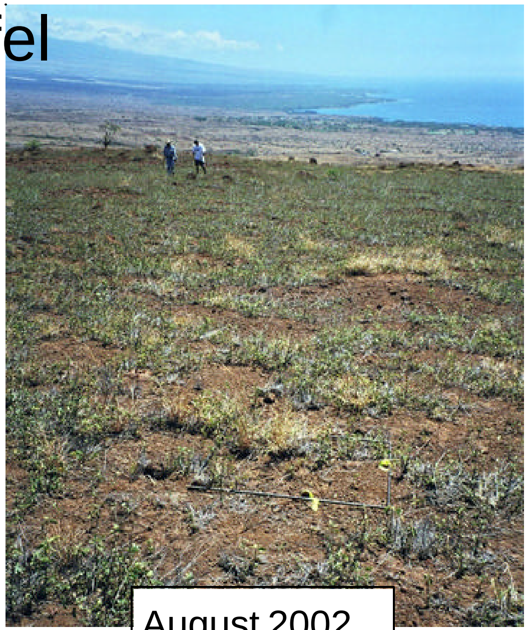
October 2003
Average stubble height

March 2004
Average stubble height 9.9”

# Paddock 3B
# Key Forage Species: Buffel



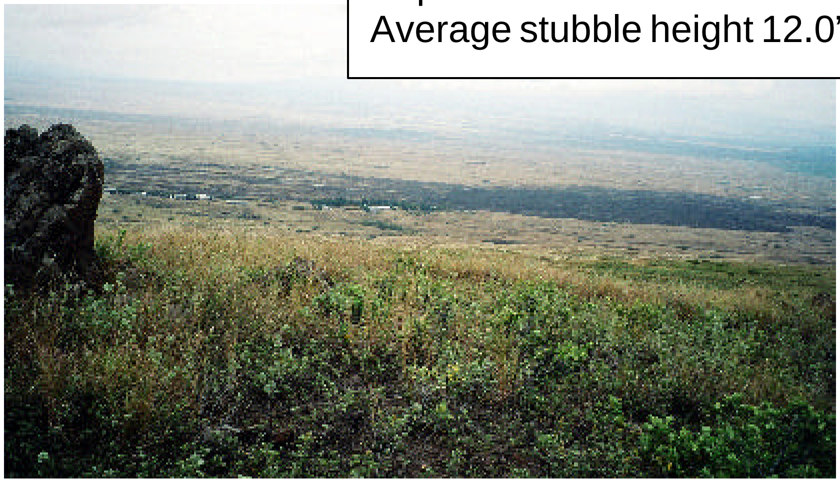
March 2001
Average stubble height 0.875"



August 2002

February 2003
Average stubble height 9.2"

September 2004
Average stubble height 12.0"



February 2005
Average stubble height 13.1"

# Paddock 3B
# Native Plant Species

This paddock has a tremendous number of native ground and shrub species, which are dominating the revegetation of the area.

`Akia (*Wikstroemia* sp.)

A`ali`i in flower (*Dodonaea viscosa*)

# Paddock 3C
# Key Forage Species: Buffel

February 2001
Average stubble height 2.0”

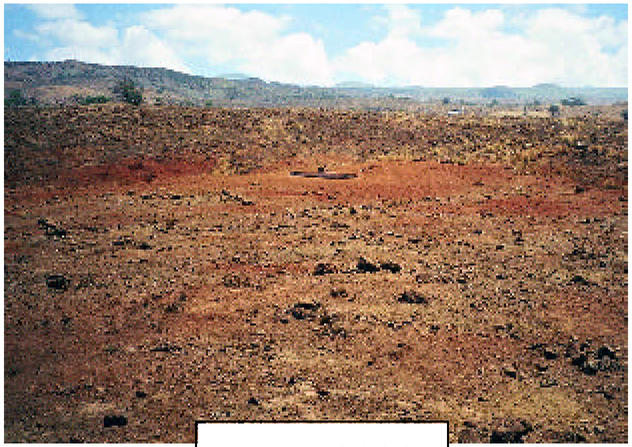
September 2004
Average stubble height 4.65”

February 2003
Average stubble height 3.2”
(recently grazed)

February 2005
Average stubble height 11.2”

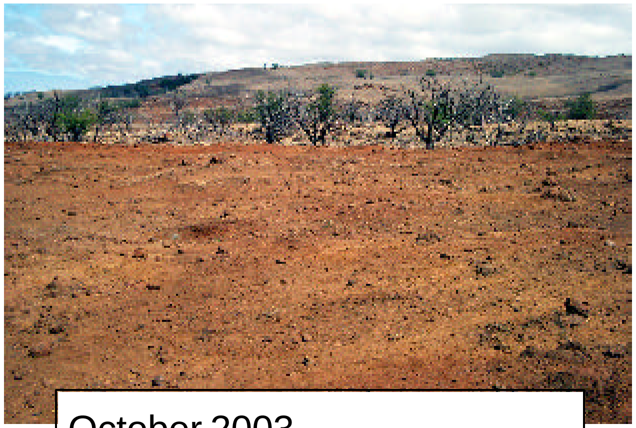
# Paddock 4A
# Key Forage Species: Buffel

March 2001
Average stubble height 1.9”



August 2002

February 2003
Average stubble height 2.25”



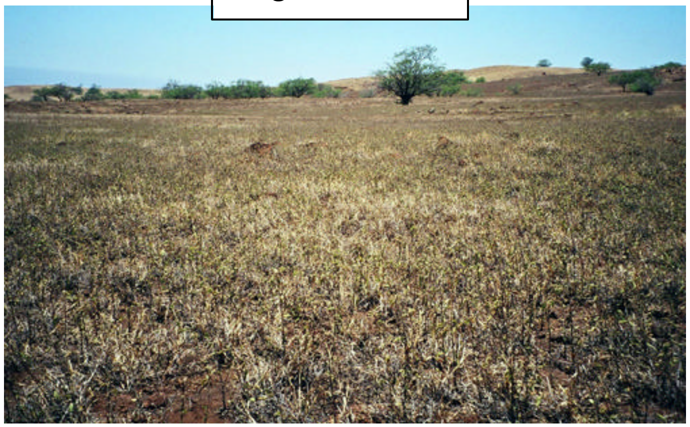
October 2003
Average stubble height 2.0”

March 2004
Average stubble height 2.9”

February 2005
Average stubble height 5.0”

# Paddock 4B
# Key Forage Species: Buffel

March 2001
Average stubble height 1.9”



August 2002

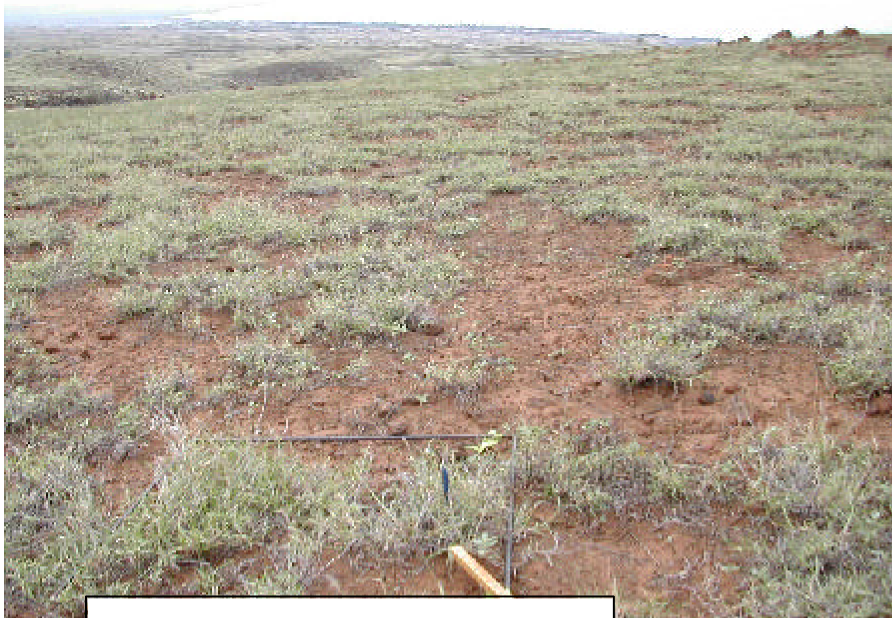
February 2003
Average stubble height 3.1”
(recently grazed)

October 2003
Average stubble height 1.85”

February 2005
Average stubble height 7.0”

Paddock 4C

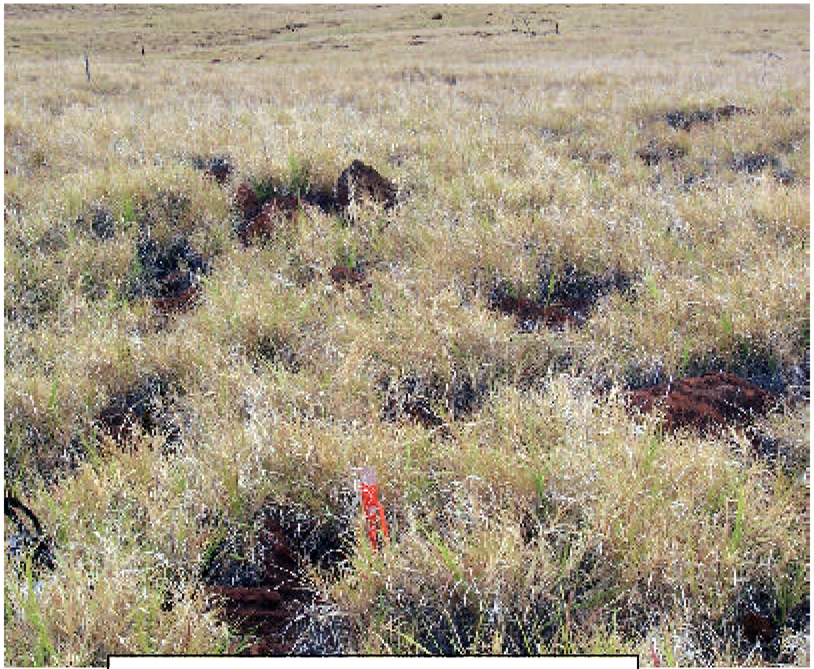
Key Forage Species: Buffel



February 2003
Average stubble height 6.95”

February 2005
Average stubble height 10.0”

Paddock 5A
Key Forage Species: Buffel



September 2004
Average stubble height 9.8”

February 2005
Average stubble height

Paddock 5B

Key Forage Species: Buffel

September 2004
Average stubble height 10.6”

February 2005
Average stubble height 12.2”

**APPENDIX D. ADDENDUM TO THE PELEKANE BAY WATERSHED MANAGEMENT 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 Pelekane Bay Watershed Management 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

[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.

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. 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. |

| Management Practice | Description |
|---|---|
| Feral Ungulate Removal | Hunting or trapping wild goats, pigs, and other non-native hoofed mammals to reduce erosion caused by trampling and vegetation removal, as well as nutrient and bacterial impacts from defecation in and around water bodies. |

Through this addendum, these BMPs are now eligible for funding under Section 319 to address water quality concerns caused by invasive species (if the BMPs were not already identified in the original plan). Implementation of these BMPs will lead to a reduction in pollutant loading in the watershed. The original watershed-based plan may include information on specific locations or land use types that may be most appropriate for invasive species BMPs. Additional information can be found in other resources, such as the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service's *Field Office Technical Guide* for Hawaii.[3]

## Calculating Pollutant Reductions

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

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

## Description of the InVEST Model

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

The InVEST sediment delivery ratio model is focused on sediment loading and erosion. The model outputs a set of maps showing the sediment erosion, including the amount of sediment soil loss per pixel, and the amount of erosion that is prevented by the presence of vegetation per pixel. The effect of BMPs on sediment erosion can be measured by comparing model outputs ran under the current conditions against model outputs ran with BMPs implemented. To calculate the annual soil loss per pixel, the InVEST model uses the Revised Universal Soil Loss Equation (RUSLE; Renard et al.,

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

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): $R = 0.5 \times P \times 17.02$, where R is the rainfall erosivity value in the proper SI units and P is the annual rainfall in mm/year. |
| **Soil Erodibility**: A map showing the soil erodibility in the watershed. Soil erodibility, also called K factor, is the likelihood of soil | 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 |

[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

| | | |
|---|---|---|
| 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). | | 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. |
| **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** |

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

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

| | | |
|---|---|---|
| management practices are implemented in that land cover/land use type. | | |
| **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 |

[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)

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

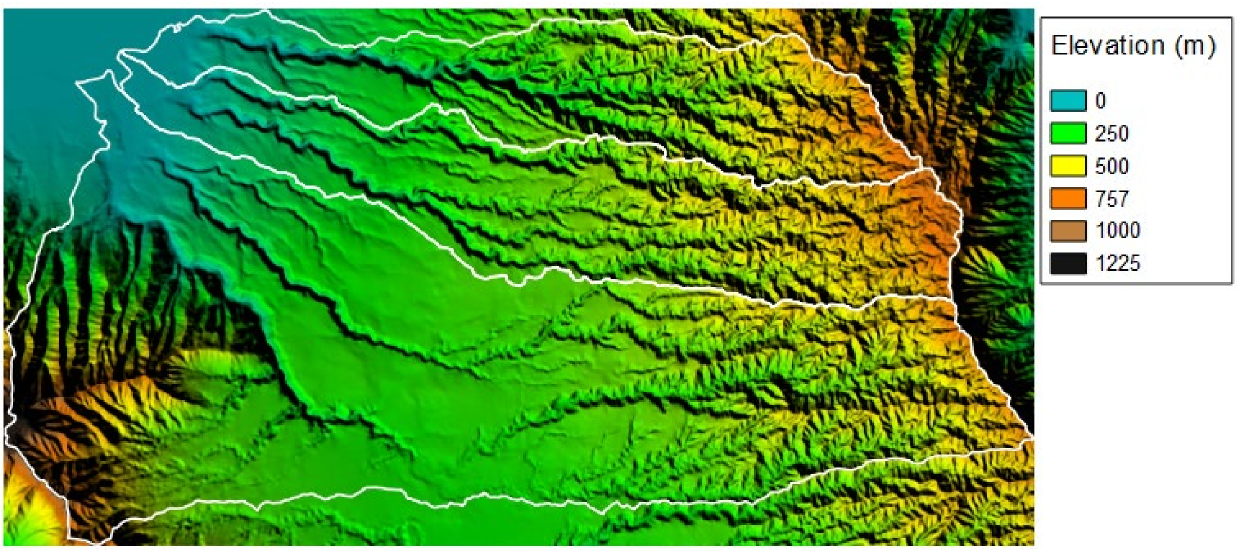
To determine the effect that the implementation of best management practices would have on sediment exports, the outputs from both model runs can be compared. The sum across every pixel in “sed_export.tif” outputs illustrate how much sediment load reduction would occur with BMP implementation on the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

[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.

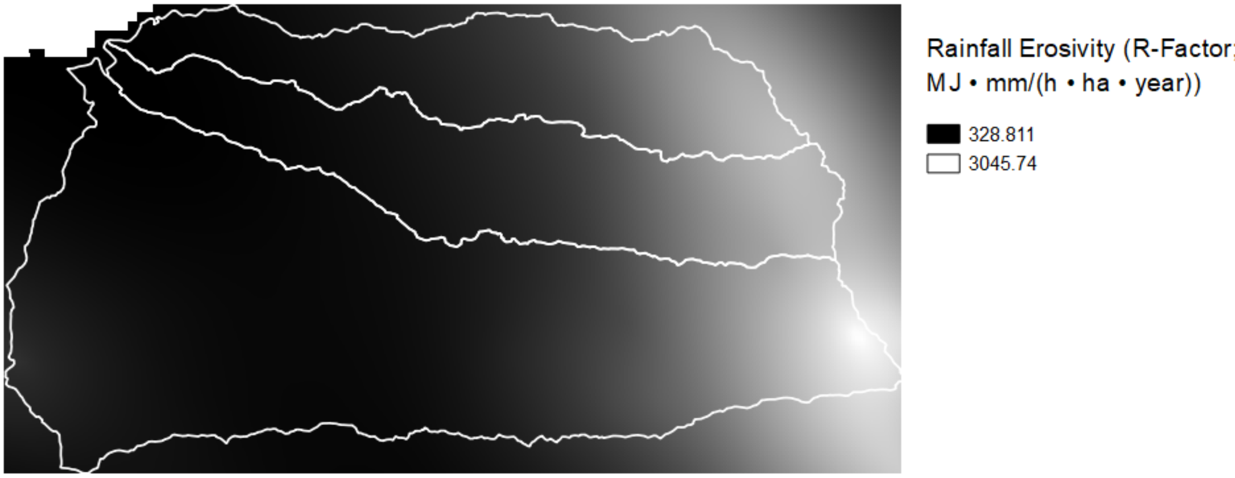
## Example Use of the Procedure

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:

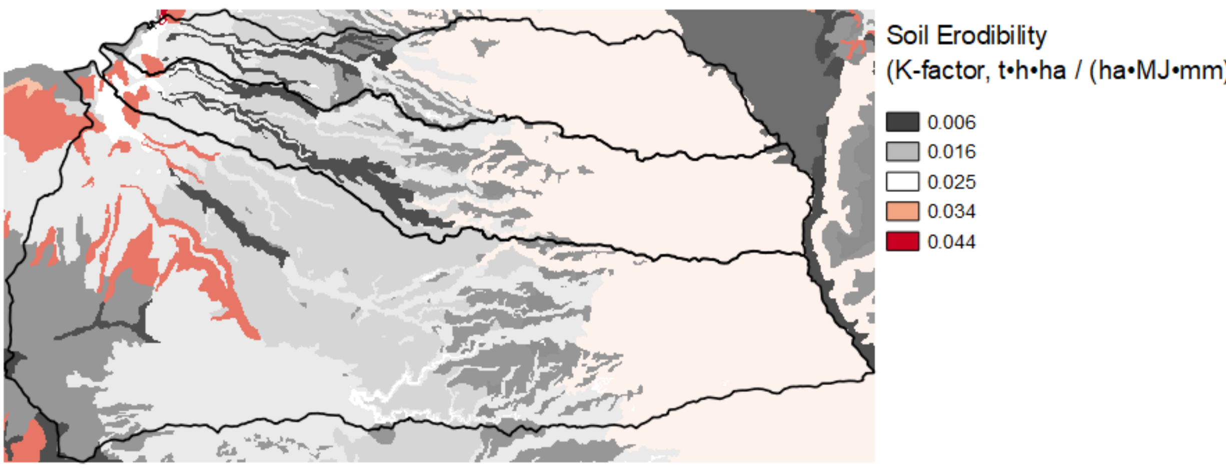
- Elevation Map: A DEM raster showing elevation in meters in the Kaiaka Bay and the surrounding area. This raster is a valid input for the InVEST model because the elevation is in meters and it extends beyond the Kaiaka Bay watershed boundary.



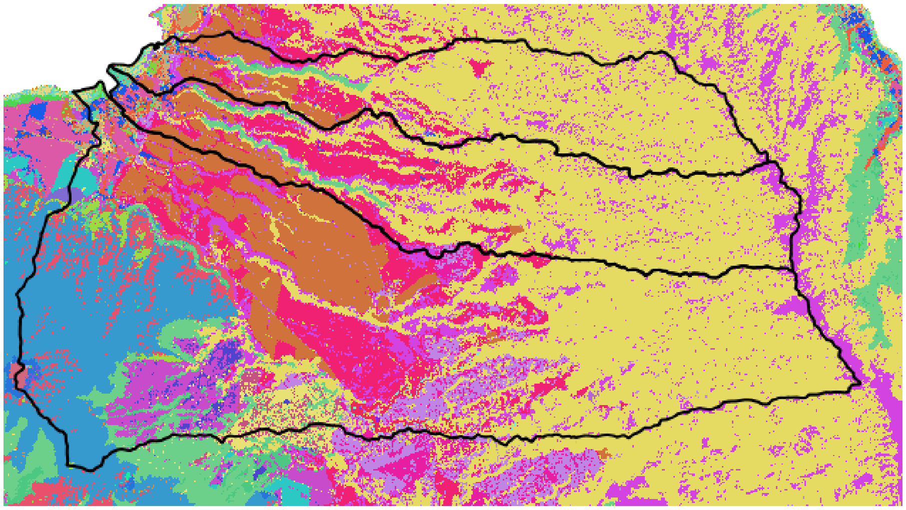

- Rainfall Erosivity: A rainfall erosivity map in raster format showing the rainfall erosivity throughout the Kaiaka Bay watershed in MJ • mm/(h • ha • year), the units required by the model.



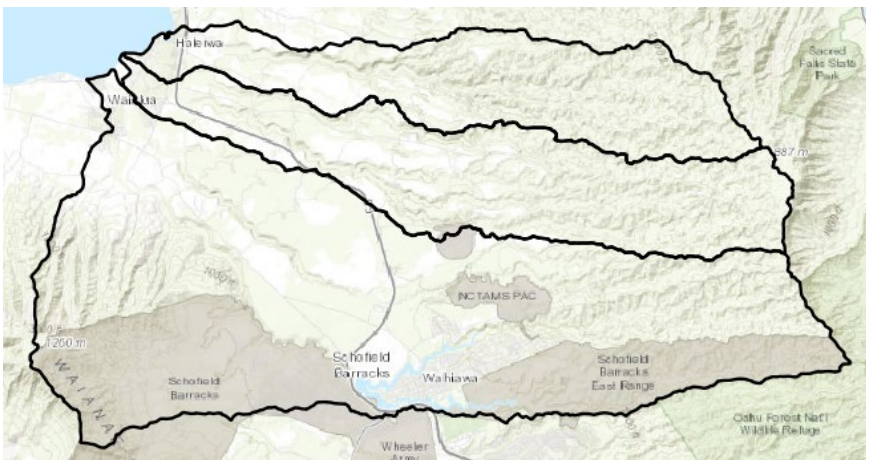

- Soil Erodibility: A map showing soil erodibility, or K factors, within the Kaiaka Bay watershed in raster format. The values in the raster format are in the proper units for the model, t • h • ha / (ha • MJ • mm).




- 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.

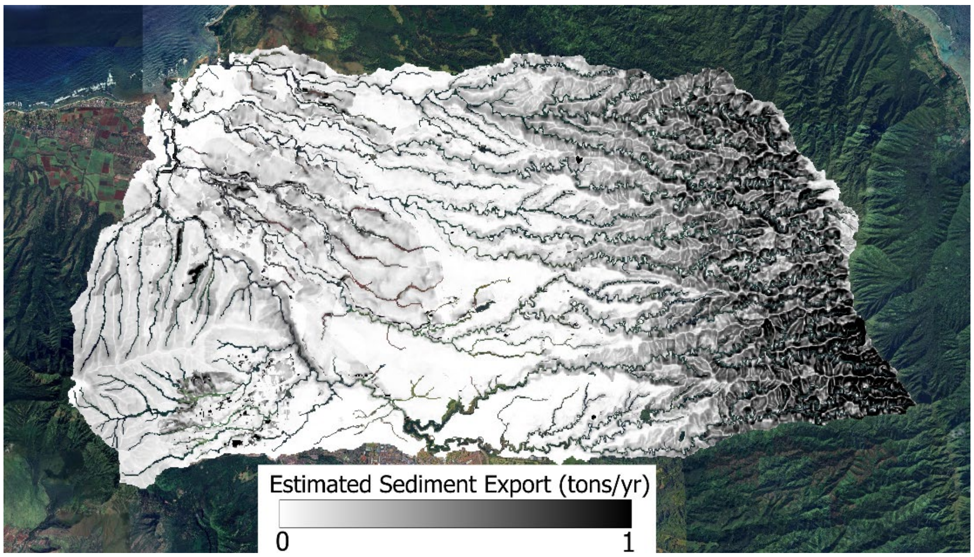
- Borselli k Parameter: The Borselli k parameter for this model run is 2.5, the value for all watersheds on Oahu.

- 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:



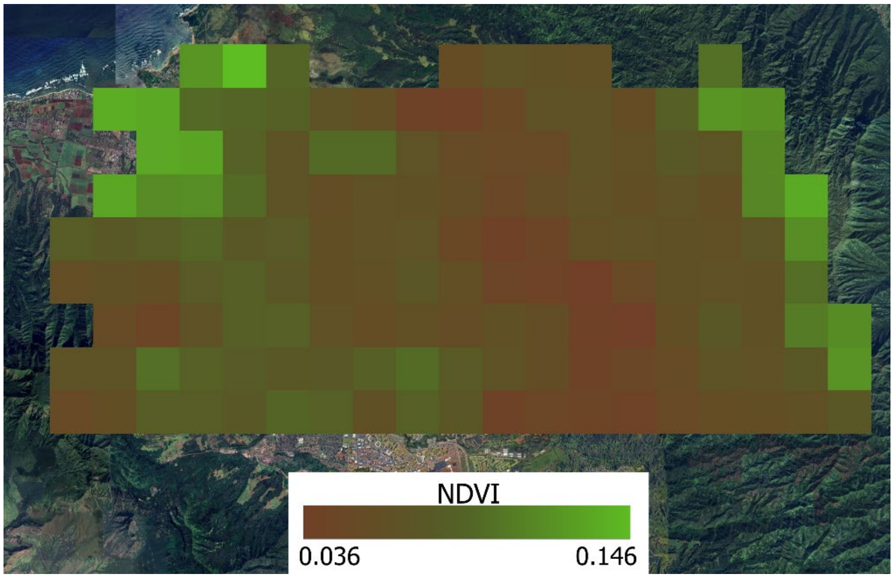

This raster indicates that the model expects the highest amount of sediment export to occur at the higher elevations of the watershed, but as discussed in the Step-by-Step Procedure section, the InVEST model tends to overestimate sediment export in high elevation areas. For this reason, multiple lines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

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