ASSESSMENT AND PROTECTION PLAN FOR THE KAULANA AND HAKIOAWA WATERSHEDS ON KAHO'OLAWE, HAWAI'I.

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1- EXECUTIVE SUMMARY

A Wahi pana (Storied Place) and Pu'u Honua (Place of Refuge), Kaho'olawe still serves as a focal point for the navigation of voyagers to and from Hawaii. However, on December 8, 1941 martial law was declared and the island of Kaho'olawe was taken by the US Navy. It was subsequently used as a bombing range for 50 years. While severe erosion had begun before this time, in conjunction with the military presence, persistent winds and intermittent rains continued to impact the landscape. Surface runoff on Kaho'olawe is estimated at 7×10^7 m^3 or 19 billion gallons each year sometimes with sediment content at 90%, and much of this enters into the pristine ocean waters and unique reef environment off of Kaho'olawe. A former two-year Hawai'i DOH, Clean Water Branch, Watershed Restoration project around 50ha of the summit of the island, concluded in September 2005, and significantly increased (α=0.0493) the mean cover (%) of native plants and significantly reduced (α=0.001) the mean cover (%) of bare soil. Rates of soil erosion in the former DOH project site were estimated at 1.7 tons/ha/year. Approximately 430 tons/year and 1045 tons/year of soil is being lost in Kaulana and Hakioawa watersheds, respectively. Currently, a new DOH three-phase KIRC project extension is expanding out into the headwaters of Kaulana and Hakioawa watersheds. BMP's include irrigation, native plants, non-native species control, hydroseeding, check dams, swales, pili rolls, planter boxes and geotextiles. The USGS Pacific Science Center (PSC) in Santa Cruz, CA., is assisting with ocean turbidity monitoring in the shallow waters off of these two bays, as well as analyzing water samples taken repeatedly at three depths (1,15, ~30ft) above the turbidity monitors. The USGS at the Pacific Island Water Science Center (PIWSC) in Honolulu, HI is assisting with the installation and monitoring of soil erosion pin transects in control (Tier I) and treated (Tier II) areas; and two stream gages, one near the mouth of Hakioawa stream, and one farther inland up Kaulana stream. Sediment load (mg/l) and stream flow from the stream gages will be correlated to both precipitation (cm) from the Hakioawa RAWS and the ocean turbidity data (NTU). This WBP addresses the 9 EPA elements, for assessing the results from restoration in the headwaters of these two watersheds. Strategies for improving water quality in the Kaulana and Hakioawa watesheds are to, manage storm water by implementing NPS management measures, and continue to develop education and outreach programs. A $10,000,000 budget has been proposed for 5 years starting in 2008 to 2013, and would address the NPS pollution from excessive sedimentation. With the cultural integration of hundreds of volunteers that will assist with the work on island, a community-based approach will assure success in executing the restoration work required to reverse the current soil erosion trends on Kaho'olawe and continue to fulfill the vision of restoration on the island established by the Kaho'olawe Island Reserve Commission.

2- INTRODUCTION

Project Site Description

Kaho'olawe is the smallest of the eight main Hawaiian islands, and is located 11.2 km southwest of Maui (Figure 1). It is approximately 1.03 million years old (Naughton et al. 1980) occupies an area of $117km^2$, and is 17km long by 11km wide. Its highest point is at Pu'u Moa'ulanui, elevation 452m. It is a single shield volcano (MacDonald et al., 1983) with a 5km wide caldera and a north rift zone that contains Lua Makika crater and the summit area of Pu'u Moa'ulanui. The island is a Wahi Pana (Sacred Place) and a Pu'uhonua (Place of Refuge) (Kaho'olawe Cultural Resources Management Plan, 1995).

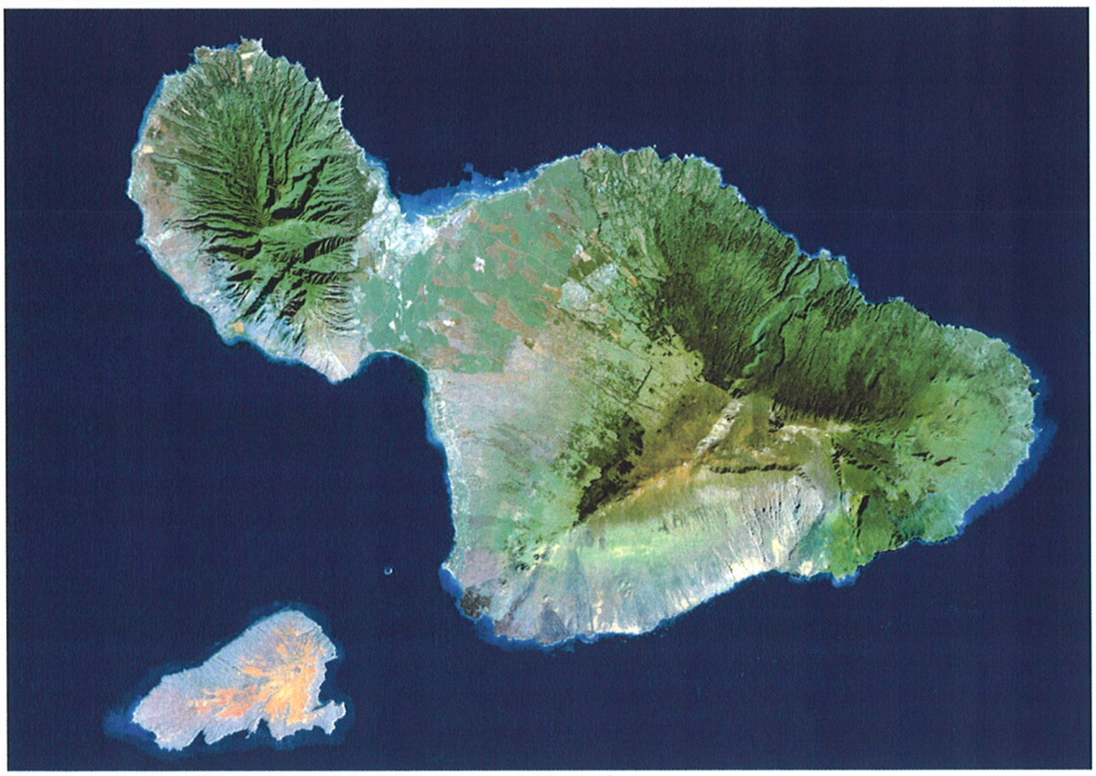

Figure 1. Landsat image of Maui and Kaho'olawe.

Surface runoff on Kaho'olawe is estimated at 7×10^7 m^3 (19 billion gallons) per year (Cox et al., 1995). Soil is lost through surface runoff into the ocean causing dense plumes of turbidity (Figure 2).

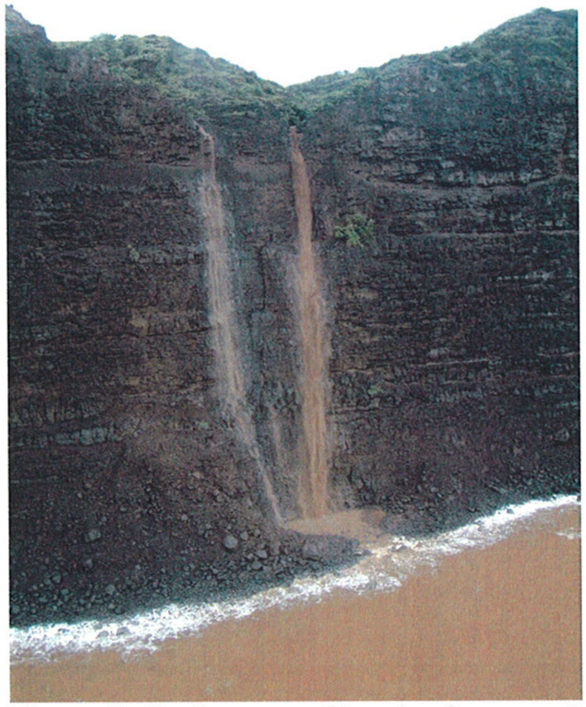

Figure 2. Surface runoff and subsequent turbidity in the ocean off of Kaho'olawe.

During the period between October and March, there may be three or as many as seven major storm events in any particular year, and these storms may bring heavy rains and are sometimes accompanied by strong winds (Figure 3), at least on a local scale. The storms are usually associated with the passage of a cold front, and may also be associated with a large eddy, or Low, that has been generated in the moving air. Moist, warm air swirling into such eddies produces clouds and torrential rains.

Figure 3. Wind erosion on Kaho'olawe.

The watersheds of Kaulana and Hakioawa are located on the Northwest and Northeast side of Kaho'olawe (Figure 4) and cover an area of 280ha and 310ha respectively.

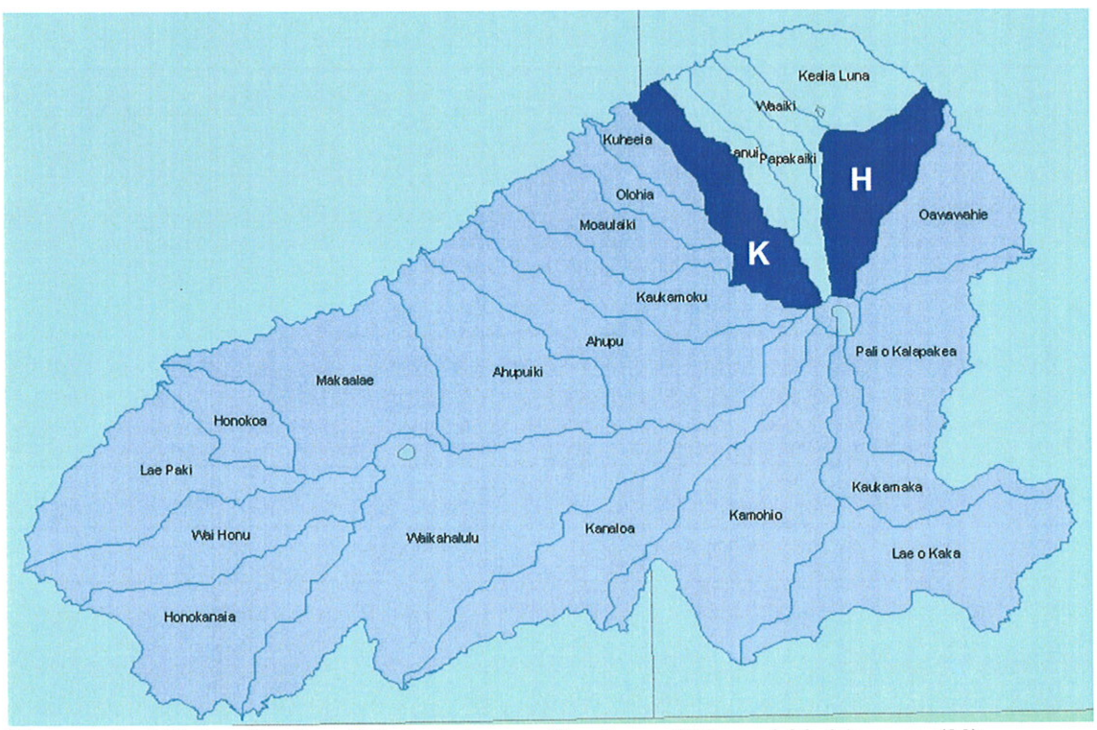

Figure 4. Watersheds of Kaho'olawe, Kaulana (**K**) and Hakioawa (**H**).

A watershed is defined as a geographic area in which all sources of water, including lakes, rivers, estuaries, wetlands, and streams, as well as ground water, drain to a common surface water body. Because all watersheds are defined by natural hydrology and ultimately drain to coastal waters, they are good focal points for managing coastal resources.

A USGS quadrangle map of the streams in the watersheds of Kaulana and Hakioawa is in Figure 5. Dotted black lines are the stream channels.

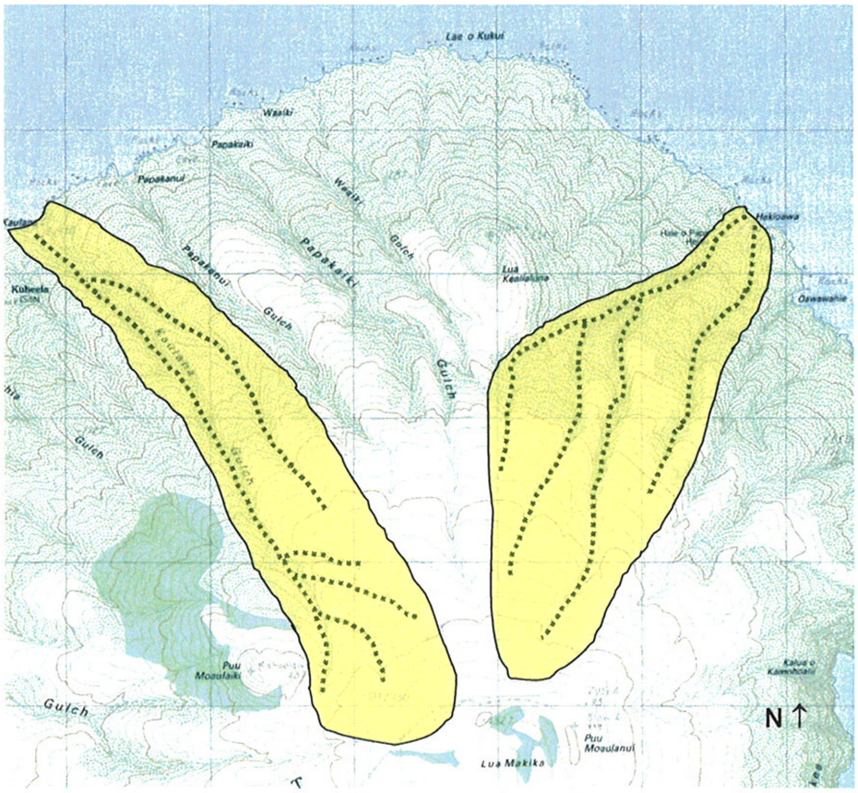

Figure 5. USGS quadrangle map of the streams in the Kaulana and Hakioawa watersheds.

Soil erosion rates from KICC (1993) are listed at 429 tons/year and 1045 tons/year for Kaulana (280ha) and Hakioawa (310ha) watersheds, respectively.

An aerial photograph of the headwaters of Kaulana watershed is presented in Figure 6 and of the streams of Hakioawa watershed in Figure 7. Dotted black lines are the stream channels.

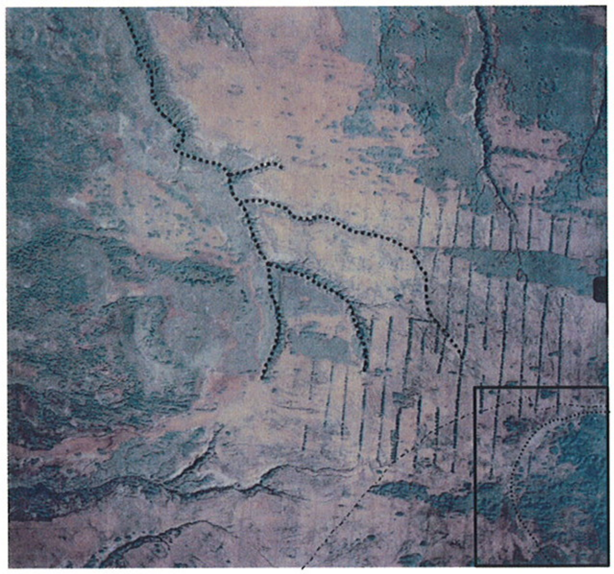

Figure 6. Headwaters of Kaulana watershed and boundary of previous DOH project site.

Figure 7. Streams of Hakioawa watershed and boundary of previous DOH project site.

Precipitation Trends

Monthly precipitation averages from the Hakioawa Remote Access Weather Station (RAWS) from September 2001 to January 2006 are illustrated in Figure 8. The wettest months are January through March, and the driest are June through August.

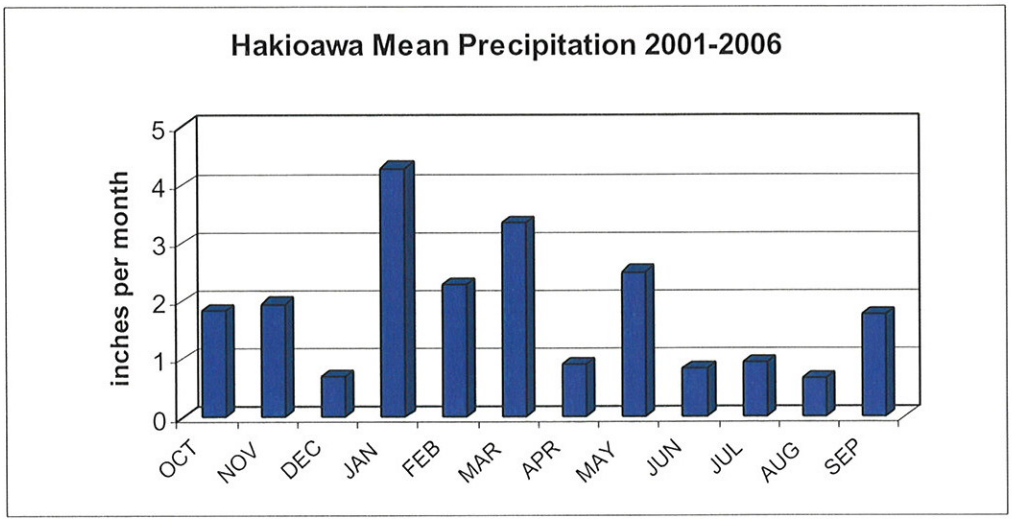

Figure 8. Average monthly precipitation form 2001 to 2006 at the Hakioawa RAWS.

Zone A and B of the Kaho'olawe Island Reserve (KIR)

The Kaho'olawe Island Reserve (KIR) is comprised of Zone A (Figure 9) which includes the island of Kaho'olawe and all the submerged lands and waters between the shoreline and the 30 fathom isobath which surrounds the island (HRS SS6K HAR SS13-261). Zone B is all waters and submerged lands between the 30 fathom isobath surrounding Kaho'olawe and two nautical miles from the shoreline of the island.

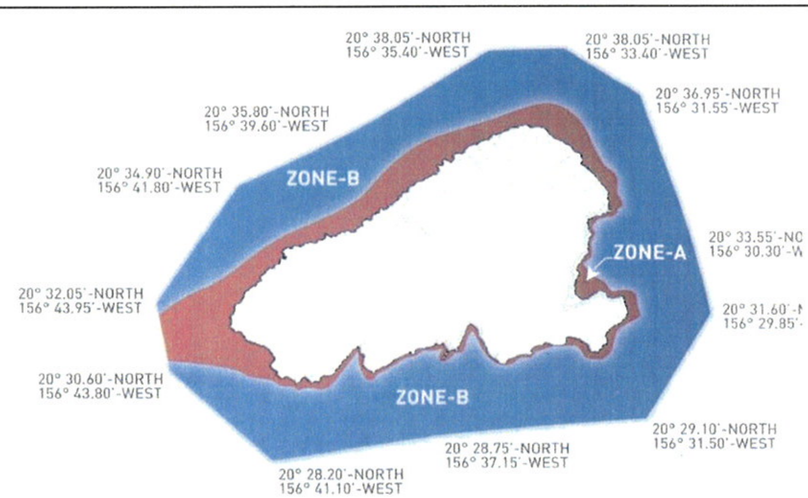

Figure 9. Zone A and B of the Kaho'olawe Island Reserve.

The KIRC is responsible for the management of the KIR which includes the island of Kaho'olawe and the marine waters two miles seaward of the shore.

The waters around the main Hawai`ian Islands including Kaho`olawe constitute one of the world's most important North Pacific humpback whale (*Megaptera novaeangliae*) habitats and the only place in the U.S. where humpbacks reproduce (Figure 10).

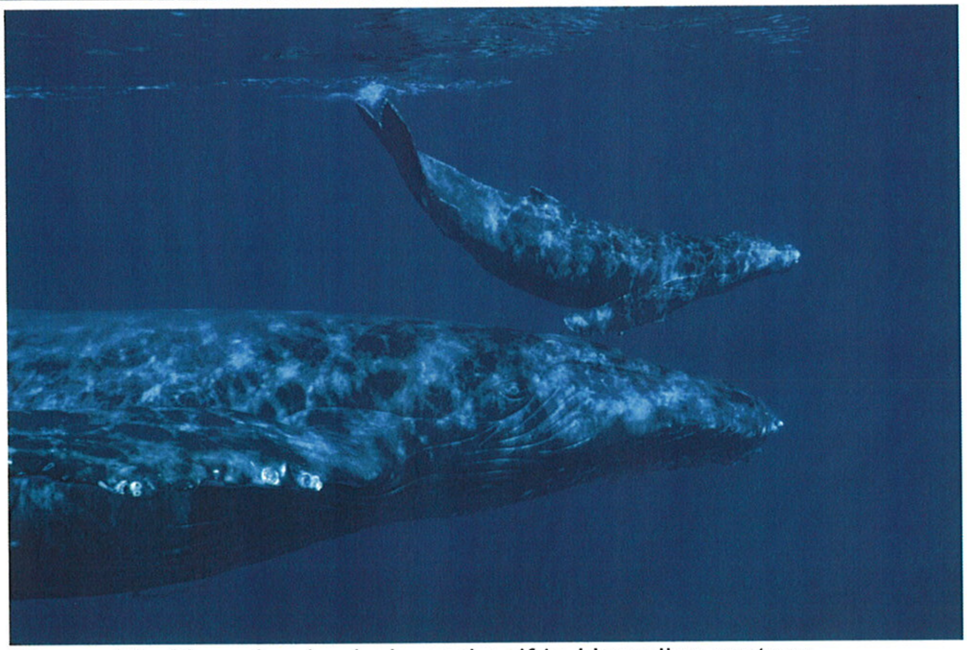

Figure 10. Humpback whale and calf in Hawaiian waters.

More than 60 percent of coral reefs in U.S. waters are found in the extended Hawaiian Island chain. These complex and diverse marine ecosystems are not only ecologically important but also provide hundreds of millions of dollars annually to Hawaii's economy. (Field et al., 2005). In the final report of the Kaho'olawe Island Conveyance Commission (1993), Recommendation 2.12 states that "The State of Hawaii shall recognize the waters surrounding Kaho'olawe for their pristine nature - and their importance in maintaining numerous marine species populations - and designate these waters with special status under the law".

The Kaho'olawe marine protected area (78mi^2) encompasses beaches with intact dune ecosystems, pristine near shore coral reefs, and rare, intact deep-water habitats of commercially valuable bottom fish. Restoration of marine habitats depends upon the effectiveness of terrestrial revegetation efforts. As revegetation proceeds inland, near shore reefs once characterized by silt are clearing to reveal hard substrate, which will provide more habitat for coral colonization, and potentially restoring subsistence fishing areas (Kaeo and Whitcraft, 2004).

On Kaho'olawe, "the northern coast is characterized by gentler slopes and low rocky cliffs, interspersed with numerous small sandy and silty pocket beaches . A relatively shallow shelf extends offshore. Numerous gulches along this coast bring soil down from the slopes and continue underwater as deep beds of terrestrial sediments. Turbidity is particularly high after periods of rain and during periods of waves that disturb the sediment bottom. Normal trade winds and currents mobilize inshore sediment deposits. As the trade winds increase during the day, inshore turbidity increases. Sediment plumes move out of the bays and along the coast. Along the western shore of these underwater valleys, coral coverage is low and sediment damage is evident. There is a sharp demarcation between the turbid waters of the sediment plumes and the clearer waters along the eastern shores of the underwater valleys, and in the clearer waters, corals typical of less disturbed habitats, *Porites compressa* and several species of *Montipora*, are common and coral coverage is high. The northeastern coast has a steeper shoreline. Turbidity can be high nearshore after rains or disturbance of bottom sediments (Figure 40). Coral coverage and diversity in this zone are high." (Cox et al., 1995). Coral coverage was relatively high at Hakioawa and the coral community included *Porites compressa* and *Montipora spp.* Total coral coverage was positively correlated with coral diversity ($r = 0.432$, $p < 0.01$, $df = 31$).

3- HISTORY

Pre-European Contact

Traditional accounts indicate that Kaho'olawe was closely associated with several deities, including Kanaloa, the god of the ocean, the deep sea, and of navigation and carving (DLNR, 2003). Kaho'olawe is thought to have been an ahupua'a of Maui and to have been divided into smaller sections called 'ili which were occupied and worked. Prior to European contact, Kaho'olawe had long been important to Native Hawaiians as a site for religious practices, astronomical and navigational training, tool making fishing and agriculture. As many as 100 or more people may once have lived at Hakioawa, the largest settlement on the Island. The archaeological and historic resources of the Island are valuable treasures that provide insight into the Island and its past inhabitants.

Traditionally, Kaho'olawe served as the navigational center or piko and crossroads connecting Hawaiians to their ancestral homeland, Tahiti. The Kealaikahiki Channel aligns with the north-south Kane- Kanaloa line at the zenith of the heavens, dividing east from west. In aligning the stern of a voyaging canoe in the Kealaikahiki channel with Lae O Kealaikahiki on Kaho'olawe, Pu'u O Hoku on Moloka'i, and Hoku Pa'a (the North Star) a navigator can set a straight course for Tahiti.

Mo'olelo, mele, and archaeological data provide the background for what is known about the pre-contact period on Kaho'olawe. Hawaiian traditions (especially the tradition of La'amaikahiki) link Kaho'olawe with the South Pacific voyaging tradition that resulted in the introduction of a new ruling class, new gods, and a more stratified society around 1200 AD.

Most prominent western scholars believe people from East Polynesia originally settled in the Hawaiian Islands between AD 200 - 500. This is evident by the Hawaiian language, culture, social organization, and technology. The original settlers brought with them domestic plants and animals: sweet potatoes, taro, pigs, dogs, and chickens.

Archeologists believe the pre-contact history of Kaho'olawe began around A.D. 1000, based on radiocarbon dates from habitation sites. Small communities were established along the coast. In time, greater use of inland areas occurred for cultivation of dry-land crops and adz quarrying, and the original dry forest environment changed to an open savannah of grassland and trees as a result of vegetation clearance for firewood and agriculture. From approximately A.D. 1500 – 1600, dry-land agriculture was practiced on a small scale on inland slopes and coastal gulches.

Kaho'olawe is one of the traditional names the island has and means "to be caused to be carried away" or "to be brought together" (KICC, 1993). It is believed that this is a reference to the ocean currents between Maui and Lana'i and Hawai'i that meet at Kaho'olawe and bring a varied assortment of flotsam from around the world. One of the principle names of the island is Kanaloa, God of the ocean and navigation. According to accounts of Kahuna from Kamehameha, Kaho'olawe was born of Wakea. However, another account from Fornander (2004) indicates Kaho'olawe was born of Hina. Kanaloa has many kino lau (body forms), which include the nai'a or porpoise, and he'e or octopus. Other traditional names include Kohemalamalama o Kanaloa which refers to the navigational significance of the island for voyagers between Hawai'i and Tahiti. Finally, other names include Kahiki Moe, Hineli'i, Kohema or 'Ai lani Kohemalamalama and Kukulu Ka'iwi o ka Aina.

While the first Polynesians came to Hawaii in about 200AD, Kaho'olawe was probably settled around 1000AD. As the main islands were settled, Kaho'olawe was the last place for gods, goddesses and spirits to dwell. Then between 1200 and 1400AD another influx of voyagers arrived and Kealaikahiki on Kaho'olawe became a prominent navigational aid.

Between 1400AD and 1600 AD the interior of the island experienced increased agricultural use, and Hakioawa grew to become the islands largest community. However, at the end of the 18th century the islands population had declined due to inter island warfare between Ali'i, disease introduced from traders and whalers and emigration to Maui and Lana'i.

Historical Period

Written history for Kaho'olawe begins in 1779 when descriptions of the islands appear in ships logs. The eight components of the Historical period are listed in Table 1.

Number	Period	Dates
1	Early Contact Period	1779-1825
2	Missionary Period	1825-1853
3	Early Ranch Period	1853-1910
4	Forest Reserve Period	1910-1918
5	Later Ranch Period	1918-1941
6	Military Period	1941-1980
7	Joint Use Period	1980-2003
8	State Use Period	2003 to present

Table 1. Historical periods of Kaho'olawe.

Early Contact Period (1779-1825)

Early historical accounts of this period come from western explorers sailing past Kaho'olawe. For example, Lieutenant James King of H.M.S. Discovery writes on

February 24, 1779, describing the western part of Kaho'olawe as "*very desolate, neither houses, trees nor any cultivation that we saw. It has no wood on it...*"

In 1779 James Cleke Maxwell on The Cook Expedition wrote, " ...*the SW point of it is moderately low but very barren, we could see nothing at all except a few shrub bushes*".

From Surgeon Samwell,
"*[Kaho'olawe] is a small low island without any trees...upon it.* "

Captain Vancouver on his 1793 voyage, was told that Kaho'olawe and Lanai "*which had formerly been considered as fruitful and populous islands, were nearly overrun with weeds...*"

In 1793, Captain Vancouver presented Chief Kahekili of Maui with several goats which were taken out to Kaho'olawe. During the 18th century Kalaniopu'u invaded Kaho'olawe for control of the island in a battle with Chief Kahekili and residents of the island were certainly affected. King and Clerke made observations from the barren and steep cliffs off of the south shore mentioning fires possibly in conjunction with agricultural use. By 1795, Kamehameha I had conquered Maui, Lanai Kahoo'lawe and Oahu, and in this effort to unify the islands, reportedly lit fires on Kaho'olawe. In November, 1819 after the death of Kamehameha I, Kamehemeha II abolished the Kapu system in an event known as the 'Ai Noa . One of the wives of Kamehameha I called the chief "an uku, a fish of Kaho'olawe" referring to the fact that he was a rebel. While some of the cultural practices disappeared along with the Kapu system, some of these past traditions and beliefs were preserved on Moloka'i and Kaho'olawe. Arago in 1819 noted, " *We coasted along Taourae [Kaho'olawe] a barren island, flat, and moderately elevated, on which not a slightest appearance of vegetation. The soil was reddish and furrowed at intervals.*" Other explorers such as Vancouver, Freycinet and Kotzebue also describe the island.

<u>Missionary Period (1825-1853)</u>

In 1820 Puritan Missionaries from Boston arrived in Hawai'i. Reverend Ellis describes the island in 1823, "*It is low, and almost destitute of every kind of shrub or verdue, excepting a species of coarse grass.*" Charles Steward, a missionary in the1820's wrote, *"[Kaho'olawe] has but few inhabitants, a mass of uninteresting and barren rock... Not a sign of life, in the animal or vegetable creation can be discovered on or about them...*"

Building churches and schools the missionaries began teaching reading and writing so that the population could begin to understand the bible. By 1840, Hawaii had become one of the most literate countries in the world. Kaho'olawe was considered part of the Maui mission and Reverend William Richards reported in 1828 that he had a School on the island with "28 scholars attending".

While the school continued on until 1838, the Edict of 1829 proclaimed the Ali'i class subscribed to Protestant Christianity, and all Catholics were banned to Kaho'olawe. Although it is uncertain that any Catholics were ever sent to Kaho'olawe, it set the stage for the island to become a Penal Colony for other transgressors. In 1832 Reverend Hiram Bingham writes that "*a son of a foreigner*" was sentenced to Kaho'olawe for manslaughter. Other punishable crimes included rebellion, theft, divorce, breaking marriage vows, murder and prostitution. The penal colony was located at Kaulana bay and in 1840 had 80 people living in the colony. On May 2, 1853, the law which established Kaho`olawe as a penal colony was repealed and all exiles still on island were pardoned. (KICC, 1993).

In 1841, 100 years before Pearl Harbor, Kaho'olawe's first encounter with the military occurred. Crews from the Leopard and Greyhound were marooned on the western end of the island. Under the command of Lieutenant Budd, the crews were part of the Captain Charles Wilkes Pacific Expedition. Before they eventually made it back to Maui to rejoin the Wilkes expedition, Budd reportedly observed 15 convicts, 8 huts and an unfinished Adobe church in Kaulana.

Early Ranch Period (1853-1910)

During this period the Great Mahele was initiated under Kamehameha III and Kaho'olawe became "Government Land" a status it still maintains today. A member of the First Land Commission, Zorobabela Kaawai, and C.C. Harris offered $400 to purchase the island in 1849. However, their offer was refused by the King's Privy Council and the land was leased instead.

In 1857, the Maui Governor, P. Nohuolelua, and Ioane Richardson went to Kaho'olawe to inspect the possible lease conditions and noted that "*...there is about three thousand acres of good land, mauka in the mountain which we saw when we made this inspection.*"

In 1858, one of the future lessees W.F. Allen noted "*...the best soil is on top of the Northern part of the island...*"

The government issued the first of four leases to Robert C. Wyllie on April 1, 1858 for $505 per year. Wyllie introduced sheep to Kaho'olawe and developed a large ranching operation. The sheep became infected with a form of scabies however which ruined the wool, and Wyllie transferred his lease to other ranchers.

In 1859, Allens' partner, R.C. Wyllie visited the island and wrote, "*On the summit of the island there is about four or five thousand acres of land...about half of this land is at present covered with scrubby, brittle succulent called 'Akoko', which when broken, yields a thick milky juice...*"

By 1884, more than 9,000 goats and 12,000 sheep were present on the island. Over grazing soon became problematic and the severe erosion problems experienced today are a direct result of these large and uncontrolled ungulate populations (Table 2).

Year	Goats	Sheep	Pigs	Cattle	Horses
1859	Present	2,075	Present		
1875		20,000			
1881	2,000	1,000			
1884	9,000	2,000		200	40
1888		1,000		800	100
1890		1,2000		900	
1903 to 1904		5,000			
1904				60	
1909	5,000	3,200		40	40
1920				500	
1939	25	200		500	17

Table 2. Summary of Goat, Sheep, Pig, Cattle, and Horse populations on Kaho'olawe from 1859 to 1939.

Unfortunately in 1880, to correct the problem of erosion they were witnessing, the ranchers began planting Kiawe (*Prosopis pallida*) which quickly spread and is now ubiquitous over the entire island. Kiawe is a prolific source of evapotranspiration as the deep taproots can reach 50 to 60 feet (http://www.botany.com/prosopis.html) down to the shallow water table and disperse the limited amount of groundwater into the atmosphere.

In 1893, the Hawaiian Monarchy was overthrown with support from 162 U.S. sailors and marine forces from the U.S.S. Boston anchored in Honolulu Harbor. The Republic of Hawaii was soon formed and Kaho'olawe continued to be considered as Government land. In 1898, congress passed the Newlands Resolution and Hawaii became a Territory of the United States. Government and Crown Lands were transferred or ceded to the U.S. Government. However, passage of the Organic Act in 1900 allowed the Territory of Hawaii to manage all lands not needed for the purposes of the United States, and Kaho'olawe remained under Territorial management with a ranch lease to Benjamin F. Dillignham and then Eben Low until 1910.

Forest Reserve Period (1910-1918)

"On August 25 1910, the island of Kaho'olawe was designated a forest reserve by Territorial Governor of Hawaii Walter Frear. Prior to this Kaho'olawe had been subject to decades of grazing by goats, sheep and cattle raised for commercial ranching. Denudation of vegetation resulting from intense grazing led to sever soil erosion problems by 1880. Ranchers at this time began the first of many attempts to stem soil erosion by introducing new vegetation such as Kiawe

(*Prosopis pallida*). Federal Funds never materialized and Governer Lucius Pinkham revoked the Forest Reserve Status in 1918 so that the island could be leased again. With the requirement that the lessee continue to undertake conservation activities."

"Despite the short period of the reserve status, territorial officials were able to make limited progress on restoration goals including the reduction of the sheep and goat population on the island down to about 500 from a high of 9000 goats and 12000 sheep in 1884. Revegetation using "spineless" cactus, ironwood trees, candle and grape trees, koa haole, and other species, introduction of Australian Salt Bush (*Atriplex semibaccata*), grass planting experiments, and the first collection of rainfall data for the island."

However, Kaho'olawe's soil erosion problems were continuing unabated and a report to the Territorial Board of Agriculture stated that "as a result of long continued overgrazing, this... island...has become almost worthless through erosion and loss of soil. " The designation of Kaho'olawe as a Forest Reserve allowed for the possibility of appropriating Federal Funds for restoration of former environmental and rainfall regimes. The Federal funds were never allocated, and in 1918, the Territorial Governor Lucius Pinkham withdraws the island from Forest Reserve status and it reverts back to the Commissioner of Public Lands for public lease.

<u>Late Ranch Period (1918-1941)</u>

"Following the Forest Reserve Period, Kaho'olawe was leased in 1918 to a cattle rancher Angus MacPhee, and his partner Harry Baldwin, with the stipulation that they continue goat eradication, limit cattle to 200 head, plant kiawe trees and continue revegetation efforts. Located at Kuhe'eia Bay (Figure 11) the ranch's water system was based on cisterns and reservoirs that were constructed. Between 1918 and 1922, they removed approximately 13,000 goats and terminated many more. They also planted about 5000 trees and hundreds of pounds of Australian saltbush, Natal Redtop (*Rhynchelytrum repens*) and Pili grass (*Heteropogon contortus*) seeds. Tree seedlings planted near Lua Makika and Pu'u Moa'ulaiki with a double row of eucalyptus as a windbreak. Australian saltbush, Natal Redtop and pili grass were included around the rim of Lua Makika, Other species included mamane, iliahi, kamani, kukui, ohia lehua, ohia ai, ma'o and tobacco, olona, and

Figure 11. Ranching on Kaho'olawe.

wauke. During the 1920's and 1930's, the military occasionally used Kaho'olawe for bombing practice. Apparently, Harry Baldwin had an arrangement with the Army that allowed pilots to practice dropping hand held bombs from their bi-wings at the Western end of the island. Restoration efforts came to a halt when Kaho'olawe was seized by the military on December 8, 1941, after the bombing of Pearl Harbor.

Military Period (1941-1980)

In May, 1941, seven months before the Japanese bombing at Pearl Harbor, MacPhee and Baldwin agreed to allow the United States Army Air Corps to use portions of the island for bombing practice. The sub-lease with the United States of America stipulated that the U.S. Government pay $1.00 per year and allowed the Navy to set out a runway with fake aircraft and to begin to use the area for target practice. The U.S Navy also requested use of the island to test its large guns from warships. The agreement became moot on December 7, 1941 with the attack on Pearl Harbor, and all ranching activities ceased on December 8, 1941 when the Territory of Hawaii was placed under Martial Law.

The military took over the entire island, and "Ship-to-Shore" bombardment of the island commenced in 1941. During the war, Kaho'olawe played a major role as a training site for Navy ship gunners and Marine fire control observers. The rehearsals prepared Marines for the landing at Iwo Jima, Okinawa and other sites throughout the southwest Pacific. Ship to shore bombardment intensified starting on October 21, 1943, when the USS Pennsylvania conducted rehearsals for the Gilbert Islands invasion. From 1942-1943, American submarine commanders tested torpedoes by firing them at the shoreline cliffs at Kanapou. Additional torpedoes were test fired from 1943 to the 1960's. Under Executive Order 10436 (signed on February 20, 1953), President Dwight D. Eisenhower reserved the island for the use of the United States for naval purposes, except for 23.3 acres on the southern end previously reserved for lighthouse purposes. The Order directed the Navy to eradicate, or reduce to less than 200, all cloven-hooved animals; to allow the Territory of Hawaii to initiate soil and reforestation studies; and when the island was no longer needed for naval purposes and without cost to the Territory of Hawaii, to render the island reasonably safe for human habitation. During the Korean War era, weapons usage shifted from naval projectiles to air-dropped, general purpose bombs. Targets and mock airfields were built on-island for practice air attacks and strafing runs.

Four months after the Navy began bombing the island, Territorial officials discussed how best to "rehabilitate" the land. Although all cattle were removed, the island was still inhabited by thousands of wild sheep. In 1947, Territorial officials again expressed concern over the need to begin soil conservation measures and address ongoing soil erosion problems. The Kaho'olawe Ranch lease was set to terminate and the Territorial officials agreed to continue Military use of the island. Executive Order 10346 signed by Dwight Eisenhower in 1953 reserved Kaho'olawe for the use of United States for Naval Purposes, placing it under the jurisdiction of the Secretary of the Navy.

On August 21, 1959, Hawaii became the 50th state and provisions of the Statehood Admissions Act made Kaho'olawe part of the Crown and Government Lands ceded to the United States in 1898. As a result of Executive Order No. 10346, Kaho'olawe remained under military jurisdiction continuing to serve as a bombing and live fire range during the Korean and Vietnamese conflicts. By 1967, the island became a testing and training range for the air war over Vietnam. The need for protection from North Vietnamese surface-to-air missiles led to the construction of surface-to-air targets and target airfields on the island. The entire island was used as a weapons range with no restrictions on target locations. By the late 1960's, additional portions of the island were equipped with various types of targets for both ships and aircraft. Between 1968 and 1970, American F-4 Phantom fighter bombers training for the Vietnam War, dropped 2500 tons of bombs on Kaho'olawe. In 1970, the island was bombed for 315 days making it the most bombed island in the Pacific. However, the accidental dropping of bombs on Maui, coupled with numerous complaints of noise from the live fire activities, led the Navy to re-evaluate the on-island target placements. This lead to the designation of the Naval Gun Fire Range on the northern slope and the relocation of the practice air fields and aerial bombardment targets to the central southern third of the island. The dividing lines between these areas were the troop safety lines which demarcate the impact area, leaving the target zone to include the central one third of the island. At that time, the Kaho`olawe Archaeological District contained 544 recorded archaeological/historical sites and over 2,000 features, as well as previously unrecorded features associated with traditional and historic Hawaiian land use, ranching, and military activities.

A series of vegetation trials were established on Kaho'olawe to identify tree, shrub and grass species most adaptable to the islands harsh environment. This project was directed under the jurisdiction of the United States Department of Agriculture (USDA) Forest Service. It was conducted in cooperation with the State of Hawai'I Department of Land and Natural Resources, Division of Forestry (DLNR-DOFAW) on Maui. Other participants included the USDA Soil Conservation Service and the DLNR. The duration of the project was from 1970 to 1974.

To accomplish the objectives of the trials, trees, shrubs and grasses were planted in six fenced exclosures. These exclosures were located in areas representative of the bare, windswept and highly eroded conditions found on the hardpan area.

One of the exclosures was located on the rim of Lua Makika, and two others were located downslope of Lua Makika. Two were constructed downslope of Pu'u Moa'ulaiki, and the sixth exclosure was located on the beach at Honokanai'a.

Grass and shrub species planted by the USDA Forest Service Vegetation Trials for Rehabilitating Kaho'olawe in 1971 and 1973, are listed in Table 3.

	Common Name	**Taxa**	**1971**	**1973**
1	Forage Peanut	*Arachis glabrata*		X
2	Australian Saltbush	*Atriplex canescens*		X
3	Australian Saltbush	*Atriplex semibaccata*		X
4	Bufflegrass	*Cenchrus ciliaris*	X	X
5	Giant Bermuda Grass	*Cynodon dactylon*	X	X
6	Star Grass	*Cynodon plectostachyus*	X	X
7	Pangola Grass	*Digitaria pentzii*	X	X
8	Finger Grass	*Digitaria eriantha*		X
9	Salt Grass	*Distichilis*		X
10	Weeping Lovegrass	*Eragrostis curvula*		X
11	Lovegrass	*Eragrostis supurba*		X
12	Veldt Grass	*Eragrostis calycina*		X
13	Glycine (Tinaroo and Kokomo)	*Glycine wightii*	X	X
14	Pili Grass	*Heteropogon contortus*	X	X
15	Blue Panic Grass	*Panicum antidotale*		X
16	Guinea Grass	*Panicum maximum*	X	X
17	Green Panic Grass	*Panicum maximum var. trichoglume*	X	X
18	'Ilie'e	*Plumbago zeylanica*		X
19	Stylosanthes	*Stylosanthes fruticosa*		X
20	Townsville Lucerne	*Stylosanthes humilis*		X
21	'Auhuhu	*Tephrosia purpurea*		X
22	Tephrosia	*Tephrosia vogelii*		X

Table 3. Grass and shrub species planted by the USDA Forest Service vegetation trials for rehabilitating Kaho'olawe in 1971 and 1973.

The tree species planted by the USDA Forest Service vegetation trials for rehabilitating Kaho'olawe in 1971 and 1973, are listed in Table 4.

	Common Name	**Taxa**	**1971**	**1973**
1	Formosa Koa	*Acacia confusa*	X	
2	Koai'a	*Acacia koaia*	X	X
3	Screwpod wattle	*Acacia implexa*		X
4		*Acacia mangium*		X
5	Sisal	*Agave sisalana*	X	
6	Norfolk Island Pine	*Araucaria heterophylla*		X
7	Pine	*Callistris calcarata*		X
8	Murray River Pine	*Callitris columellaris*	X	
9	Black Cypress Pine	*Callitris endlicheri*	X	
10	Kamani	*Calophyllum inophyllum*	X	X
11	Shortleaf Ironwood	*Casurina equisetifolia*	X	X
12	Longleaf Ironwood	*Casurina glauca*	X	X
13	Seagrape	*Cocoloba urifera*	X	X
14	Coconut, niu	*Cocos nucifera*	X	X
15	Kou	*Cordia subcordata*	X	X
16	Mediterranean	*Cupressus sempervirens*	X	

	Common Name	Taxa	1971	1973
	Cypress			
17	Lama	*Diospyros ferrea var sandwicensis*		X
18	Wiliwili	*Erythrina sandwicensis*	X	X
19	Murray Redgum	*Eucalyptus camadulensis*	X	X
20	Lemongum	*Eucalyptus citriodora*	X	
21	Compacta Eucalyptus	*Eucalyptus globulus var. compacta*	X	
22	Gray Gum	*Eucalyptus punctata*		X
23	Robusta Eucalyptus	*Eucalyptus robusta*	X	
24	Redbark Ironwood	*Eucalyptus sideroxylon*	X	X
25	Redgum Eucalyptus	*Eucalyptus tereticornis*	X	
26		*Eucalyptus torelliana*		X
27	Eucalyptus sp. "a"	*Eucalyptus sp.*	X	
28	Eucalyptus sp. "b"	*Eucalyptus sp.*	X	
29	Ma'o, Hawaiian Cotton	*Gossypium tomentosum*		X
30	Gyrocarp	*Gyrocarpus americanus*	X	
31	Pride of India	*Melia azederach*	X	
32	Tree Heliotrope	*Messerschmidia argentea*	X	
33	Naio	*Myoporum sandwicense*		X
34	Sweet scented Oleander	*Nerium indicum*	X	
35	Madagascar Olive	*Norohia emarginata*	X	
36	Pandanus	*Pandanus odoratissimus*	X	X
37	Ombu	*Phytolacca dioica*		X
38	Brutis Pine	*Pinus brutia*	X	X
39	Beach Naupaka	*Scaevola coriacea (E)*		X
40	Beach Naupaka	*Scaevola sericea*	X	X
41	Sesban	*Sesbania grandiflora*	X	
42	Tamarisk	*Tamarix sp.*	X	X
43	False Kamani	*Terminalia catappa*	X	
44	Milo	*Thespesia populnea*	X	X
45	Tree Heliotrope	*Tournefortia argentea*		X

Table 4. Tree species used by the USDA Forest Service vegetation trials for rehabilitating Kaho'olawe in 1971 and 1973.

A satellite image with the watershed boundaries of northern half of Kaho'olawe is in Figure 12 (see legend) with the past revegetation efforts.

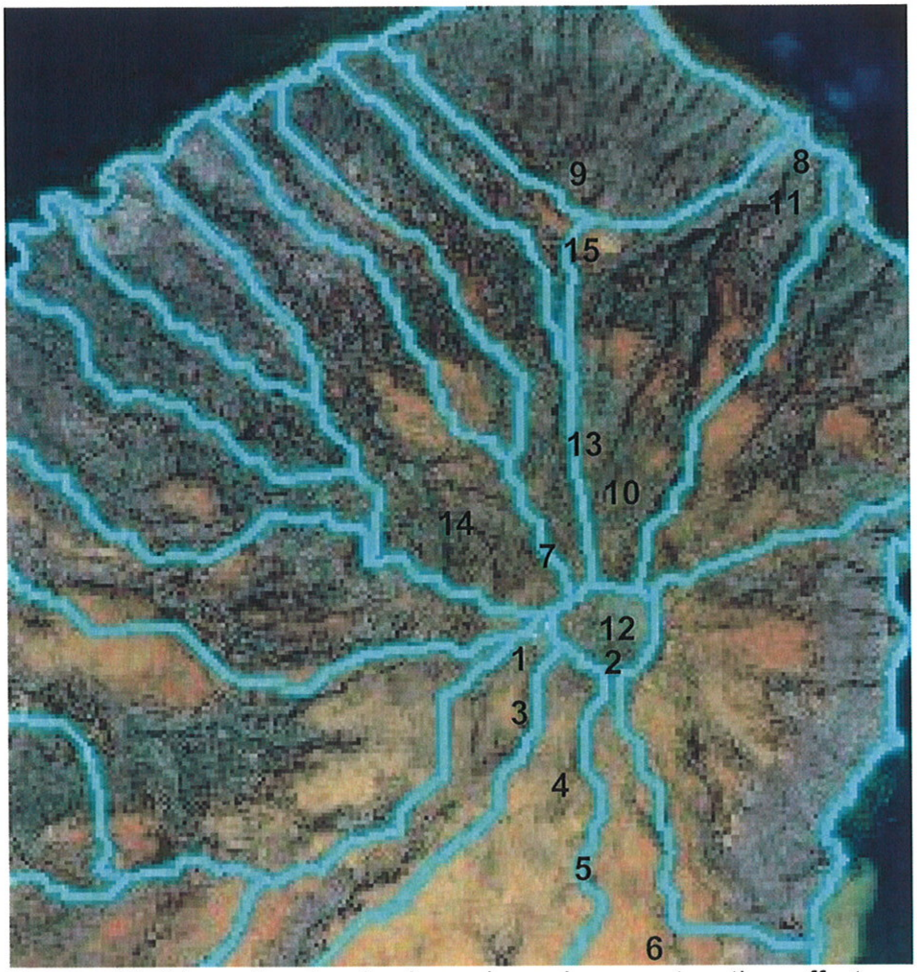

Figure 12. Map of watersheds and previous restoration efforts on Kaho'olawe.

	Legend for Figure 12		
Number	**Description**	**Number**	**Description**
1	CERL 1	8	PKO/F Hakioawa
2	CERL 2	9	PKO/F Kealialuna
3	CERL 3	10	PKO/F Lua Makika
4	NHPS 3	11	PKO/F Wailuna
5	NHPS 4	12	USFS Vegetation Trial 3
6	Navy Grassland Planting Area	13	USFS Vegetation Trial 4
7	NiFTAL	14	USFS Vegetation Trial 5
		15	Wind Station

The Tamarisk tree lines planted in the 1970's have been utilized in the previous and current DOH project as wind breaks for the native plants serving as a buffer against the strong and gusty trade winds.

In January 1976, an initial group of nine people traveled from Maui across to Kaho'olawe and occupied the island on the first of 9 "illegal" landings. National attention was given to the protest and the Protect Kaho'olawe Ohana was created. Unfortunately during the 8th landing, March 5, 1977, George Helm and Kimo Mitchell were tragically lost at sea.

In 1977, A Civil law suit , *Aluli* v. *Rumsfeld*, (Civil Action File No. 76-0380) was filed in the U.S. District Court in the District of Hawai'i. The suit sought compliance with environmental, historic preservation and religious freedom laws. On September 15, 1977 the Federal Court ordered a partial summary judgment in favor of Aluli and the Protect Kaho'olawe Ohana, requiring the Navy to prepare an EIS and to inventory and protect historic sites on the island. One result of this decision was to place the entire island on the National Register of Historic Places in 1981.

A summary of the ownership and lessee's/use of Kaho'olawe is presented in Table 5 (Data from KICC, 1993).

Date	Ownership (landuse)	Lessee/Use
Pre 1810	Trusteeship	District Ali'i
1810 to 1848	Trusteeship	Ali'I Nui, Kamehameha I, II, III
1848	Kingdom of Hawaii	Government Land
April 1, 1858 (Terminated January 1, 1863)	Kingdom of Hawaii	Elisha H. Allen and Robert C. Wyllie 20 yrs @$505/yr (Sheep Ranching), Shepard-Hillebrand (1859)
March 1864	Kingdom of Hawaii	Elisha H. Allen and C.G. Hopkins 50 years @$250/yr. (Sheep Ranching)
March 22 1880	Kingdom of Hawaii	W.H. Cummins and A.D. Courtney (Sheep Ranching-Kahoolawe Stock Co.
1886		W.H. Cummins and W.H. Daniels (Sheep Ranching)
April 27 1887	Kingdom of Hawai'i	Randall Von Tempsky C.S. and J.R.S. Kynnersley (Sheep Ranching)
January 16 1893	Provisional Government of Hawaii	
July 4 1894	Republic of Hawaii	
August 12 1899	U.S.A.	Benjamin F. Dillingham (Sheep Ranching)
December 21 1903	U.S.A.	Christian C. Conradt (Sheep Ranching)
December 28 1906	U.S.A.	Eben Low (Sheep Ranching)
August 25 1910	U.S.A.	Forest Reserve (Board of Agriculture and Forestry)
April 20 1918	U.S.A.	Forest Reserve status revoked
December 23 1918	U.S.A.	Angus MacPhee (Cattle Ranching)
July 11 1919	U.S.A.	Angus MacPhee Kaho'olawe Ranch Company (KRC)
June 8 1920	U.S.A.	Angus MacPhee and Harry Baldwin (Cattle Ranching)
1925 to 1926	U.S.A.	1st Re-opener ($300/yr)
February 3 1927	U.S.A.	Presidential Proclamation 1527
December 19 1927	U.S.A.	Territorial Governor EO 308
March 15 1929	U.S.A.	
May 23 1933	U.S.A.	Angus MacPhee and Harry Baldwin

Date	Ownership (landuse)	Lessee/Use
		(Cattle ranching – KRC)
May 10 1941	U.S.A.	
December 8 1941	U.S.A.	MARTIAL LAW DECLARED
March 1 1994	U.S.A.	
October 18 1944	U.S.A.	
October 1 1952	U.S.A.	Territorial Governor EO 1528 cancels EO 308 U.S. Dept of Commerce (Lighthouse Service)
November 7 1952	U.S.A.	Territorial revocable permit 800 issued to U.S. Dept. of the Navy
February 20 1953	U.S.A.	Presidential EO 10436 issued: Secretary of the Navy
December 1 1980	U.S.A.	U.S. District Court of Hawaii to: Secretary of the Navy and the Protect Kaho'olawe Ohana

Table 5. Summary of ownership, and lessee's/use of Kaho'olawe.

Joint Use Period (1980 to 2003)

On December 1, 1980, due to the damaging practices of the military, the court settled with *Aluli* v. *Brown* (formerly *Rumsfeld*), by issuing a Consent Decree and Order mandating the Navy to survey and protect historic and cultural sites on the island, to clear surface ordnance from 10,000 acres, continue soil conservation and revegetation programs, eradicate goats, and limit ordnance impact training to the central one third of the island. It also allowed the PKO monthly access to the island for religious, educational, and scientific activities. Through those monthly accesses, the PKO has regularly visited the island for religious and cultural purposes, as well as revegetation and conservation programs. On March 18, 1981, the entire island was listed on the National Register for Historical Places and designated the Kaho`olawe Archaeological District. The military cleared UXO from an estimated 14,000 acres and finally after 200 years, the goats were eliminated in 1993.

On October 22 1990, President George Bush issued a memorandum to the Secretary of Defense to put a temporary halt to all bombing and munitions training on the island and discontinue use of Kaho`olawe as a weapons range effective immediately. Section 8118 of Public Law 101-511, enacted by Congress in 1990, established the Kaho`olawe Island Conveyance Commission to recommend terms and conditions for the conveyance of Kaho`olawe from federal jurisdiction to the State of Hawaii. The law prohibited the use of the island for weapons delivery training until after the final Kaho`olawe Island Conveyance Commission report was delivered to Congress. The Kaho'olawe Island Conveyance Commission (KICC) was formed and funded to fulfill its congressional mandate of studying the island and recommending the terms and conditions for the return to the State of Hawai'i. The Commission submitted its final report with findings and recommendations to Congress in March 1993, and dissolved six months later in September 1993. During the same period, the Navy in consultation with the State Historic Preservation Office, the Protect

Kaho`olawe `Ohana, and the County of Maui met and developed a Cultural Resources Management Plan for the Kaho`olawe Archaeological District which was finalized in January 1995.

In 1993, Senator Daniel K. Inouye of Hawaii sponsored Title X of the Fiscal Year 1994 Department of Defense Appropriation Act (PL 103-139, 107 Stat. 1418. 1479-1484) for $400 million in funding for the removal of unexploded ordnance and environmental restoration on Kaho'olawe. Title X authorized conveyance of Kaho`olawe and its surrounding waters to the State of Hawaii. It also provided for the "clearance or removal of unexploded ordnance" and environmental restoration of the island, to provide "meaningful safe use of the island for appropriate cultural, historical, archaeological, and educational purposes, as determined by the State of Hawaii." In 1993, the Hawaii State Legislature enacted Chapter 6K of the Hawaii Revised Statutes, which established the Kaho'olawe Island Reserve. An area composed of the island and the waters extending two miles from its shores. The law provides for the Reserve to be used solely and exclusively in perpetuity for the preservation and practice of all rights customarily and traditionally exercised by Native Hawaiians for cultural, spiritual and subsistence purposes. Also HRS 6K, created the Kaho`olawe Island Reserve Commission (KIRC) to have policy and management oversight of the Kaho`olawe Island Reserve. The KIRC was created in 1993 and is composed of 7 commissioners representing the Protect Kaho'olawe Ohana (PKO), Office of Hawaiian Affairs (OHA), County of Maui, and the DLNR (Table 6).

Name	Affiliation	Position
Dr. Emmet Alului M.D.	Protect Kaho'olawe Ohana	KIRC Chairperson
Charles PMK Burrows ED.D	Native Hawaiian Organizations	
John Waihe'e IV	Office of Hawaiian Affairs	
Milton Arakawa	County of Maui	
Robert Lu'uwai	Protect Kaho'olawe Ohana	
Burt H. Sakata	Protect Kaho'olawe Ohana	KIRC CO-Chair
Peter T. Young	Chair, Board of Land and Natural Resources	

Table 6. Current members of the Kaho'olawe Island Reserve Commission and their affiliations.

The statute (HRS 6K) requires that the island (including waters extending seaward two nautical miles from the shoreline) be used solely and exclusively for the following purposes: 1) Preservation and practice of all rights customarily and traditionally exercised by the native Hawaiians for cultural, spiritual, and subsistence purposes 2) Preservation and protection of its archaeological, historical, and environmental resources 3) Rehabilitation, revegetation, habitat restoration, and preservation 4) Education Additionally, the island is to be preserved in perpetuity for the above uses; commercial uses are strictly prohibited. As directed by Title X, a Memorandum of Understanding (MOU) between the Navy and the State of Hawaii was prepared to govern the conveyance of the island to the State of Hawaii with six specific agreements (regulatory framework; site protection; public participation; security; emergency communication; and regular interval clearance and removal of newly discovered, previously undetected ordnance). The Navy and the Governor of the State of Hawaii executed the MOU on May 6, 1994. Pursuant to Title X and the MOU, title to the island of Kaho`olawe was transferred to the State of Hawaii on May 9, 1994.

The State, through the KIRC, is the primary stakeholder and landowner, responsible for the long term restoration and management of Kaho`olawe for appropriate cultural, historical, archaeological and education purposes. The State holds statutory, regulatory, and enforcement interest in the protection of public health and the environment. The regulatory process set forth in the MOU maintains that the Navy shall proceed with the cleanup in consultation with the KIRC and in a manner consistent with the National Oil and Hazardous Substances Pollution Contingency Plan, 40 CFR Section 300 et seq. On December 13, 1996, the Naval Facilities, Engineering Command, Pacific Division, solicited a Request for Proposals entitled, Cost-Plus-Award-Fee Contract for the Unexploded Ordnance Clearance Project, Kaho`olawe Island Reserve, Hawaii (Solicitation No. N62742-95-R-1369). to conduct unexploded ordnance clearance and environmental restoration of Kaho`olawe Island. The Clearance Contract was awarded to the Parsons-UXB Joint Venture (PUXB) on July 29, 1997. It was the largest ordnance clean-up project in U.S. history, involving the combined efforts of the Federal, State and County governments, private contractors and hundreds of Hawai'i residents (Figures 13 and 14).

Figure 13. Local personnel from the Parsons-UXB Cleanup of Kaho'olawe sweeping for metal and UXO.

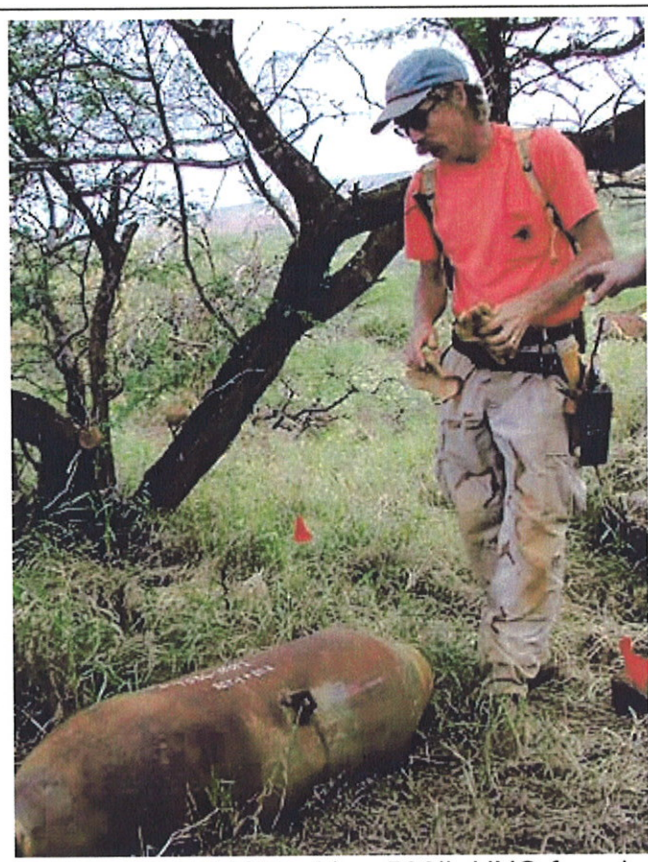

Figure 14. An EOD with a 500lb UXO found on the Parsons-UXB Clearance project.

The 10-year Parsons-UXB Clearance Project cleared 70% of the island to Tier I (surface only) and about 7% to Tier II (4 foot depth) (Figure 15). Approximately 30% of the island was not cleared at all.

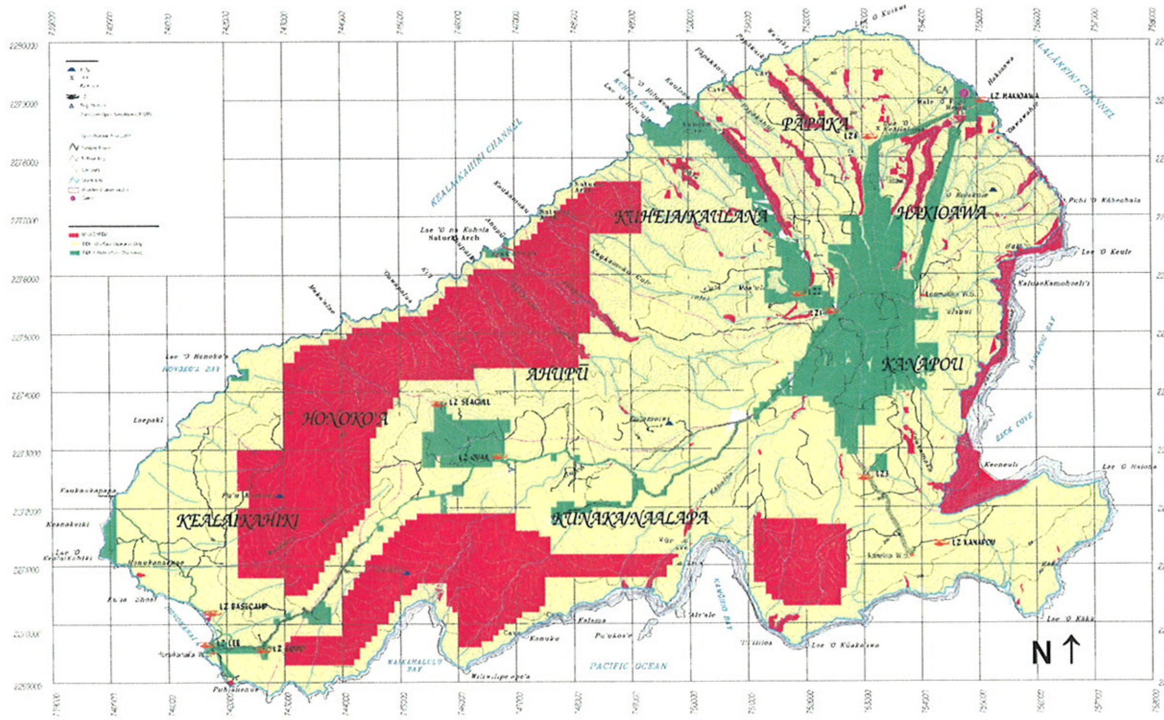

Figure 15. Final clearance map from the Parsons-UXB clearance project. (Red=No Clearance, Yellow=Tier I, Green=Tier II).

Since 1980, over 4000 people have visited Kaho'olawe with the Protect Kaho'olawe 'Ohana and several thousand with the KIRC (Figure 16).

Figure 16. Volunteers with the KIRC.

Several major planning documents were developed including the Kaho'olawe Use Plan, Cultural Resource Management Plan, Environmental Restoration Plan, the Ocean Management Plan, and the Access and Risk Management Plan.

State Use Period (2003 to Present)

On November 11, 2003 the control of access to the island was returned to the State of Hawaii from the US NAVY. On November 12, 2003 an official ceremony was held on the grounds of Iolani Palace in an event called *Hanau hou he 'ula 'o Kaho'olawe* (Rebirth of a Sacred Island) in observance of the transfer.

Future Periods

HRS Chapter 6K states "Upon its return to the State, the resources and waters of Kaho'olawe shall be held in trust as part of the public land trust; provided that the State shall transfer the management and control of the island and its waters to the sovereign Native Hawaiian entity upon its recognition by the United States and the State of Hawai'i."

NAVY Prompt Response

While April 9, 2004 marked the last day the Navy was present on the island, they are still responsible to destroy ordnance found in the future. For example, on December 5, 2005, a U.S. Navy Prompt Response Team came to Kaho'olawe to destroy items such as 5" rounds, 2.75" rockets and propellant cores, 40mm projectiles and point detonating fuses. KIRC personnel will continue to observe and record UTM coordinates on UXO Discovery Reports for any UXO uncovered by soil erosion and give that information to the NAVY.

Past Revegetation Efforts on Kaho'olawe

Major Reforestation and Revegetation Projects on Kaho'olawe from 1910 to 2005 are summarized in Table 7 (KICC, 1993).

Project Title	Date	Objectives	Participants
Forest Reserve Period Projects	1910-1918	Reduce sheep and goat populations. Plant ironwood, koa haole kiawe, Australian Saltbush.	Territorial Government of Hawaii
Kaho'olawe Ranch Company Projects	1918-1941	Reduce goat populations, plant Australian saltbush, natal redtop, pili grass	Leasee Angus MacPhee and partner Harry Baldwin

Project Title	Date	Objectives	Participants
		eucalyptus, mamane, 'Ili'ahi 'Ohi'a and Kukui.	
Vegetation Trials for Rehabilitating Kaho'olawe	1970-1974	Determine what plant species would grow better given Kaho'olawe's environment and goats. Six test plots were created and monitored.	USDA Forest Service, Hawaii DLNR Division of Forestry and Wildlife (DOFAW), Soil Conservation Service (SCS)
Tamarisk Windbreak Project	1979 to 1993	Plant 30,000 Tamarisk trees to abate erosion due to high winds.	DLNR DOFAWand US Navy
USDA SCS/DLNR/US Navy Erosion Control Program	1979 to 1986	Install a series of check dams throughout the island to stem water erosion, throw old tires into gullies.	US Navy and USDA SCS
Native Hawaiian Plant Society (NHPS) Project	1985	Test the viability of native plant species on the hardpan to illustrate survivability in harshest of conditions.	Native Hawaiian Plant Society, US Navy, USDA, DLNR, University of Hawaii, Sierra Club
US Navy Goat Eradication Program	1986-1993	Final Goat removed in 1993	US Navy
US Navy Grass Plantings	1987	Using a mixture of non native grasses, establish two plantings 12.4ha in sizeon Northeastern end of hardpan.	US Navy
CERL Project	1987 to1991	Identify an efficient and effective way to revegetate Kaho'olawe without supplemental watering.	US Army Corps of Engineers Construction, Engineering Research Laboratories (CERL), US Navy

Project Title	Date	Objectives	Participants
Protect Kaho'olawe Ohana/F Kaho'olawe Water Resources Study (Phase I) Check Dam Study	1988-1989	Project (1) identified potential sources of water (2) conducted analysis of watershed areas (3) investigated soil capturing techniques - 4000 ft^3 of soil captured during 4 month project	Watershed Management Systems, PKO, State of Hawaii - DLNR
Nitrogen Fixing and Leguminous Trees (NifTAL) Project	1989 to 1991	Determine the feasibility of planting wiliwili (*Erythrina sandwicensis*) inoculated with and without Rhizobium as a large scale reforestation project.	US Navy, University of Hawaii School of Tropical Agriculture, Dept. of Agricultural Engineering
PKO/F Restoration Project (KRP)	1991 to present	Initiate revegetation of native plant species capturing rainwater and using drip irrigation systems.	PKO/F
KIRC Restoration	1998 to 2003	Plant natives in areas released from the Parsons-UXB Clearance Project	KIRC, planting in "D4" and Lua Makika Crater
DOH Watershed Restoration at Moa'ulanui, Kaho'olawe Hawaii.	2003 to 2005	Reduce non-point source pollution (soil erosion) and increase native plant cover using BMP's.	KIRC, Hawaii Department of Health, Clean Water Branch

Table 7. Summary of major reforestation and revegetation projects on Kaho'olawe from 1910 to 2005.

4-ENVIRONMENT

Landscapes and Soils

The DOH project site has three major types of eroded landscapes that can be found within the two watersheds. The eroded landscape types include undissected hardpan, dissected hardpan, and deep gullies and head cuts. Undissected hardpan is primarily characterized by sheet flow erosion from high levels of water runoff. In this type of landscape the surface crust must be broken to allow seed germination and to increase water infiltration. In some depressions and areas naturally protected from wind, revegetation is occurring from wind scattered seeds. It is unlikely, however, that vast areas will revegetate naturally without controlling wind and water erosion. Dissected hardpan has channels, which can carry flash floods. These floods are intermittent and follow periods of high rainfall. Most of these soil types are low in Phosphorus and Zinc and have very little organic matter (Nakao et al., 1997). The hardpan soils are also nutrient poor, lack moisture, and lack nitrogen-fixing bacteria (*Rhizobium sp., Glomus sp.,*) necessary for plants to survive. Most of the deep gullies consist of headcuts at lower slopes. There are a few original upland soil hummocks located within the project area. These pockets serve as a natural, native seed bank and are also a source for soil inoculum.

Hydrologic Groups

Soils with the same runoff potential under similar storm positions are grouped into one of four (**A, B, C, D**) hydrologic groups and are used to estimate runoff from rainfall (USDA, 1995). Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting. The influences of ground cover and slope are treated independently, not in hydrologic groups.

Soils in Hydrologic Group **A** have high infiltration rates even when thoroughly wetted and consist primarily of deep, well drained to excessively drained sands or gravels. These soils have a high rate of water transmission (Low runoff potential).

Soils in Hydrologic Group **B** have moderate infiltration rates when thoroughly wetted, consist primarily of deep, well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Soils in Hydrologic Group **C** have slow infiltration rates when thoroughly wetted, consist primarily of (1) soils with a layer that impedes the downward movement of water or (2) soils with fine textures and slow infiltration rate. These soils have a slow rate of water transmission.

Soils in Hydrologic Group **D** have very slow infiltration rates when thoroughly wetted, consist primarily of (1) clayey soils with high swelling capacity or potential, (2) soils with a high permanent water table, (3) soils with a claypan or clay layer at or near the surface and (4) shallow soils or nearly impervious materials. These soils have a very slow rate of water transmission (High runoff potential).

Soil Types

There are six distinct soil types found within the project area. These soil types range from steep badlands with saprolite to silt loam and silty clay loam. The soil erodability factor (K) within the project area ranges from 0.17 to 0.49, the higher K value indicating the high erodability of the steep badlands. The basic descriptions and nutrient status of these soil types are below. Soil types by watershed and hydrologic group are listed in Table 8.

USDA Soil Type Number	Soil Type	Hakioawa	Kaulana	Hydrologic Group
1	Badland, Steep	X	X	C
3	Badland Koele Complex 8 to 70 % slopes	X		B
5	Kaho'olawe Silty Clay Loam 8 to 15% slopes	X	X	B
6	Kaneloa Silty Clay Loam 3 to 8% slopes		X	B
7	Kaneloa Silty Clay Loam 8 to 15% slopes		X	B
16	Puu Moiwi Silty Clay Loam 3 to 8% slopes	X		B
17	Puu Moiwi Silty Clay Loam 8 to 15% slopes	X		B
25	Rock Outcrop Ustorthents, Very Steep	X	X	D

Table 8. USDA soil type number, soil type, watershed, and hydrologic group.

Badland, Steep (1)

These areas require revegetation as they now are the most actively eroding areas on the island. Runoff must first be controlled on the plateau to effectively reduce gully formation. Calcium, magnesium, potassium and phosphorus levels are low, Zinc deficiencies are likely.

Badland, Koele Complex (3)

Stabilization requires decreasing runoff from plateau. As gullies cut headward creating new badlands, they also deepen and trigger further sideslope cutting.

Estimated that calcium, magnesium, potassium and phosphorus levels are moderate to low. Zinc deficiencies are possible.

Kaho'olawe Silty Clay Loam (5)

This very friable silty clay loam supports deep root penetration of vegetation which in turn creates wind protection and serves as a dust trap allowing the soil unit to grow laterally downwind and thicken in depth. These areas should not be disturbed as removal of any vegetation creates severe erosion hazards. Conversion to native vegetation should be done in small increments to ensure that large areas are not bare for long periods, as the wind erosion hazard is severe even when small areas of the existing vegetation is removed. Calcium, magnesium and potassium levels are moderate to high. Phosphorus is low and Zinc deficiencies may be present due to neutral pH in surface layers.

Kaneloa Silty Clay Loam (6,7)

To establish vegetation on the soil surface, large clods should be created that cannot be blown away and will trap wind blown sediment. The subsurface layer is consists of a fine subangular blocky structure and many pores which are clogged with sediment at the surface. Small areas of highly eroded bedrock (saprolite) exist within this soil unit. Calcium, magnesium and potassium status are moderately high. Phosphorus is low and Zinc deficiencies may be present due to alkaline pH. Available water holding capacity is moderate and soil structure is favorable for root growth, but the sealed surface prevents most water from entering the soil and germinating seeds cannot take root.

Pu'u Moiwi Silty Clay Loam (16,17)

Water and wind erosion has removed most of the 6 inch thick brown silty clay loam surface layer of the soil. Incoming soil and seeds cannot be trapped and therefore the soil type remains bare. To establish vegetation on the soil surface, large clods should be created that cannot be blown away and will trap wind blown sediment. Calcium, magnesium potassium levels are generally adequate but phosphorus is low. Some gullies exist that are up to 6 to 10 feet across.

Rock Outcrop, Ustorthents, Very Steep (25)

Hard exposed bedrock in gulches with 30 to 70% slopes. Surface layer is loose friable very stony clay loam or silty clay loam, about 4 to 10 inches thick. Underlying material is soft weathered basic igneous basalt. Not sampled but calcium, magnesium and potassium levels would be adequate to high.

1995 USDA soil maps for portions of the Kaulana and Hakioawa watersheds are presented in Figures 17, 18, and 19.

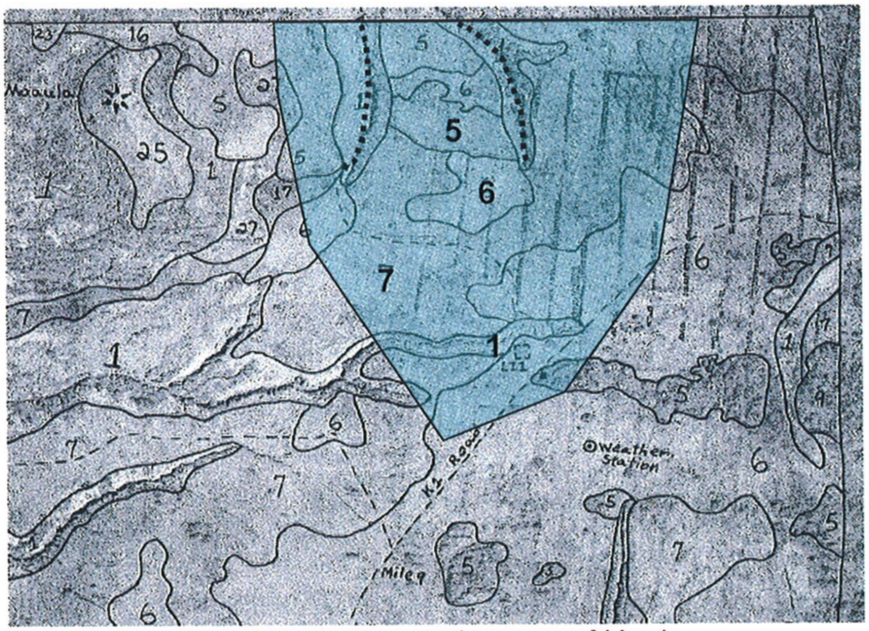

Figure 17. Soil types in the headwaters of Kaulana watershed.

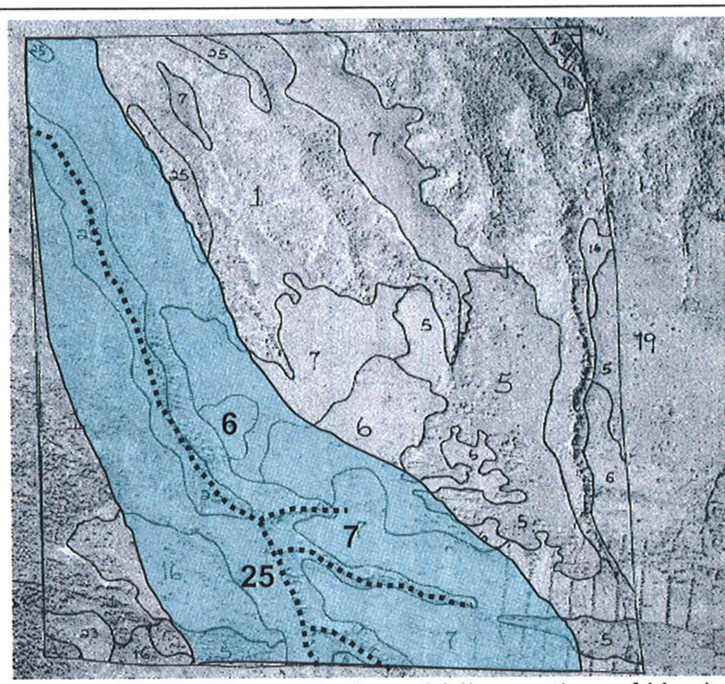

Figure 18. Soil types in the middle section of Kaulana watershed.

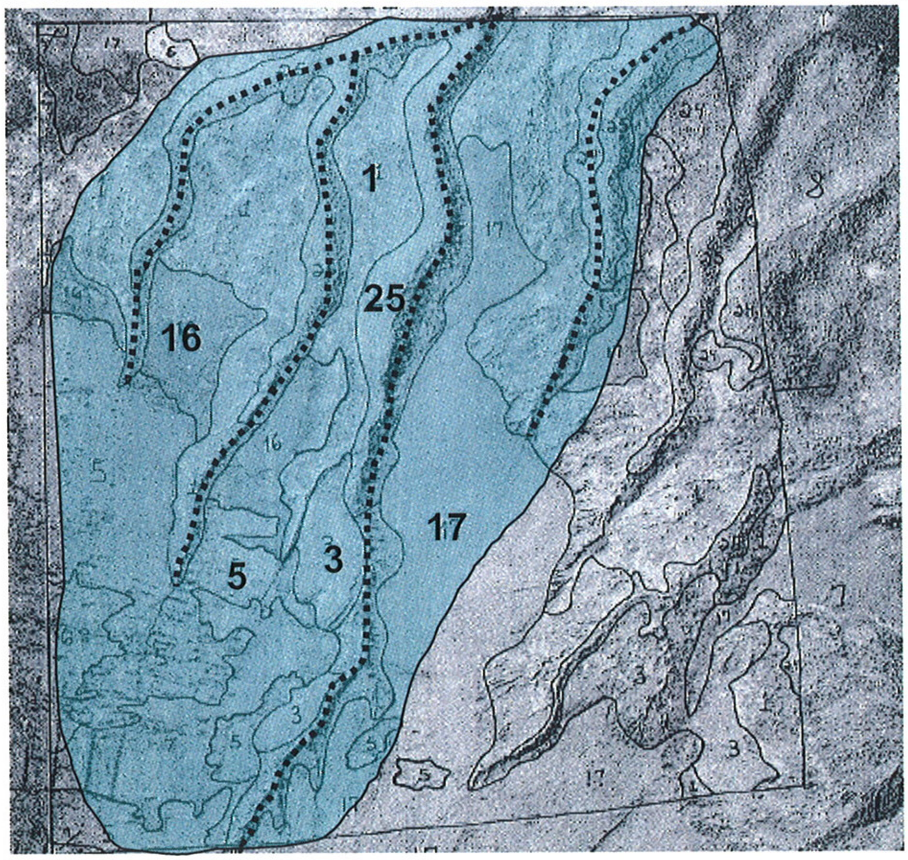

Figure 19. Soil types of Hakioawa watershed.

Plant Communities

The classification of Hawaiian plant communities is based on elevation, moisture regimes, and physiognomy. The name of each plant community consists of the dominant or co-dominant species and the following Native Dry Plant Community descriptions are from Wagner et al., (1999).

Native Coastal Dry Grasslands and Shrublands

'Aki'aki (*Sporobolus virgincus*) Coastal Dry Grasslands are present on Kaho'olawe mostly along the coastlines. These grasslands are salt tolerant and typically cover ocean-facing dunes.

'Ilima (*Sida fallax*) Coastal Dry Shrublands occur mostly on flat, rocky sites. The environment is harsh with highly seasonal precipitation, large temperature fluctuations and intense solar radiation. Nehe (*Lipochaeta integrifolia*) forms a co-dominant with 'Ilima on southwestern Kaho'olawe.

Ma'o (*Gossypium tomentosum*) Shrubland substrate consist of shallow weathered clays with numerous rocks scattered over the surface. The Hawaiian cotton has proven to be a valuable genetic resource because it lacks floral nectaries and has been hybridized with commercial cotton (*Gossypium spp.*) to decrease insect pest problems.

Coastal Cliff Mixed Shrublands occur on the dry coastal cliffs of Kaho'olawe and may include 'ilima (*Sida fallax*), 'akoko (*Chamaesyce celastroides*) and Kawelu grass (*Eragrostis variabilis*).

Lowland Dry Grassland

Pili (*Heteropogon contortus*) Lowland Dry Grasslands form an extensive natural community along the northwest coast of Kaho'olawe. These areas were possibly maintained by early Hawaiians by regular firing to foster Pili grass production. Pili grass does not form a stable community and might be subject to eventual displacement by woody invaders.

Maia pilo (*Capparis sandwichiana*) growing in lower reaches of Hakioawa watershed is pictured in Figure 20.

Figure 20. Maia pilo (*Capparis sandwichiana*) in lower reaches of Hakioawa watershed.

Non-Native Vegetation

Non-native species refers to a species transported or established outside its native range by the activities of humans. It has been estimated that the rate of new species establishment in the Hawaiian Island was approximately one new species every 35,000 years prior to human arrival in the islands; it is now on the order of 20-30 species/year. Those that are problematic are termed invasive which significantly disrupt the community structure or proper function of an ecosystem. Of the approximately 13,000 alien species of plants that have been introduced to Hawaii, only about 1% (130 species) of those have become invasive so far. Biological evidence suggests another 200-300 species already present in the state may become problems in the future.

Non-Native vegetation accounted for 20% of the cover in the 5 vegetation plots in the previous DOH project. Some of the invasive non-native species found in the current DOH project site are listed here.

Agave (*Agave sisalana*) is a perennial native to Yucatan, Mexico but is widely cultivated in tropical areas. It was originally introduced in Hawai'i as a commercial fiber crop (fibers from the leaves), by the Hawaiian Commissioner of Agriculture and Forestry in 1893.

Bufflegrass (*Cenchrus ciliaris*) is one of the most abundant grasses and dominant ground cover in the project site. It is a mat forming rhizomatous perennial grass native to Africa and Asia and has been naturalized in Hawai'i since the 1930's. It is an undesirable species because of its adaptation to fire and aggressive and competitive growth habit.

Glycine (*Neonotonia wightii*) First collected in Hawai'i in 1975, this aggressive vine colonizes disturbed areas and is widely naturalized. *Neonotonia* is distinguished from *Glycine* by its psuedoracemose infloresences and calyx with the upper two lobes completely connate.

Guinea Grass (*Panicum maximum*) is a large perrenial bunch grass with wide leaves and a large spreading panicle of tiny flowers and was probably naturalized prior to 1871 (Hillebrand, 1888). Native to Africa it was introduced in Hawai'i as a forage grass and is able to form dense ground cover beneath Kiawe trees and shade out native plants beneath it. As it dries out, it is able to carry fire, and forms extensive thickets in parts of the project site. It has the potential to invade archeological sites and displace the structural integrity of the structure.

Indian Fleabane (*Pluchea indica*) Native to southern Asia and first collected by Rock on Oahu in 1915, this fleabane will hybridize with Sour bush (*Pluchea symphytifolia*) to form *Pluchea X fosbergii*.

Ironwood (*Casuarina equisetifolia*) native to Australia and introduced to Hawaii around 1882, it is scattered throughout the Tamarisk windbreaks and is beginning to spread. The regeneration of this species is a potential problem, as it can form dense stands with thick needle litter, which preclude other species from growing beneath it.

Koa Haole (*Leucaena leucocephala*) was introduced to Hawaii in 1837 and grows at all elevations on Kaho'olawe.

Lantana (*Lantana camara*) is found extensively throughout the project site and many biocontrol agents have been introduced to Hawaii to control it. (Davis et al. 1992) In conjunction with the biocontrols, low rainfall in the project site might be the reason for its lack as a dominant ground cover.

Molasses grass (*Melinis minutiflora*) is a mat forming perennial grass from Africa introduced to Hawai'i for cattle forage. The grass is common in dry lowlands and can choke out other vegetation. The consequences of mollases grass invasion is typically an increase in the frequency and severity of fire and the replacement of native vegetation (Hughes et al. 1991).

Silver Oak (*Grevillea robusta*) or Silk Oak is an Australian tree introduced to Hawai'i in the late 1800's as a potential timber species. It should be removed wherever found in the project site.

Sour bush (*Pluchea symphytifolia*) is found throughout the project site and is native to Mexico, the West Indies and northern South America.

Integrated Pest Management Plan (IPM)

An Integrated Pest Management Plan (IPM) will be developed to review control methods for insect pests, rodents, and non-native plants in the DOH project site. Prioritizing the most important species to target for control would be a beneficial outcome of this plan, as well as developing an overall non-native plant management strategy. Project Managers will continue to keep a log of herbicide use and maintain good records of management activities.

Ocean Environment

Tides

The tides off Kaho'olawe are semi-diurnal (half-daily) type with two uneven hightides and two uneven low tides per day. The mean daily tidal range is roughly 0.6 m, and the minimum and maximum daily tidal ranges are 0.4 m and 1.0 m, respectively. Storlazzi and Jaffe (2003) found higher turbidity during large wave events, strong Trade winds, and falling tides off of West Maui during a long-term study of currents, temperature, salinity and turbidity in 2001-2003. Offshore of the Hawaiian islands, the seas are moderately rough, with significant wave heights of 1-4 m (3-14 ft), varying seasonally with the intensity of the trade winds. Figure 21 illustrates the mean significant wave height (SWH) in the Central Pacific for Winter, from 1992 to 1995. Data is from US NAVY and TOPEX Altimeter mission, NASA and CNES. Mean SWH units are in meters.

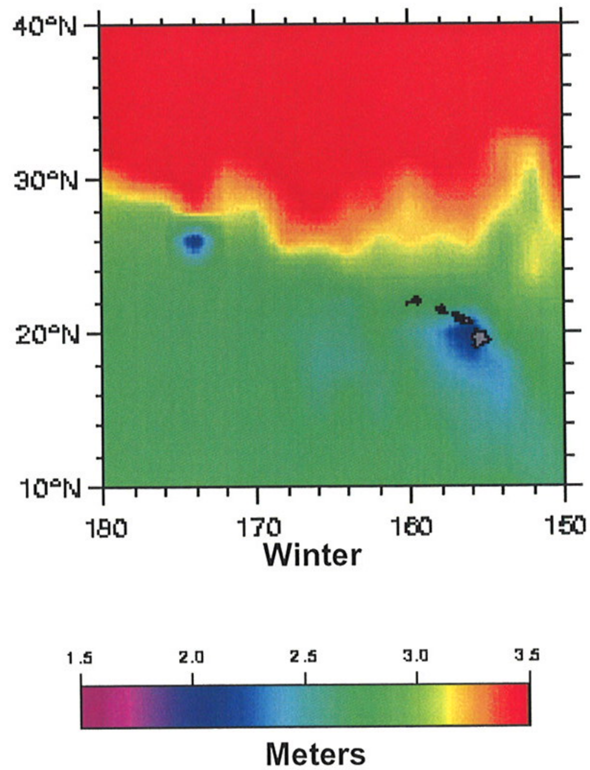

Figure 21. Mean Significant Wave Height in winter from 1992-1995.

Direction of wave swell and local offshore bathymetry contribute to the impact of the influx of excessive sediment to the reef environment. While some coastal sections of Kaho'olawe with high wave exposure, would have lower silt content, a low coral cover in these areas may also be due to mechanical breakage as caused by the strong waves (Figure 22). The north coastal sections had higher coral cover due to the protection from mechanical damage caused by storms (Cox et al., 1995).

Figure 22. Large swell hitting Kaho'olawe's North Coast.

There is a net cooling of the ocean by the atmosphere over the entire region. Average surface pressure changes from Summer (June to August) and Winter (December to February).

At ebb tide the direction of the tidal current reverses, although the net effect due to the over-riding importance of the wind-driven surface current is flow southward along the coast (US NAVY, 1979).

In some weather situations the trade winds are replaced by other general winds, some of which are not nearly as uniform in direction or speed. For all these reasons, average wind speed values are informative only in a broad descriptive sense, and it is necessary to consider a variety of wind situations even to begin to describe realistically the true wind conditions.

Coral Reef Biology

Coral reefs are among the world's richest ecosystems, second only to tropical rain forests in plant and animal diversity. However, they are extremely sensitive environments that have special temperature, salinity, light, oxygen, and nutrient requirements. If environmental conditions fall outside the acceptable range of these requirements, the health and dynamics of a coral reef community can be severely disrupted. That's why coral communities are sensitive indicators of water quality and the ecological health of the coastal watershed. They respond to alterations within the entire coastal watershed, such as changes in freshwater flows and nutrient inputs. Consequently, pollution from the destruction and alteration of surrounding coastal watersheds can directly affect the health and productivity of a coral reef (Figure 23). Coral reefs are vulnerable to harmful environmental changes, particularly those resulting from human activities. One of the primary threats to coral reefs is pollution from land-based sources, including

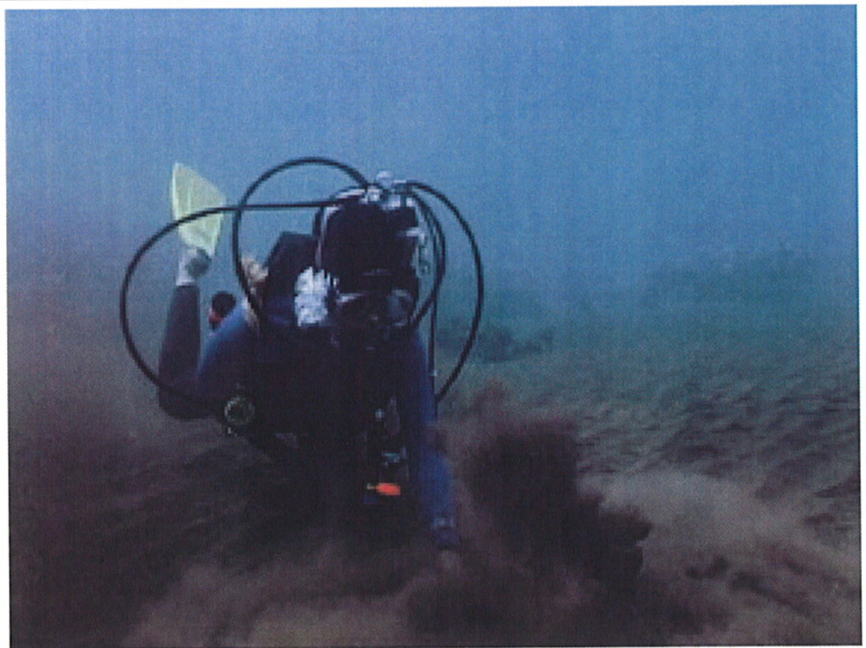

Figure 23. Scuba diver stirring up silt on ocean bottom off of Kaho'olawe.

runoff of nutrients and sediments from watersheds adjacent to nearshore coral reef ecosystems (http://policy.nrcs.usda.gov).

Corals are long-lived organisms and their distribution reflects environmental conditions over long periods of time. Related to jellyfish and anemones, coral polyps, the individual animals that make up both colonial and solitary corals, catch plankton (microscopic plants and animals) and other suspended food particles with arm-like tentacles, which feed a centrally located mouth. Polyps extend their tentacles to capture prey, first stinging them with toxic nematocyst cells, then drawing them toward their mouths. Coral reefs are formed by colonies of hard corals that secrete calcareous exoskeletons, giving them structural rigidity. Almost all reef corals are sessile organisms, and spend their entire adult lives fixed to the same spot on the ocean floor.

Because of their dependence on light, reef corals require clear water and are generally found only where the surrounding water contains small amounts of suspended material and low turbidity. Whether it is direct sedimentation onto the reef or an increase in the turbidity of the water due to eutrophication, decreases in the amounts of light reaching corals may cause bleaching (Brown and Ogden 1993). In addition, increases in the amounts of nutrients enhance the growth of other reef organisms such as sponges which may outcompete the corals for space on crowded reefs. Coral bleaching is the whitening of coral colonies due to the loss of symbiotic zooxanthellae from the tissues of polyps. This loss exposes the white calcium carbonate skeletons of the coral colony. Corals naturally lose less than 0.1% of their zooxanthellae during processes of regulation and replacement (Brown and Ogden, 1993). However, adverse changes in a coral's environment can cause an increase in the number of zooxanthellae lost. There are a number of stresses or environmental changes that may cause bleaching including disease, excess shade, increased levels of ultraviolet radiation, sedimentation, pollution, salinity changes, and increased temperatures. Reefs are harmed when human, animal waste and/or fertilizer is dumped into the ocean or when stream systems carry these pollutants to reef waters. These pollutants increase the level of nitrogen around coral reefs, causing an overgrowth of algae, which smothers reefs by cutting off their sunlight.

Zooxanthellae are the photosynthetic microalage, single-celled dinoflagellates, living in the endodermal tissues of stony corals polyps. During photosynthesis, zooxanthellae fix large amounts of carbon, part of which they pass on to their host polyp. This carbon is largely in the form of glycerol but also includes glucose and alanine. These chemical products are used by the polyp for its metabolic functions or as building blocks in the manufacture of proteins, fats and carbohydrates. Although the zooxanthellae supply a major part of their energy needs, most corals also require zooplankton prey.

The corals found on fringing reefs of Kaho'olawe include, table coral (*Acropora cytheria*) rice coral (*Montipora capitata*), lobe coral (*Pavona duerdeni*), corrugated coral (*Pavona varians*), mushroom coral (*Fungia scutaria*), lace coral (*Pocillopora damicornis*), antler coral (*Pocillopora eydouxi*), cauliflower coral (*Pocilopora meandrina*), finger coral or Ko'a (*Porites compressa*) and plate coral (*Porites rus*) see Appendix B.

Coral Reef Research Techniques

In order to establish a basis from which scientists can objectively detect changes in reef health, the USGS and its cooperators are applying many new techniques to the mapping and monitoring of coral reefs in Hawaii (Figure 24).

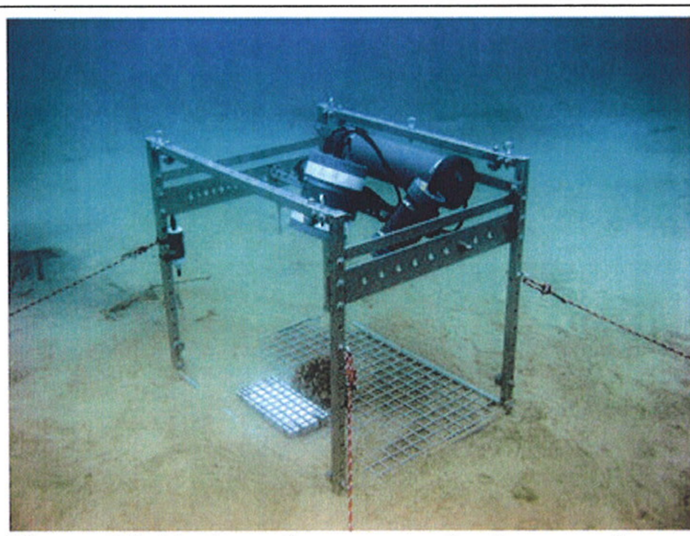

Figure 24. Underwater camera to document sediment deposition.

No single approach is effective for evaluating the overall health of a reef. It is only through combining techniques that scientists can establish the most complete view of a reef, one that can be used for evaluating reef health and for future monitoring. Lidar (light detection and ranging) is a laser-ranging technique that can penetrate shallow water to depths as great as 120 feet (36 m) to create precise bathymetric maps that are accurate to within a few inches (±15 cm). These maps show details of reef structures and zonations that cannot be revealed using traditional sonar technology, which requires deeper water for successful operations. Combining LiDAR digitally with aerial photographs, results in a better understanding of shallow-water coral reef development. The channels across the reefs typically contain sediment that is a mixture of calcium carbonate ($CaCO_3$) debris (derived from the breakdown of reef material) and silt and other sediment eroded from the island. The role of these channels in transporting sediment and their relation to coral reef health are poorly understood and are one focus of USGS investigations in Hawaii.

Hyperspectral imagery, collected from aircraft, is being used in Hawaii to map coral reefs and potentially identify areas of dead coral. Hyperspectral imagers measure reflected sunlight in many narrow wavelengths, ranging from ultraviolet to near infrared. This spectral information allows for detection of subtle variations in the reef substrate that are not visible to the naked eye.

Another technique being used by scientists to map coral reefs in Hawaii is acoustic mapping. Dual-frequency sonar technology is used to map areas of coral reefs in water depths ranging from 25 feet (8 m) to 120 feet (35 m). By processing data from two frequencies, it is possible to identify the acoustic signatures of different types of material, such as soft sediment deposits or hard coral.

On shallow reef-flat areas in Hawaii, scientists are using sediment probes (graduated stainless steel rods) to measure sediment thickness. Maps of sediment thickness made using these measurements, combined with sediment ages and compositional data, provide a detailed record of the history of deposition.

Ocean Research in the Kaho'olawe Island Reserve (KIR)

While annual point-discharge rates range from 0.6×10^8 to 5.1×10^8 kg (62,000 to 561,000 tons) occur at the largest stream mouths, anthropogenic stress factors often associated with sediment loading are not present. Thus, Kaho'olawe offers a unique opportunity to study sediment dynamics on coral reefs in a situation that is free from many confounding influences (Cox et al., 1995).

High sediment loads have been correlated to low coral cover and poor coral diversity (Cortés and Risk, 1985; Rogers, 1990; Wittenberg and Hunte, 1992). Observations by Cox et al., (1995) suggest that sediment deposits on the reefs of

Kaho'olawe are presently being removed more rapidly than being replenished due to a gradual increase in vegetation cover of the island over the past 20 years. Rapid recruitment of new coral colonies onto newly uncovered reef surfaces was observed indicating that the coral community is undergoing recovery as sediment input diminishes.

While a long-term study on Kaho'olawe would be required to completely describe changes associated with sedimentation and recovery from sediment damage (Cox et al., 1995), it is hoped that within a 5-year time span, significant changes in sedimentation rates will be observed.

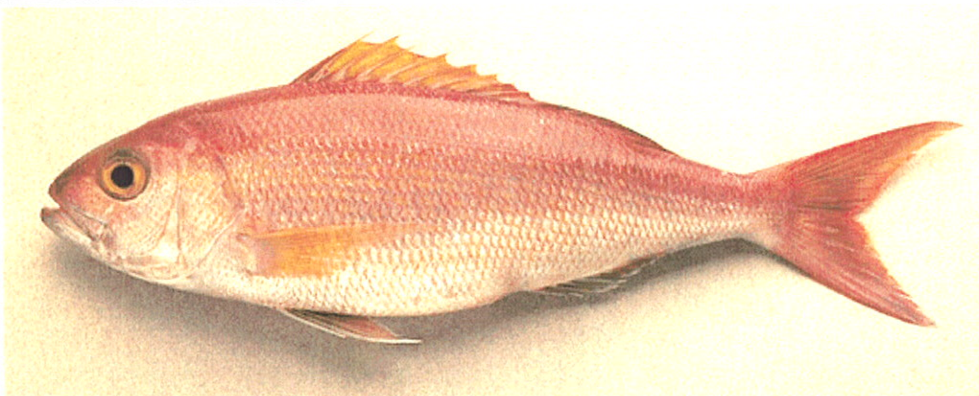

Figure 25. 'Opakapaka or Hawaiian Pink Snapper (*Pristipomoides filamentosus*)

Data, from a 2004 bottomfish spillover project was conducted by the Ocean program at the KIRC, the Hawaii Underwater Research Laboratory (HURL, 2005) at the University of Hawaii at Manoa, and the Oceanic Institute at Makapu'u Point (OI). The Hawaiian pink snapper, 'Opakapaka (*Pristipomoides filamentosus*) (Figure 25) has been becoming more scarce in Hawaiian waters due to overfishing. For nearly a century, 'opakapaka has been the most important bottomfish species in terms of total landed weight and value in Hawaii. Several acoustic receivers were placed on the boundary of the KIR and acoustic transmitters implanted in 'opakapaka indicated they were leaving the KIR to go into deeper waters (~600ft) during the day, and then returning to shallower waters (~350ft) back into the KIR at night. This indicated for the first time that the Kaho'olawe Island Reserve (KIR) was functioning as a reservoir for several species of bottom fish.

5- KIRC MASTER PLAN

Since 1995, there have been 5 major planning documents developed for the reserve.

1.) Palapala Ho'onohonoho Moku Aina o Kaho'olawe , Kaho'olawe Use Plan (1995)
2.) Ola I Ke Kai O Kanaloa, Kaho'olawe Ocean Management Plan (1997)
3.) Ho'ola Hou I Ke Kino O Kanaloa, Kaho'olawe Environmental Restoration Plan (1998)
4.) Access and Risk Management Plan for the Kaho'olawe Island Reserve (2002)
5.) Cleanup Plan, UXO Clearance Project, Kaho'olawe Island Reserve (by Parsons-UXB Joint Venture for the Naval Facilities Engineering Command Pacific Division)

Vision Statement (1995)

The kino of Kanaloa is restored. Forests and shrublands of native plants and other biota clothe its slopes and valleys. Pristine ocean waters and healthy reef ecosystems are the foundation that supports and surrounds the island.
Na Po'e Hawai'i care for the land in a manner which recognizes the island and ocean of Kanaloa as a living spiritual entity. Kanaloa is a pu'uhonua and wahi pana where Native Hawaiian cultural practices flourish.
The piko of Kanaloa is the crossroads of past and future generations from which the Native Hawaiian lifestyle spreads throughout the islands.

Mission Statement (1993)

Our mission is to implement the vision for Kaho'olawe, in which the kino of Kanaloa is restored, and na po'e Hawai'i care for the land. We pledge to provide meaningful, safe use of Kaho'olawe for the purposes of the traditional and cultural practices of the native Hawaiian people, and to undertake the restoration of the island and its waters.

KIRC Strategic Plan

A 5-year Strategic Plan (2004 to 2008) was developed by the KIRC, creating specific Priorities and Core Values. In developing its strategic priorities, the commission acknowledges the following.

- The primary planning documents previously adopted serve collectively as the foundation for the KIRC, especially Palapala Ho'onohonoho Mouk'aina O Kaho'olawe (The Kaho'olawe Use Plan).
- There is an inherently Native Hawaiian purpose to the Kaho'olawe Island Reserve, as recognized by history, the public, and in State and Federal

laws, including but not limited to the statutory framework for KIRC and the constitutional protection of customary and traditional access.

- The Protect Kaho'olawe 'Ohana has a historical and cultural relationship with Kaho'olawe.
- There are kupuna and families that have traditional and historical relationships with Kaho'olawe.
- By State law, the Kaho'olawe Island Reserve is to managed in trust until such time and circumstances as a sovereign native Hawaiian entity is recognized by the federal and state governments.
- The remote geography of Kaho'olawe presents its own challenges.
- The environment is fragile.
- There are extensive cultural and historical places.
- There are unexploded ordnance and other hazards.
- Monitoring and management of the risk is a State responsibility. By Federal law, there is a perpetual federal responsibility for the unexploded ordnance.
- As of January 2004, the trust fund has $35 million, which will be insuffiecient to fully provide for meaningful, safe use of the Reserve unless additional funds are secured.
- By state law, commercial uses of the Reserve are banned.

Strategic Priorities

Leadership – To increase the size, diversity and sustainability of the trust fund and to manage the organization's budget in a manner that protects the trust fund. To be prepared for the transition of the Reserve to the future Native Hawaiian Sovereign nation.

Restoration and Perpetuation – To access and stabilize cultural sites, and provide for appropriate access and cultural practices. To systematically restore the environment.

Sterwardship- To develop a significant volunteer base, especially in concert with stewardship organizations such as the PKO, for the purposes of cultural, antural resource, and marine resource restoration. To develop and maintain appropriate and sustainable infrastructure (including on-island and inter-island transporation, energy, communication, water, sanitation, and Kihei information center) To develop an enforcement network spanning the community and government, in order to protect Kaho'olawe and its waters from illegal, inappropriate and unsafe uses. To maintain a significant on-island presence for the purposes of managing and protecting the reserve.

Education- To develop and distribute educational programs and materials towards the public's understanding of the cultural, historical and spiritual significance of Kaho'olawe.

Core Values

KIRC holds these values to be true to its mission and organization;

In our programs and in the way we operate, we embrace Kaho'olawe's significant role in perpetuating the Nayive Hawaiian culture. We recognize Kaho'olawe as a *pu'uhonua* and *wahi pana* – a scared place. In our actions, programs, training, and plans, we live and incorporate the values, practices and protocols of the host culture. Our job is to restore the island and its waters and to increase the culturally appropriate, safe use of the Reserve towards the fulfillment of the vision for Kaho'olawe.

6- GOALS AND OBJECTIVES

The primary goal is to restore 300ha of severely eroded landscape in the Kaulana and Hakioawa watersheds on the island of Kaho'olawe. Implementing BMP's and NPS management measures will reduce soil erosion rates, runoff and subsequent sedimentation in the ocean. Altering the terrestrial ecosystem will aid in the regeneration of native plants such as A'ali'i (*Dodonaea viscosa*) which is a host for the native Hawaiian Blue Butterfly (*Udara balckburni*). Reducing runoff and excessive sedimentation into the marine environment will assist in maintaining the pristine nature of the nearshore reefs. Monitoring these improvements to the land will assure the measures in place are contributing to the reversal of the severe erosion that has been occurring for decades.

Goals of the Watershed Based Plan are; (1) continue to improve the native ecosystem around the summit of Pu'u Moa'ulanui and the headwaters of Kaulana and Hakioawa watersheds, and (2) reduce sediment load in the two streams and subsequent turbidity in the near shore ocean waters off of Kaulana and Hakioawa Bays, and (3) restore the most severely eroded hard pan areas in the watersheds.

7- NPS MANAGEMENT MEASURES AND BMP'S

NPS Management Measures and BMP's are used to control non-point source pollution and can be correlated to decreased rates of erosion through monitoring (EPA, 1999). Geotextiles are used to cover soil, retain moisture and encourage plants to take root (KERP, 1998). Therefore, geotextiles in conjunction with native grasses Pili (*Heteropogon contortus*), or Kawelu (*Eragrostis variabilis*) will be tacked with wooden Eco-stakes around exposed hummocks to contain the soil and stabilize the exposed sites with native vegetation. Hydroseeding will reduce the amount of exposed bare soil and introduce native grasses to hardpan areas completely devoid of vegetation. The data quality objective includes determining current soil erosion loss rates in the DOH project site and offshore in the ocean, and comparing them to loss rates after restoration efforts in 2010.

Due to the extensive distribution of hardpan soils, erosion control measures will be needed throughout the project site. The upper watersheds of both Kaulana and Hakioawa streams in the project site are sometimes devoid of any cover. As these areas are often exposed to the high wind speeds that can occur, the Tamarisk (*Tamarix aphylla*) tree lines established in the late 1970's will be used as wind breaks for new plantings. Table 9 lists the ten (10) BMP's planned during the course of the three to five year DOH project.

	BMP	Description
1	Irrigation System	½", 1" and 2" Drisco pipe with Pumps
2	Planting	Native Grass, Shrubs and Trees
3	Mulching	Kiawe Chips
4	Soil Amendments	Fertilizer and Mychorrizae
5	Non-Native Plant Species Control	Loppers, Weedeating, Chain Saw
6	Herbicide Application	Garlon 4 and Round-Up Pro
7	Hydroseeding and Straw Blower	EasyLawn C60 Hydroseeder and Straw Blower
8	Hummock Restoration	Irrigation, Pili Grass and Geotextile
9	Pili Rolls, Check Dams and Swales	Geotextile, Pili Grass Bales, Pallets
10	Planter Boxes	Pili Grass bales, fertilizer, native seed, irrigation

Table 9. Ten (10) BMP's to be used during the DOH Project.

In association with some of these 10 BMP's are nine (9) standard operating procedures (SOP's) which have been written for the benefit of both the KIRC employee and the safety of the volunteer. SOP's have been prepared for the implementation of watershed restoration modifications and include instructions for the construction, operation, and maintenance of 2" main, 1"sub-mains, and ½" laterals for drip irrigation, safe operation and proper PPE for use of power augers, weed eaters, and chainsaws, proper PPE for mixing and safe application of herbicides, proper planting techniques, mulching and soil amendments (fertilizer and Mychorrhizae), hydroseeding and straw blowing, g) hummock restoration, h) construction, installation and maintenance of check dams and swales, and i) safe and responsible use of Kawasaki 4WD Mule. Table 10 below lists the nine (9) SOP's that have been generated to support operation of the tools and machinery a volunteer may encounter while assisting with the restoration efforts on Kaho'olawe.

	SOP #	Description	Topics Covered/Attachments
1	123	Pesticide Application and Use	Safe Use/Record of Pesticide Application and Use
2	124	Brush Cutter Operation	Safe Use/Instruction Manual
3	125	Chain Saw Operation	Safe Use/Instruction Manual
4	126	Power Auger Operation	Safe Use/Instruction Manual
5	127	Best Management Practices	General Information
6	128	Transplanting Native Plants	Proper Planting Technique
7	129	EasyLawn Hydroseeder Operation	Safe Use/Instruction Manual
8	13X	DR Brush Mower Operation	Safe Use/Instruction Manual
9	13X	EasyLawn Straw Blower Operation	Safe Use/Instruction Manual

Table 10. Nine (9) SOP's to be used in conjunction with the BMP's.

Irrigation System

An irrigation system has already been established within the project site. Establishing a 2" (Drisco or Poly line Pipe) irrigation main from Tank 2 (148,00 gallon) near the rain catchment roof and from Tank 3 (128,000 gallon) near the summit will potentially provide 600,000 gallons of water at planting time and through the dry summer months. A 2" pump will provide water to the 2" mains that will be constructed out from the large water tanks. The main line will deliver water into 1" sub-mains and then to ½" laterals layed out in appropriate intervals along the contours of the land.

Ford couplings with 2" brass tees will connect sections of the 2" main and will also have a Watts 2" gate or ball valve to control water flow to the 1" sub-main. Each 1" sub-main junction will have a Rain Bird Control Zone 1" filter to capture and extract soil particulates from the 2" main. Finally, along the ½" laterals, 0.5 gallon/hr pressure-compensating emitters (Xeri-bugs) will be inserted immediately after planting for distribution of 0.5 gallons of water per hour twice a week. Other items required to construct the drip irrigation system will include, Teflon tape, hose clamps, and two 24" pipe wrenches for connecting the Ford male and female brass 2" couplings to the 2" main.

KIRC personnel will be trained for the daily operation and maintenance of the entire irrigation system to prevent deterioration of installations and also to be able to repair, and provide replacements for parts that may fail. Due to the rugged construction and composition of the Drisco Pipe 2" main, it is believed only the 1" sub-main and ½" lateral irrigation lines would be affected by extreme weather.

Planting

Native plants will be obtained from Ho'olawa Farms Plant Nursery in Haiku, Maui. It has been specified that the plants will be between 20cm to 30cm in height, appear healthy, and be free from insects. Some plant material may also be obtained from Lyon Arboretum on Oahu. Before planting, saplings will be hardened off in dibble tubes near the project site on island and will be watered twice a week on Mondays and Thursdays. This process is expected to improve their chances of surviving transplanting shock. For safety reasons (due to the possibility of the presence of UXO below 1.2m), augering holes for the plants will be limited to a depth of 30cm. To prevent root binding in the hardpan soils, the sides of the holes will be broken up with picks to allow for root development. Planting will be performed in accordance with the Planting SOP that outlines proper steps of adding EndoRoot, mulch, and fertilizer to the plant. Plants will be watered at a rate of 0.5 gallons/hr twice a week. Plants that have perished will be replaced on a one time only basis.

Native plant species that will be used for restoration in the project site are listed in Table 11. (E) = Endangered

Common Name	Taxa
'A'ali'i	*Dodonaea viscosa*
Achyranthes	*Achyranthes splendens*
Akiaki	*Sporobulus virginicus*
Alahe'e	*Psydrax odorata*
'Anapanapa	*Colubrina asiatica*
'Aweoweo	*Chenopodium oahuense*
Awikiwiki	*Canavalia hawaiiensis*
Bonamia	*Bonamia menziesii*
Hao	*Rauvolfia sandwicense*
Hau	*Hibiscus tiliaceus*
Hinahina	*Heliotropium anomalum ssp. argenteum* (E)
'Ihi	*Portulaca molokiniensis*
'Iliahi	*Santalum ellipticum*
Kamanomano	*Cenchrus agrimonioides* (E)
Kawelu	*Eragrostis variabilis*
Ko'oloa'ula	*Abutilon menziesii* (E)
Koaia	*Acacia koaia*
Koali Awa	*Ipomoea indica*
Kou	*Cordia subcordata*
Kului	*Nototrichium sandwicense*
Lama	*Diospyros sandwicensis*
Ma'o	*Gossypium tomentosum*
Ma'o hao hele	*Hibiscus brackenridgei* (E)
Maia pilo	*Capparis sandwicense*
Milo	*Thespesia populnea*

Common Name	Taxa
Naio	*Myoporum sandwicense*
Nehe	*Lipochaeta spp.*
Ohai	*Sesbania tomentosa*
Ohe	*Reynoldsia sandwicense*
'Ohi'a	*Metrosideros polymorpha*
Pa'u o Hi'iaka	*Jacquemontia ovalifolia*
Pili	*Heteropogon contortus*
Plectranthus	*Plectranthus parvilfora*
Pohinahina	*Vitex rotundifolia*
Uhaloa	Waltheria indica
'Ulei	*Osteomeles anthylidifolia*
Wiliwili	*Erythrina sandwicense*

Table 11. Native plant species to be used in restoration of the DOH project site.

Mulching

Mulching around the transplanted native species with Kiawe (*Prosopis pallida*) wood chips or grass mulch available near the project site will assist with soil water retention and decrease soil surface temperature as well. The Kiawe wood chips have been decomposing for three years and should provide organic matter to the soil. Although simple in concept, mulching is a critical component of plant survival in the extremely dry and hot weather conditions on Kaho'olawe.

Soil Amendments

At two weeks seedlings at the Ho'olawa Farms Plant Nursery will receive EndoRoot EndoMycorrhizae. This is expected to allow the formation of root nodules in the young seedlings and improve the ability of the plants to uptake Nitrogen (N_2) in the form of ammonium (NH_4^+). Just prior to transplanting into the ground, plants in dibble tubes will be immersed in a solution of EndoRoot EndoMycorrhizae consisting of two tablespoons dissolved into 5 gallons of water. The relationship that forms in the roots also reduces stress caused by drought, soil compaction, high soil temperatures, heavy metals, soil salinity, soil toxins and extreme variations in soil pH. Three native plant species which do not form a relationship with the bacteria are 'Aweoweo (*Chenopodium oahuense*), Kului (*Nototrichium sandwicense*) and Achyranthes (*Achyranthes splendens*).

Soil amendments in the form of fertilizer is needed as the soils in the project site are poor in organic matter and low in micronutrients, especially Zinc (Zn). Fertilizing with one to two tablespoons of Kula Blend 13-34-11 in the bottom of the hole at planting time is expected to improve the survival rate of plants in the project site. Guaranteed analysis of the Nitrogen, Potassium, Phosphorus (NPK) in the fertilizer is listed in Table 12.

Component	Percent
Total Nitrogen (N)	13.00%
Ammoniacal Nitrogen	7.31%
Urea Nitrogen	5.69%
Available Phosphate (P_2O_5)	34.00%
Soluable Potash (K_2O)	11.00%
Sulfur (S)	1.7%
Iron (Fe)	0.06%
Zinc (Zn)	0.07%

Table 12. Guaranteed Analysis of Kula Blend 13-34-11 fertilizer.

Non-Native Plant Species Control

Non-native species such as Koa Haole (*Leucaena leucocephala*), Lantana (*Lantana camara*), Ironwood (*Casurina equisetifolia*), Sourbush (*Pluchea symphytifolia*), Glycine (*Neonotonia wightii*), Sisal (*Agave sisalana*) and fireweed (*Senecio madagascariensis*) will be targeted for control using loppers, weed eaters, chainsaws and herbicide. Non-native plant control will take place only where deemed necessary to minimize soil erosion. Non-native plant species control will take place before planting and equipment needed includes loppers, weed eaters, chain saws, chaps, KEVLAR chaps (for chainsaw), leather gloves, hearing protection, and protective goggles. Green waste will be utilized on site as erosion control, as it will be too costly to ship it off island.

Herbicide Application

Herbicide application to cut stumps of Koa Haole (*L. leucocephala*), Lantana (*L. camara*), and Ironwood (C. *equisetifolia*) will proceed after manual removal of these species. Basal bark application may also be used when the non-native species are not manually removed. Herbicide application will consist of Garlon 4 (98%) mixed with Turf Trax blue dye (2%). Round Up Pro (2%) in water (96%) with blue dye (2%) may also be applied to certain non-native grasses such as Guinea grass (*Panicum maximum*). Herbicide will be applied in conjunction with non-native plant species control methods at before planting. Approximately 5 liters/ha of Garlon 4 will be applied. Equipment and PPE needed for herbicide application will include protective eye goggles, Niosh masks, herbicide sprayers, rubber gloves, Tyvek Suits, soap for washing hands, and an emergency eye wash kit.

Hydroseeding and Straw Blower

Hydroseeding will reduce the amount of exposed bare soil and introduce native grasses such as Pili and Kawelu to hardpan areas completely devoid of vegetation. With the addition of products such as Soil Guard to the hydromulch, the rate of soil loss from the project site should also be significantly reduced. The hydrocompost included in the hydromulch mixture will also provide nutrients to the native grasses. A 600 gallon Easy Lawn C60 Hydroseeder with a stainless steel tank, and a 25Hp water pump that delivers 125gpm at 65psi will enable application of hydromulch material to the most severely eroded portions of the project site. Additional 600 gallon water tanks may be used to support the hydroseeding operation.

The hydromulch material will consist of water, recycled paper or cardboard, a tachyphyre, native Pili (*Heteropogon contortus*) grass with cuttings of Kamanomano (*Cenchrus agrimonioides*) grass, ʻAweoweo (*Chenopodium oahuense*) or Pa'u o Hi'iaka (*Jacquemontia ovalifolia*), and seeds of ʻAʻaliʻi (*Dodonaea viscosa*). An Easy Lawn Straw Blower will also be utilized to throw pili grass straw out onto the hardpan before application of the hydromulch mixture.

Hummock Restoration

Hummocks are mounds composed of relict soils, and are evidence of the former level of the ground surface that existed before severe erosion took place on Kaho'olawe. They are often topped with a combination of native and non-native vegetation cover, which has helped to retain the soil still present. Hummocks are often bare around the base and, without further protection, will eventually erode away to the base level of the hardpan layer. Therefore, to protect the hummocks from further erosion Figure 26), native grass bales of Pili (*Heteropogon contortus*) will be broken up into shingles and placed in a

Figure 26. Hummock restoration on Kaho'olawe.

checkerboard pattern on the base of the hummocks. Geotextile material will be layed on top of the Pili grass and staked down with Eco-stakes. Geotextiles are composed of natural Coconut (*Cocos nucifera*) material with synthetic black plastic netting. Cultural material such as basalt, coral, and shell may also erode out and come to rest at the base of hummocks. Thus restoring these mounds will also help protect some of the archeological features in the project site. Non-native plants and grasses growing on the top of the hummocks will not be removed at this time to retain their beneficial effect of soil stabilization. Wherever possible, drip irrigation lines (½") will be installed over the geotextile/native grass cover to irrigate the slopes of the exposed hummocks.

Pili Rolls, Check Dams and Swales

Pili Rolls (wattles) in Figure 27, have proved to be very efficient at capturing soil during overland sheet flow, reducing soil erosion and sediment load, and provide a new substrate for plants. These will be installed along contours as appropriate in the project site (Figure 28). Plants may be irrigated along the uphill side of the roll to promote growth.

Figure 27. Volunteers constructing a Pili roll on Kaho'olawe.

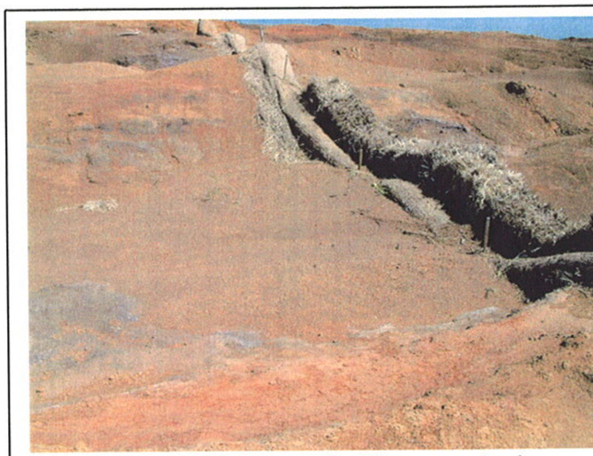

Figure 28. Pili roll and pili grass bales capturing sediment.

Check dams are permeable barriers built across a gully or waterway to slow or redirect the flow of water and increase sediment capture (KERP, 1998). Stream flow rate and overland sheet flow will also be reduced with the use check dams. Kawelu (*Eragrostis variabilis*) grass bales will be used in conjunction with wooden pallets staked at the bottom of deep gullies over 1m in depth. The bales will be zip tied to the pallets on the up-stream side to keep them from moving during stream flow. The check dams will be staggered at intervals to capture silt and reduce high rates of stream flow. The length of the interval will vary depending on the gradient of the deposits expected to accumulate above the dam (Heede, 1976), particularly in gullies that are over 1m in depth.

Swales will be made of geotextile wrapped around Kawelu (*Eragrostis variabilis*) or Pili (*Heteropogon contortus*) grass. Kawelu grass bales may also be used and placed throughout the project site in smaller stream channels less than 1m deep. These devices capture silt and will provide a substrate for future plantings and natural seedling establishment.

On the open hardpan, wind is the most significant factor preventing revegetation (KERP, 1998). Therefore whenever possible, native plants will be placed in the lee of the previously established Tamarisk Tree rows, which serve as wind breaks.

Planter Boxes

Planter boxes (Figure 29) will require 8 to 10 pili grass bales per box, but once constructed, has proven to provide a "Kipuka" effect for propagation and further dispersal of native vegetation. To be built primarily in Tier I areas (surface cleared only) the planter boxes will be fertilized, seeded and possibly irrigated.

Figure 29. Construction of a planter box in a Tier I area on Kaho'olawe.

Location of BMP's

The 2" mains will extend down from the large holding tanks to the 2276000 line (UTM NAD 83) in the project site. The 1" sub-mains and ½" laterals for drip irrigation will be used in all of the areas in the project site.

Non-native plant species control and herbicide application will take place in all areas. Where there is significant plant cover, non-native plant species control and herbicides will not be applied as to preserve the integrity of the erosion control the vegetation provides.

Planting of native grass species will occur in the hardpan areas. Shrubs will be planted with mulch and soil amendments behind pre-existing Tamarisk (*Tamarix aphylla*) tree windbreaks. The Tamarisk trees were sometimes planted three trees deep, and therefore the native shrubs and tree species will occur outside on the leeward side of the last row of trees. Areas that will receive the highest concentration of native tree species will occur where they will be most protected from the wind and have the most remnant soil within the project site.

Hydroseeding will occur wherever there is hardpan, and therefore throughout most of project site.

Hummock restoration will take place around the base of the features using drip irrigation, pili grass, native plants and geotextile. Maintenance of these erosion control devices will be minimal, however, periodic checks will be carried out after heavy rains.

Check dams will be built primarily in areas that contain gullies that are more that 1m in depth. Swales will be built in dry streams channels that are less than 1m deep to capture silt. The check dams will be built with stronger materials and inspected after periods of high rainfall. All of these BMPs will be maintained and operated by KIRC personnel and volunteers.

Operation and Maintenance of BMP's

Operation and maintenance of the BMP's will be the responsibility of the KIRC Project Manager and Project Assistant. Weekly schedules will be drafted by the Project Manager to guide the work for specific tasks and objectives in the project site. Standard Operating Procedures (SOP's) will be read and signed by all participants before the procedures are performed. The operation and maintenance of each BMP and the personnel responsible for the implementation is listed in Table 13.

BMP	Operation and Maintenance	Personnel Responsible
Irrigation	Weekly maintenance will include proper upkeep of the Honda pumps. Monthly maintenance will involve walking the 2" main looking for leaks at the brass	KIRC personnel

BMP	Operation and Maintenance	Personnel Responsible
	junctions of the 100m lengths of Drisco Pipe and 2" Polyline and plastic fittings. The 1" sub-mains and ½" laterals will also be periodically inspected during watering to detect leaks and check overall integrity of the system. The 1" RainBird filters will be checked monthly for particulate matter.	
Planting, Mulching, and Soil Amendments	Volunteers will be the main work force for carrying out the planting, mulching, and applying soil amendments in the project site. Planting will occur throughout the course of the year depending upon water availability. SOPs on soil augering and planting techniques will be read and signed by all participants before these activities are performed.	KIRC personnel and volunteers
Non-native Plant Species Control	Loppers, weed eaters and chainsaws will be used to control targeted non-native plant species in the project site. Ideally, manual control should take place one month before planting occurs so that herbicide application may occur. Standard Operating Procedures (SOPs) will be read and signed by all participants before the machines are used.	KIRC personnel and volunteers
Herbicide Application	Garlon 4 and Round Up Pro will be the two herbicides used in the project site. Herbicides will be mixed by KIRC personnel only and application will be performed by KIRC personnel and volunteers. Herbicide application should take place immediately following non-native plant species control for best results. SOP's will be read and signed by the participants before the mixing and application of the herbicides is performed.	KIRC personnel and volunteers
Hydroseeding and Straw Blower	The EasyLawn C60 Hydroseeder and Straw Blower will be maintained on a per use basis by KIRC Personnel. KIRC personnel and volunteers will use the Hydroseeder extensively in the hardpan areas in the project site and in conjunction with planting. SOPs on Hydroseeding and Straw Blower techniques will be read and signed by all participants before these activities are performed.	KIRC personnel and volunteers
Hummock Restoration	Geotextile on the hummocks will be checked for blowouts only after heavy rains. They will be checked on a minimal basis.	KIRC personnel and volunteers
Check Dams	Check Dams will be checked for structural integrity after heavy rainfall to ensure that they are functioning as designed. Blowouts will be repaired when they occur or if the check dam has been compromised in any way.	KIRC personnel and volunteers
Swales	Swales will require minimal maintenance as they are low lying and will eventually be covered with silt. They will be checked on a minimal basis and repaired if necessary.	KIRC personnel and volunteers
Planter Boxes	Planer Boxes will be built primarily in Tier I areas and will require 8 to 10 pili grass bales per box. Construction will involve addition of fertilizer, native seeds and in some cases irrigation, but maintenance will be minimal but should provide an excellent	KIRC personnel and volunteers

BMP	Operation and Maintenance	Personnel Responsible
	"Kipuka" for native plant dispersal.	

Table 13. Schedule for operation and maintenance of BMP's.

Vegetation Monitoring

Native plant density will be surveyed in 2008 for each of the 40 0.1ha subplot. Initial monitoring of the 5 vegetation-monitoring plots for plant cover (%) was completed in March 2004, read again in March 2005, and will be read a final time on March 2008. The 50m transects will be surveyed for percent cover by the Line Intercept method with an emphasis to determine if hyrdoseeding was an effective method to increase native plant cover and reduce the cover of bare soil.

Assesement of Erosion Control Needs

The vegetation plots will be hydromulched to assess the efficacy of Pili and or Kawelu grass in restoring Tier I (surface cleared only) hardpan in the project site. With the addition of products such as Soil Guard, to the hydromulch mixture, overland sheet flow, stream flow rate, and soil loss from the project site should also be significantly reduced. The fertilizer included in the hydromulch mixture will also provide nutrients to the native grasses.

Baseline Photo Points

Baseline photo points have already been established from the centers of each of the 5 vegetation-monitoring plot in the four cardinal directions (N, E, S, and W). Initial photo documentation was completed by March 2004. Another set of photos were taken in March 2005 for the purpose of comparison. A third set will be collected in 2007 to compare with the two previous sets of photos. Furthermore, various photo points around the new project site have been established using rebar and PVC with an aluminum tag indicating the identification number of the photo point. The 4 photo points were initially taken, GPS'd and mapped in March, 2006 and will be re-taken in August, 2006. More photo points will be taken and GPS'd as the project evolves and then be retaken from these vantage points in 2007 for comparison.

Discussion of the Margin of Safety and Annual and Seasonal Variation.

Erosion is inherently variable, both temporally and spatially, and sediment delivery to streams does not always coincide with erosion. Therefore, the sediment load allocations are designed to apply to the sources of sediment, not the movement or delivery of the sediment to the streams.

8-MONITORING

UNITED STATES GEOLOGICAL SURVEY (USGS)

The USGS Pacific Island Water Science Center (PIWSC) in Honolulu, Hawaii, and the USGS Pacific Science Center (PSC) in Santa Cruz, California, will be responsible for the following items listed in Table 14.

	Item	USGS Office
1	USGS Stream Gages	USGS PIWSC, Honolulu, HI
2	Soil Erosion Pins/T-LiDAR	USGS PIWSC, Honolulu, HI
3	Ocean Turbidity Monitors/Ocean Water Sampling	USGS PSC, Santa Cruz, CA

Table 14. List of USGS responsibilities.

USGS Stream Gage Descriptions

The USGS Pacific Island Water Science Center (PIWSC) in Honolulu Hawai'i, will install two stream gages, one approximately 300m up Kaulana stream, and the other about 350m up Hakioawa stream. These gages will be maintained by the USGS and will revert to the State of Hawaii at the end of the project. Water levels, also called stage or gage height, will be monitored at 15-minutes intervals using a compressed air pressure sensing system (Design Analysis Associates H-355). A compressor and regulator maintain a supply of air to a small plastic tube attached to the streambed. As water rises above the tube, the hydrostatic pressure imposed by the weight of the water causes the pressure of the air in the tube to increase. Pressure in the tube is monitored with a transducer, which converts pressure into voltage. The voltage is then supplied electrically to a data logger (DAA H-350XL) that converts the voltage readings to stage in feet, stores the data, and provides data to a radio transmitter (Signal Engineering 1200) for telemetry at hourly intervals.

Periodic stream flow measurements made directly with current meters or indirectly after peak flows by the slope-area method are used to develop a stage-discharge rating. Ratings are used to obtain records of stream flow from records of stage in the USGS Automated Data Processing System.

Stream Suspended Sediment

Automatic sediment samples will be collected with ISCO 6712 samplers. These samplers will be programmed to begin sampling when flow in the channel begins, and at intervals thereafter. If visits to the gages can be made when the streams are flowing, cross-section samples will be collected with DH-48 sediment samplers to calibrate the point samples. Sediment samples will be shipped to the USGS Cascades Volcano Observatory Laboratory for analysis. The approximate location of the USGS stream gage 300m up Kaulana stream is in Figure 30.

Figure 30. Approximate location of USGS Stream Gage (△) 300m up Kaulana stream.

Sediment records will be computed from stream flow data and sample concentrations using the Graphical Constituent Load Analysis System. Stage-discharge ratings will be developed for the two stream gages based on direct and indirect measurements of stream flow with associated gage heights. These ratings are then used to convert the continuous gage height readings to continuous stream flow values. The automatically collected point sediment samples will be calibrated with the cross-sectional isokinetic depth-intergrated samples, only if the stream can be accessed while water is flowing. QA/QC samples will be collected, including duplicates, blanks, and sand break analyses. For variability in sediment concentrations, the flexibility of the programming of the automatic sampler is relied upon to get a good representation of sediment concentrations over peak flows. In-situ turbidity monitoring will not be done on Kaho`olawe. Figures 31 and 32 illustrate the approximate positions of the turbidity monitors off of Kaulana and Hakioawa Bays.

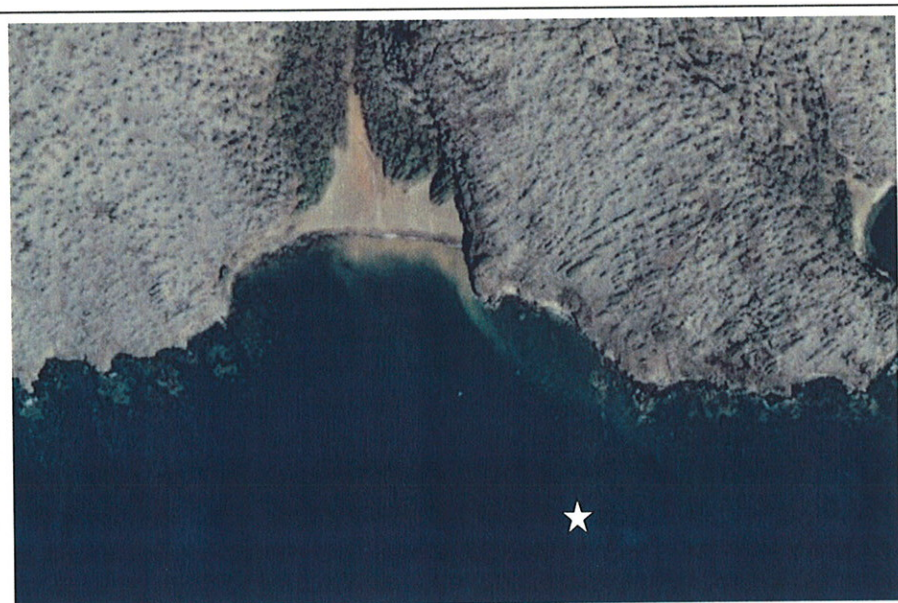

Figure 31. Kaulana Bay with approximate location of AQUATEC AQUA*logger* 210TY (☆).

Figure 47 also shows the approximate location of the USGS Stream gage approximately 350m up Hakioawa stream.

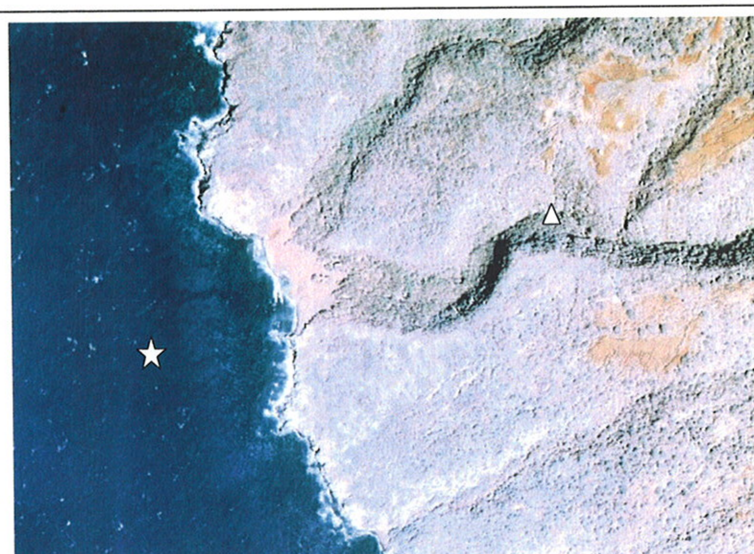

Figure 32. Hakioawa Bay with approximate location of USGS stream gage (△) and AQUATEC AQUA*logger* 210TY (☆) in 28 feet of water.

Ocean Turbidity

According to EPA criteria, suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonably established norm for aquatic life. Suspended solids effects on fish and fish food populations act directly on the fish swimming in water, either killing them, or reducing their growth rate and resistance to disease. Suspended solids also tend to prevent the successful development of fish eggs and larvae, modifies natural movements and migrations of fish, and reduces the abundance of food available to the fish (EPA, 1975).

Inorganic suspended materials reduce light penetration into the water body reducing the depth of the photic zone. This reduces primary production and decreases fish food. The depth of light penetration should not be reduced by more than 10 percent. The near surface waters are heated because of the greater absorbency of the particulate material, which tends to stabilize the water column and prevents vertical mixing. Such mixing reductions decrease the dispersion of dissolved oxygen and nutrients to lower portions of the water body (EPA, 1975).

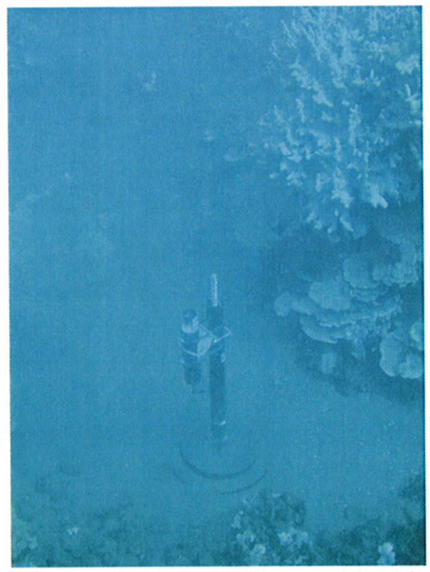
Figure 33. Turbidity monitor in Hakioawa Bay.

Two AQUATEC AQUA*logger* 210TY turbidity monitors have been installed off of Kaulana and Hakioawa bays (Figure 33) and have been recording data since November 17, 2005. They are periodically cleaned on a monthly basis to correct for bio-fouling of the lens. The initial 6 week data set revealed a turbidity spike coincident with a precipitation event around the 10th day, November 27 2006, after initial deployment. The Hakioawa RAWS weather station (E753187, N2277584, Elevation 1200ft), recorded rainfall on that day (November 27, 2005) at 3.63cm (1.43 in). The mean NTU averaged for 288 readings for that day was 80, with a high of 606 (Figure 34). In this example it took approximately 8 hours for the turbidity flux to dissipate.

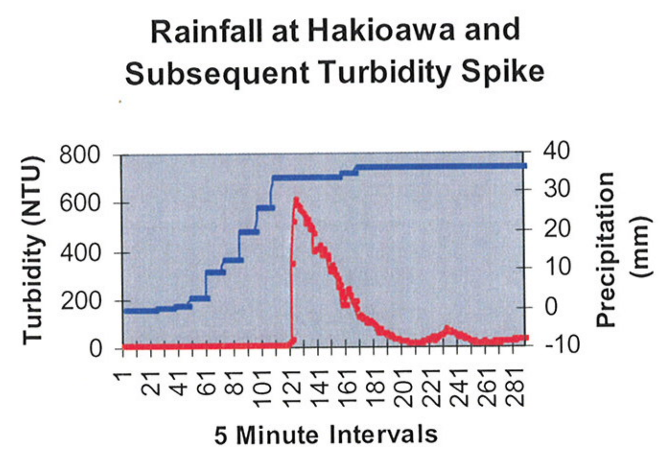

Figure 34. Rainfall event of November 27, 2005 and subsequent turbidity spike in Hakioawa Bay. (Blue = Precipitation Red = Turbidity)

Ocean Suspended Sediment Sampling

Ocean water samples will be taken at the two turbidity monitor sites at Kaulana and Hakioawa Bays. Three samples will be taken, at 1ft, 15ft, and the third at the turbidity monitor itself. For the turbidity monitor at Kaulana, this is at 25 feet, at Hakioawa, it is at 28 feet depth. The samples will be collected using a Niskin bottle (Figure 35) and poured into a 1 liter Nalgene bottle using a plastic funnel. The ocean water samples will be shipped to the USGS Pacific Science Center in Santa Cruz, CA. initially for analysis, and if then if appropriate, a wet lab will be constructed at the Kihei Boat House facility on Maui, for subsequent suspended sediment analysis. The suspended sediment (mg/l) results will be correlated to the turbidity monitor readings (NTU) at the date and time the ocean water samples are collected.

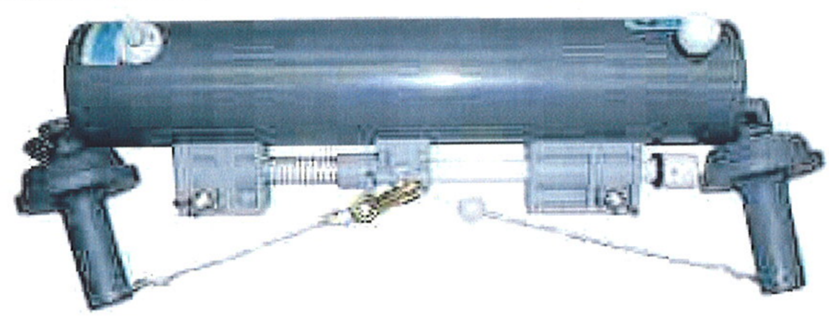

Figure 35. Niskin bottle sampler.

Other recent studies in Hawai'i have observed the dispersal and transport of suspended-sediment along a 35 mile long shallow coral reef off the south shore of Moloka'i. One of the primary goals of this study was to understand the sediment dynamics and to assess the impact of sediment on the health of this coral reef.

Soil Erosion Pins

On May 2, 2006, the initial trip to install the first 12 of 200 soil erosion pins along 100 transects occurred. The soil erosion pins (2 per transect) were installed in Tier I (surface cleared only) and Tier II (4 foot depth) areas in the headwaters of Kaulana, Hakioawa and Papakanui watersheds (Figure 36), and were paired for future analysis. Pairing the transects will allow for the comparison of the rate of soil erosion in a control (Tier I) versus a treated (Tier II) area. They were measured initially upon installation, and will be re-measured every 6 to12 months thereafter. The installation of the other 88 transects will be completed by the end of 2006.

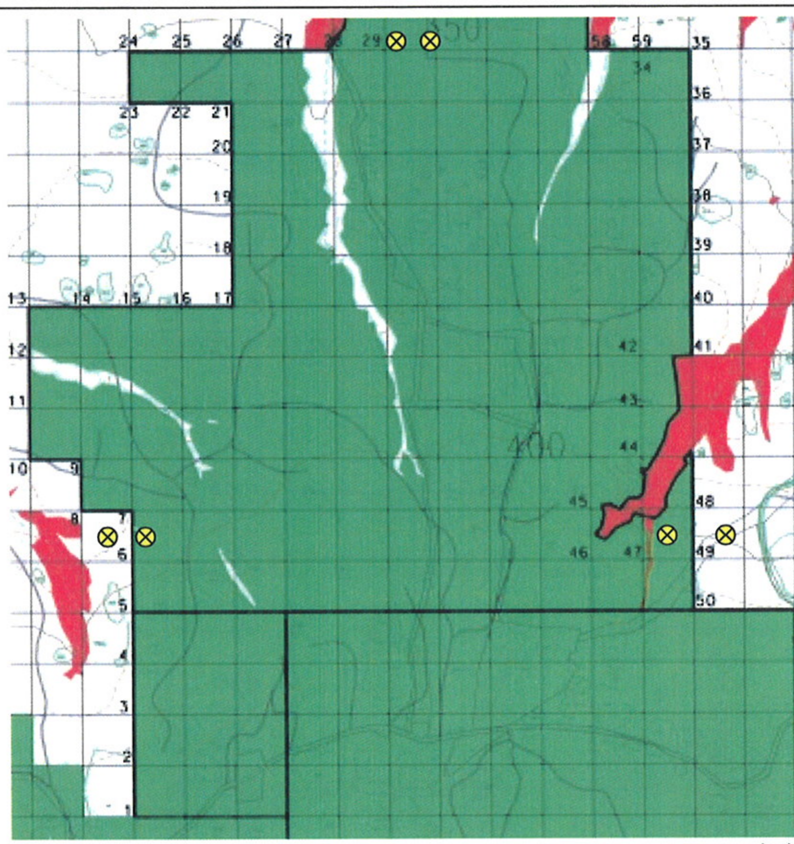

Figure 36. Location of first six paired soil erosion pin (⊗) transects.

Light Detection and Ranging (LiDAR)

Light Detection and Ranging (LiDAR) technology involves a scanning and ranging laser system that produces pinpoint accurate, high-resolution topographic maps, and generation of digital terrain models. The basic components of a LiDAR system are a scanning laser. The laser scanner emits an infrared laser beam at a high frequency and the scanner records the difference in time between the emission of laser pulses and the reception of the reflected signal. The round trip travel time of the laser pulses are measured and recorded. By accurately timing the round trip travel time of the light pulses to the surface, it is possible to determine the distance from the laser to the ground. These parameters yield enough data points to create a digital terrain model (DTM). Maps created using LiDAR data reveal topography details and morphology that are not available from aerial photographs.

Ground Based Tripod LiDAR (T-LiDAR) is a portable remote sensing instrument that accurately (± 4 mm) measures and monitors subtle changes in landscape through repeated three dimensional laser scans. Scanning at 2000 laser shots per second and distance up to 500m over 7 million point position measurements can be collected in an hour. T-LiDAR is an active source technology that collects measurements independent of sky view and time of day but is limited to line of sight. A full 3D image is obtained by scanning a target from multiple directions. Laser scans taken at different times are precisely aligned and differenced. Direct measurements of length change and volume dimensions can then be made. T-LiDAR will be initially collected in 2006 for subsequent analysis with the digital terrain maps that are produced. These maps are expected to be accurate to ±4mm and can be obtained in both Tier I and Tier II areas. A KIRC access guide will be present in the Tier I areas that will be used to collect the T-LiDAR data.

Airborne LiDAR

LiDAR is also an airborne laser-ranging technique commonly used for acquiring high-resolution topographic data. The SHOALS (Scanning Hydrographic Operational Airborne LiDAR Survey) system collects high-resolution bathymetric data in shallow, offshore areas. These maps essentially provide a view of sea-floor topography. In areas with coral reefs, this includes not only the top surface of the reef but also associated channels and sand flats. Lidar is useful in shallow-water settings from near sea level to a depth of approximately 120 feet (35 m).

Maps created using LiDAR data reveal topography details of reef structure and morphology that are not available from aerial photographs. In addition, LiDAR systems can gather information from depths approximately three times greater than standard aerial photography.

Airborne LiDAR has the potential to map coral reefs on Kaho'olawe and an example from a study on Moloka'i is illustrated in Figure 37.

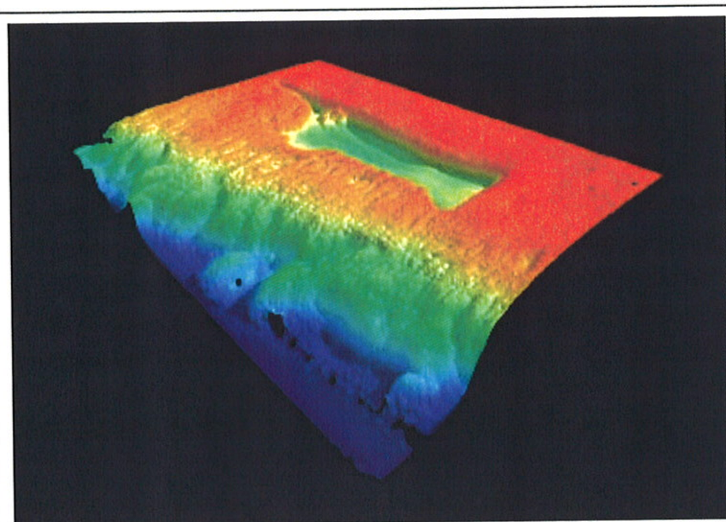

Figure 37. Example of Airborne LiDAR on a reef off of Moloka'i.

Laser Rangefinder Error

Laser Rangefinders are based on a diode pumped solid-state laser with pulse widths on the order of 10ns and rise times on the order of 1ns. Under normal operating conditions, the range error from a properly calibrated laser rangefinder of this caliber can be expected to be on the order of 5-7cm independent of altitude. In addition, atmospheric affects can impact the laser rangefinder and become significantly more critical at higher altitudes. These atmospheric effects are wavelength dependent so they can vary in magnitude depending on the particular wavelength used in the system.

Interferometric Synthetic Aperture Radar (InSAR)

A remote sensing technique called *interferometry* is now recognized as a reliable method for digital elevation model generation and centimeter level surface change detection. Interferometric Synthetic Aperture Radar (InSAR) provides two-dimensional map views of the way in which the surface of the earth deforms in response to internal and external forces. A geodetic measurement technique, the spatial resolution provided by InSAR has the potential to revolutionize studies of seismic and volcanic hazards, the relationship between fluid flow in the crust and surface deformation, the dynamics of long term strain accumulation at tectonic plate boundaries, and the relationship between glacier dynamics and climate change.

InSAR relies on repeated imaging of a given geographic location by air or space-borne radar platforms. With two complex (magnitude and phase) radar images of the same area one can construct an interferogram as the difference in phase of the return from each pixel. The phase differences are sensitive to topography and any intrinsic change in position of a given ground reflector. These two effects can be separated using either an independent topographic data set or an additional interferogram that does not include any surface deformation, i.e., with negligible temporal separation between acquisitions. The final product is a map view of the component of surface motion in the direction of the sensor, i.e., the line-of-sight (LOS) displacement. Interferograms typically have 20 to 80 meter pixel sizes and can detect displacements of a few millimeters.

Photo points

Location (UTM) and direction of photo points are listed in Table 15 and illustrated in Figure 38.

Photo Point Number	UTM Easting	UTM Northing	Direction of Photo
1	752853	2275610	North
2	752814	2275658	West
3	752719	2275607	North
4	752637	2275504	North

Table 15. Location (UTM) and direction of photo points.

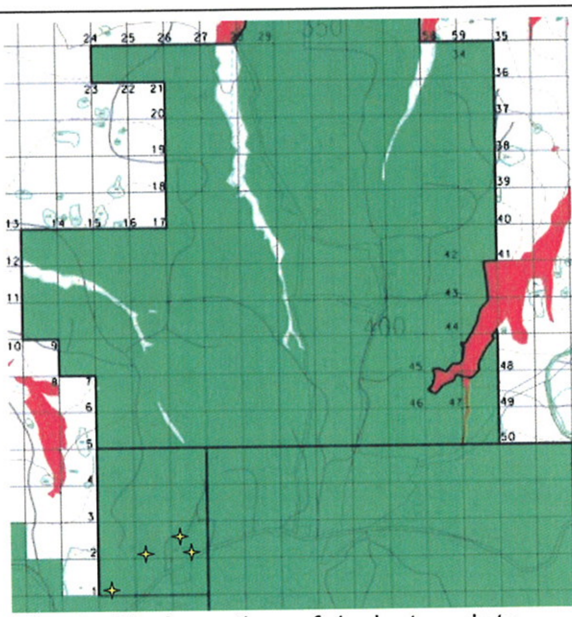

Figure 38. Location of 4 photopoints.

Figures 39a,b through 42a,b illustrate the before and after photo points.

Figure 39a. Photo point 1 March, 2006

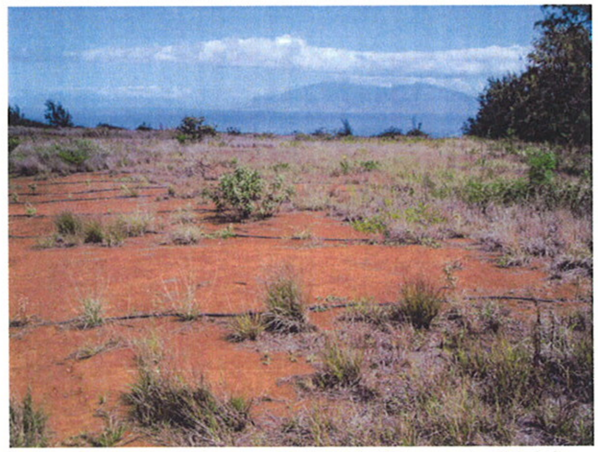

Figure 39b. Photo point 1 August, 2006

Figure 40a. Photo point 2 March, 2006

Figure 40b. Photo point 2 August, 2006

Figure 41a. Photo point 3 March, 2006

Figure 41b. Photo point 3 August, 2006

Figure 42a. Photo point 4 March, 2006

Figure 42b. Photo point 4 August, 2006

All photo points show minimal growth over a 5-month time period from March, 2006 to August, 2006.

Kaho'olawe Island Geographical Information Service (KIGIS)

Developed through the 1997 to 2003 Parsons-UXB Clearance Project, the KIGIS is a ~100GB database containing over 10,000 digital photographs, information on UXO, archeology, contours, aerial photographs, natural resources and environmental concerns. Run with Oracle it can be queried using a simple Microsoft Access interface. Figure 43 below illustrates a query on Tree Tobacco (*Nicotiana glauca*) a host plant for the native and endangered Blackburn Sphinx Moth (*Manduca blackburni*) in the Kaulana and Hakioawa watersheds.

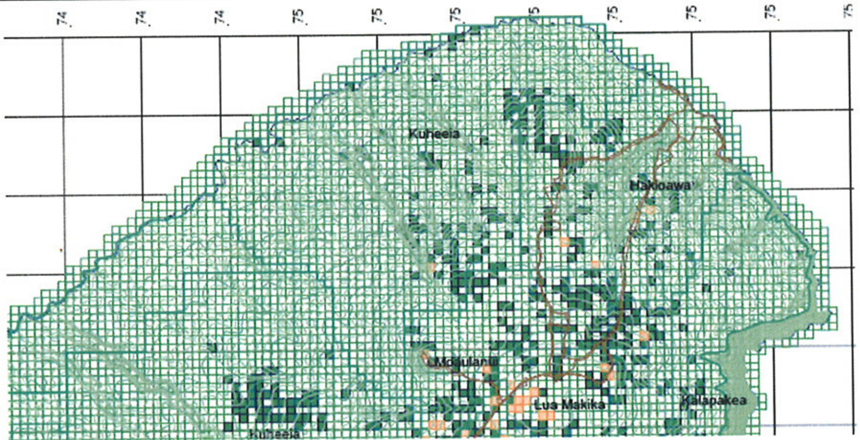

Figure 43. Example of KIGIS map query for Tree Tobacco (*Nicotiana glauca*) in the Kaulana and Hakioawa watersheds.

Table 16 below describes the natural resource elements that were recorded in each grid map unit (GMU) during the PUXB clearance project from 1998 to 2003. Any of these elements may be queried to produce a map like the one in Figure 43.

Element	Sub Heading	Common Name
Slope	Flat (0°-3°)	
	Gentle (3°-7°)	
	Moderate (7°-20°)	
	Steep (20°-45°)	
	Cliff, Gulch (>45°)	
Surface Texture	Smooth Bare Soil	
	Small Stones	
	Sparse Coverage, Large Stones/Boulders	
	Moderate Coverage, Large Stones/Boulders	
	Dense Boulder Field	
Overgrowth Type	None	
	Low Grass (<6")	
	Tall Grass/Low Shrubs	
	Tall Shrubs//Small Trees (<3')	
	Large Trees	
Vegetation Density	None (<5%)	
	Small Clumps (5-25%)	
	Moderate (25-50%)	
	Dense (50-75%)	
	Impassable (75-100%)	
Native Plant Communities	'Aki'aki Coastal Dry Grassland	
	Ma'o Coastal Dry Shrubland	Hawaiian Cotton
	'Ilima Coastal Dry Shrubland	
	Pili Lowland Dry Grassland	
	Hawaiian Mixed Shrub Coastal Dry Cliff	
Alien Plant Communites	Pickleweed Flat	

Element	Sub Heading	Common Name
	Kiawe Forest Woodland	
	Grassland/Sparse Woodland	
	Hardpan/Bare Substrate	
	Disturbed (Roads, graded areas, etc.)	
Aquatic Communties	Ephemeral Pool	
	Intermittent Stream	
	Wetlands	
	Tidepool	
	Hydrophytic Plants	
Non-Native Plants	*Acacia farnesiana*	Klu
	Atriplex semibaccata	Australian Salt bush
	Batis maritima	Pickleweed
	Botrichloa pertusa	
	Casurina equisitifolia	Ironwood
	Cenchrus ciliaris	Buffle grass
	Cynodon dactylon	Manienie
	Digitaria insularis	Sour grass
	Lantana camara	Lantana
	Leucaena leucocephala	Koa Haole
	Melinis multiflora	Molasses Grass
	Merremia aegyptia	Hairy Merremia
	Nicotiana glauca	Tree Tobacco
	Panicum maximum	Guinea Grass
	Pennisetum setaceum	Fountain grass
	Pluchea indica	Sour bush
	Pluchea symphytifolia	Indian Fleabane
	Prosopis pallida	Kiawe
	Rhyncheletrum repens	Natal Red Top
Native Plants	*Dodonaea viscosa*	'A'ali'I
	Erythrina sandwicensis	Wiliwili
	Gossypium tomentosum	Hawaiian Cotton/ Ma'o
	Heteropogon contortus	Pili Grass
	Hibiscus tiliaceus	Hau
	Jacquemontia ovalifolia	Pa'u o Hi'iaka
	Myoporum sandwicense	Naio
	Santalum ellipticum	Sandalwood/'Iliahi
	Sida fallax	'Ilima
	Sporobolus virginicus	'Aki'aki Grass
	Thespesia populnea	Milo
	Waltheria indica	Uhaloa
Animal Species	Pueo	Hawaiian Owl
	Cat	
	Mouse	
Insect Species	Honey Bee	
	Manduca blackburni	Blackburn Sphinx Moth

Table 16. Natural resource elements for Kaho'olawe in the KIGIS.

Quality Assurance PROJECT PLAN (QAPP)

A Quality Assurance Project Plan (QAPP) and schedule will be developed within 3 months upon implementation of this WBP. It will include the following;

quality assurance procedures, quality control requirements, and other technical activities that must be implemented to ensure that the results of the project or task to be performed will meet project requirements; it will contain several important guidelines for a program to follow such as objectives and milestones for achieving those objectives, lines of responsibility, accountability of staff for meeting data quality objectives, and accountability for ensuring precision, accuracy, and completeness of the data collection activities.

9- DATA ANALYSIS

The data from the soil erosion pins, native plant densities in the 0.1ha sub-plots, and vegetation cover (Line Intercept method) will be analyzed using a MS Excel spreadsheet and checked for quality. Correlation of precipitation and turbidity data will consist of using correlation and regression analysis, paired T-Tests (α=0.05), or non-parametric tests, such as Chi Square (X^2) if variance of the data is unequal.

Time Series Analysis and Autocorrelation

A time series is defined as *"an ordered sequence of values of a variable at equally spaced time intervals".* Time series analysis accounts for the fact that data points taken over time may have an internal structure (such as autocorrelation, trend or seasonal variation) that should be accounted for. Autocorrelation therefore is a correlation coefficient and the cross-correlation of a signal with itself gives its autocorrelation. However, instead of correlation between two different variables, the correlation is between two values of the same variable at different times.

Observations from the process are assumed to be independent of one another, and the Autocorrelation Function (ACF) is a good tool to use to check the independence, and detect non-randomness in the data. Autocorrelations should be near-zero for randomness and autocorrelation plots may show that the time series is not random, and has a high degree of autocorrelation between adjacent and near-adjacent observations.

The ACF will vary between -1 and +1, with values near ±1 indicating stronger correlation. Typically, residuals (the difference between an observed and an expected or predicted value) are plotted for visual assessment.

Correlation Coefficients

The correlation coefficient (r) provides an index of the degree to which paired measures (X and Y) co-vary in a linear fashion. Its value is constrained to lie between -1 and +1. A correlation coefficient (r) between .00 and .30 are considered weak, those between .30 and .70 are moderate and coefficients between .70 and 1.00 are considered high. The coefficient of determination (R^2) is the proportion of the total variation in the dependent variable Y that is explained or accounted for by the variation in the independent variable X. If expressed as a percentage it is in the range 0 - 100%. It is the square of the correlation coefficient (r) multiplied by 100.

Linear Regression Analysis

Homoscedasticy (equal variance) is a condition under which the response variable (y) has a constant variance for all values of x. It is a necessary condition for regression as is normality, independence and linearity (the relationships between the response variable and the predictors is linear).

Multiple Regression

Multiple regression analysis is an extension of simple linear bivariate regression. The difference is that it is assumed that there is information about more than one predictor (*x* variables).

One problem in multiple regression is multicollinearity (predictors are highly correlated) and a way to check for it is to regress each predictor variable in turn against all other predictors and to examine the R^2 values. If the R^2 value goes above 90.0% multicollinearity is said to be a problem.

A summary for statistical analysis and potential problems with the data is listed in Table 17.

Test	**Data Type**	**Problems**
Time series	Turbidity, Stream Gage Flow	Autocorrelation
Correlation	Rainfall, Turbidity, Stream Gage Flow	Heteroscedasticity
Liner Regression	Rainfall, Turbidity, Stream Gage Flow	Heteroscedasticity, Independence, Normaility, Linearity
Multiple Regression	Rainfall, Stream Gage Flow, Turbidity	Multicollinearity

Table 17. Summary of statistical tests, data type and potential problems encountered.

10- SUMMARY OF NINE EPA ELEMENTS

These nine EPA elements will address the reduction of excessive sedimentation after implementation of NPS Management Measures and BMP's. (http://www.epa.gov/fedrgstr/EPA-WATER/2003/October/Day-23/w26755.htm)

a. An identification of the causes and sources or groups of similar sources that will need to be controlled to achieve the load reductions estimated in this watershed-based plan (and to achieve any other watershed goals identified in the watershed-based plan), as discussed in item (b) immediately below. Sources that need to be controlled should be identified at the significant subcategory level with estimates of the extent to which they are present in the watershed (e.g., X number of dairy cattle feedlots needing upgrading, including a rough estimate of the number of cattle per facility; Y acres of row crops needing improved nutrient management or sediment control; or Z linear miles of eroded streambank needing remediation).

b. An estimate of the load reductions expected for the management measures described under paragraph (c) below (recognizing the natural variability and the difficulty in precisely predicting the performance of management measures over time). Estimates should be provided at the same level as in item (a) above (e.g., the total load reduction expected for dairy cattle feedlots; row crops; or eroded streambanks).

c. A description of the NPS management measures that will need to be implemented to achieve the load reductions estimated under paragraph (b) above (as well as to achieve other watershed goals identified in this watershed-based plan), and an identification (using a map or a description) of the critical areas in which those measures will be needed to implement this plan.

d. An estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon, to implement this plan. As sources of funding, States should consider the use of their Section 319 programs, State Revolving Funds, USDA's Environmental Quality Incentives Program and Conservation Reserve Program, and other relevant Federal, State, local and private funds that may be available to assist in implementing this plan.

e. An information/education component that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the NPS management measures.

f. A schedule for implementing the NPS management measures identified in this plan that is reasonably expeditious.

g. A description of interim, measurable milestones for determining whether NPS management measures or other control actions are being implemented.

h. A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made towards attaining water quality standards and, if not, the criteria for determining whether this watershed-based plan needs to be revised or, if a NPS TMDL has been established, whether the NPS TMDL needs to be revised.

i. A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established under item (h) immediately above.

a. Identification of Causes and Sources of Impairment

There are basically two sources that will need to be controlled to achieve load reductions. 1) sediment coming from the watershed, and 2) instream sedimentation processes such as bank erosion. Approximately 100ha will be affected in the current DOH Project. Restoration in the watersheds of Kaulana and Hakioawa would potentially affect 300ha. Table 18 lists the results from preliminary water samples taken by DOH, CWB, personnel at Hakioawa and Kuhe'eia Bay (adjacent to Kaulana Bay) in 2003 and 2004, respectively.

Place	Date	Time	Nitrate (NO_3) mg/l	Total N mg/l	Total P mg/l	Filtered Silica mg/l Si	Chlorophyll 'A" ug/l
Hakioawa Bay	11/18/2003	932AM	0.005	1.210	0.005	0.24	0.54
Kuhe'eia Bay	5/10/2004	936AM	0.006	0.145	0.010	0.24	0.16

Place	Temp °C	DO_2 (%)	DO_2 mg/l	Salinity	Conductivity	pH	(NTU)
Hakioawa Bay	26.35	93.8	6.18	35.38	53.5	8.26	1.5
Kuheeia Bay	26.80	102.0	6.62	34.74	52.6	8.25	8.9

Table 18. Results of DOH, CWB, water sampling at Hakioawa (2003) and Kuhe'eia bays (2004).

This baseline data was taken during a 2003 state wide ocean water survey by the DOH and 3 other bays including Ahupu, Honoko'a and Kealikahiki on Kaho'olawe were also sampled.

b. Expected Load Reductions

Non-Point Source (NPS) management measures that will need to be implemented to achieve the expected load reductions are listed in Table 19. Also, an estimate of the consequent load reductions expected for each of these NPS management measures is also provided.

	NPS Management Measure	Consequent Load Reduction Expected
1	Native Plantings	5%
2	Pili Rolls	5%
3	Check Dams/Swales	5%
4	Planter Box/C-Shapes	5%
5	Hydroseeding	5%

Table 19. NPS management measures and expected expected load reductions.

Due to the Tier II clearance boundaries established in the Parsons–UXB Clearance Project, only 20% of the two watersheds are actually in the current DOH project site. These 5 NPS management measures will cover most of the TIER I areas but only when the slopes are less than 15%. The amount of soil (tons) lost per watershed per year, and expected load reductions are listed in Table 20 (KICC, 1993).

Watershed	Area (ha)	Rate (tons/year/watershed)	Expected Load Reductions
Kaulana	280	429	10%
Hakioawa	310	1045	10%
Total	590	1474	20%

Table 20. Watershed, area, rate of soil loss, and expected load reductions.

A previous 2 year DOH project entitled "Watershed Restoration at Moa'ulanui, Kaho'olawe, Hawai'I" (ASO Log 04-184) using 32 soil erosion pins soil closely estimated soil erosion rates at 476 tons/year for Kaulana watershed, but underestimated soil erosion rates at 527 tons/year for Hakioawa watershed.

Due to the limitation of Tier II clearance, intrusive activities will only take place in the areas cleared to 4 foot depth. A "Planter Box" approach may be used in the Tier I (surface only) cleared areas of the two watersheds. These non-intrusive structures are made of 8 to 10 Pili grass bales in a rectangular configuration, and may be seeded, fertilized, and irrigated to produce a small island ("Kipuka") of vegetation that has the potential to disperse native seed. The Pili grass is grown, baled and then flown to Kaho'olawe (Figure 44) from the USDA Natural Resources Conservation Service (NRCS) Plant Materials Center (PMC) facility at Ho'olehua on the island of Moloka'i.

Figure 44. Pili grass bale delivery from USDA Plant Materials Center at Ho'olehua, Moloka'i.

Pili grass bales on Kaho'olawe, after they have arrived from Moloka'i are illustrated in Figure 45.

Figure 45. Pili grass bales on Kaho'olawe.

A "Planter Box" with Aweoweo (*Chenopodium oahuense*) is illustrated in Figure 46.

Figure 46. A "Planter Box" of Pili Grass bales with ʻAweoweo (*Chenopodium oahuense*).

In combination with the planter Box approach, "c-shapes" (Figure 47) may be constructed using Pili Grass Bales in an arcuate shape to capture soil and wind blown seed downwind of other established planter boxes.

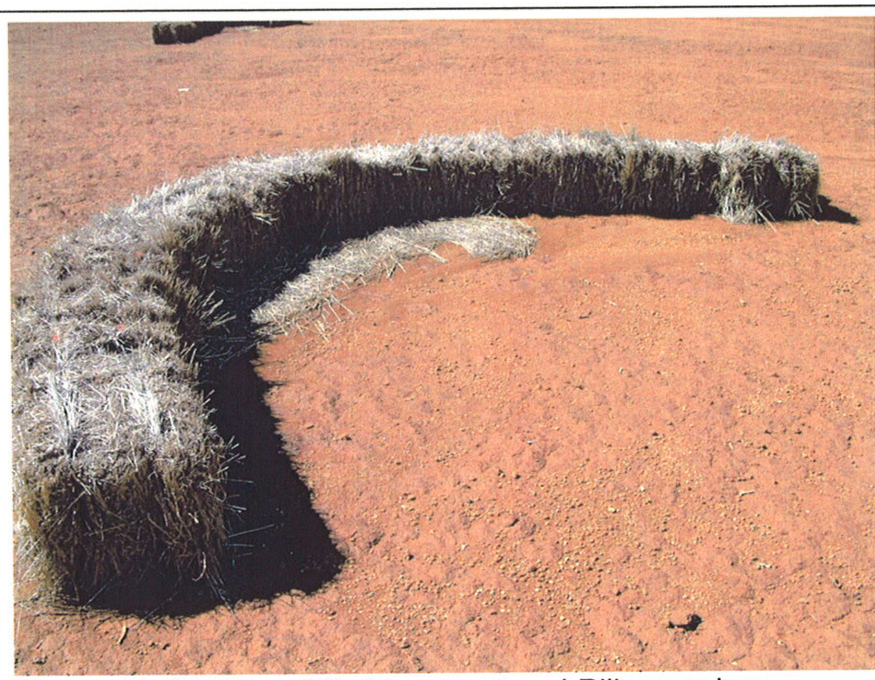

Figure 47. "C-Shape" that has captured Pili grass hay.

Ninety one (91) "c-shapes" were constructed in a Tier I (surface cleared only) area in Kanapou, downwind of a native planting area established in 1985 (Figure 48).

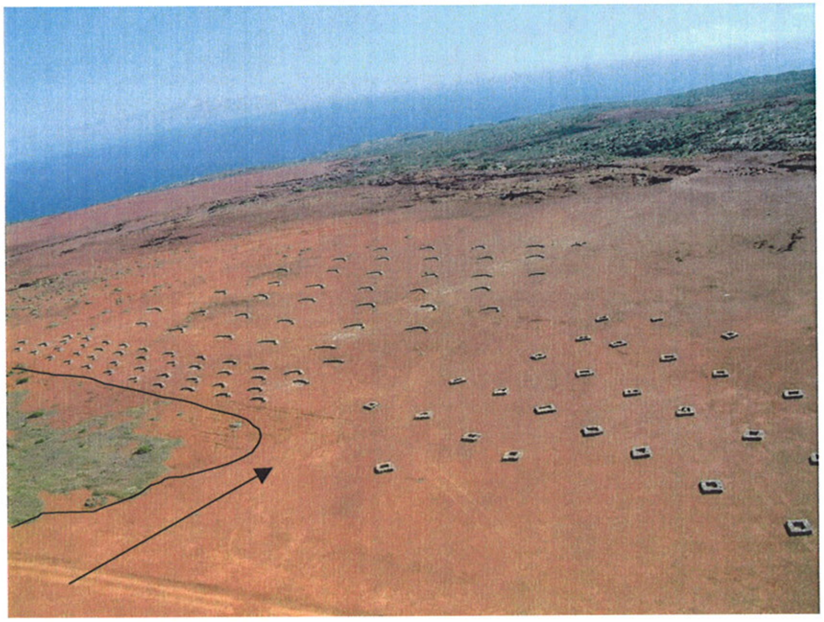

Figure 48. Combination of 91 "C-Shapes" and "Planter Boxes" in Tier I (surface cleared only) downwind of a native planting area on Kaho'olawe.

c. Proposed Management Measures

The following lengths of irrigation are based upon 1 plant per meter with irrigation lines spaced 10 m apart (Table 21)

Item	Kaulana (m)	Hakioawa (m)
Irrigation line	140,000	150,000
Pili Rolls	2000	4000

Table 21. Length of BMP's to be installed in the watersheds.

Hardpan in Kaulana and Hakioawa watersheds cover approximately 80ha and 100ha, respectively. Pili Rolls will be installed in the watersheds where there is hard pan and up to 15% slopes (Figure 49). Planter Boxes and C-shapes will be placed on the hard pan at 10m intervals intermittently, where deemed appropriate.

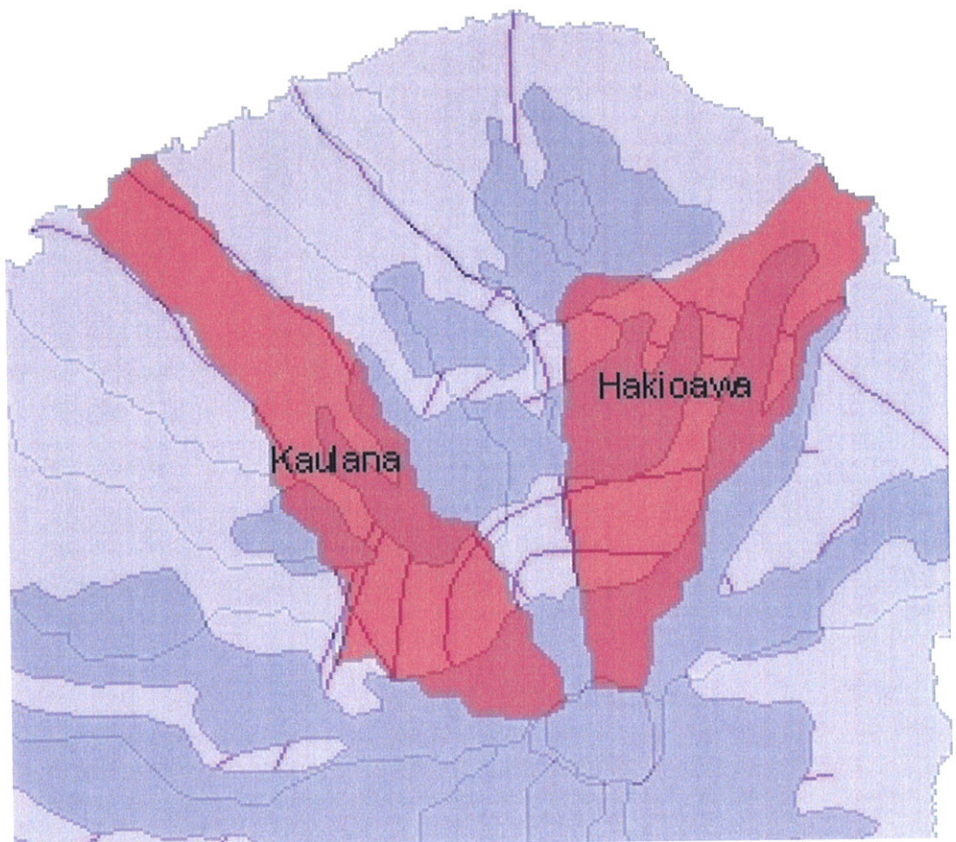

Figure 49. Proposed irrigation line and pili roll placement on the hard pan in the two watersheds. (Purple = hard pan)

d. Technical and Financial Assistance Needs

The estimate of the sources of technical and financial assistance needed over the 5-year time span is listed in Table 22.

Item Number	Item	Year 1	Year 2	Year 3	Year 4	Year 5	Total
1	Personnel[1] (9+1 Admin[2])	$560,000	$560,000	$560,000	$560,000	$560,000	$2,800,000
2	USDA PMC 2-3 personnel on Moloka'i	$100,000	$100,000	$100,000	$100,000	$100,000	$500,000
3	Helicopter Flights (5 personnel/flight)	$150,000	$150,000	$150,000	$150,000	$150,000	$750,000
4	USGS PIWSC Oahu (Soil Erosion Pins/LiDAR)	$100,000	$100,000	$100,000	$100,000	$100,000	$500,000
5	USGS PIWSC Oahu (Stream Sediment and Soil Erosion Monitoring)	$100,000	$100,000	$100,000	$100,000	$100,000	$500,000
6	USGS PSC Santa Cruz (Ocean Turbidity/Ocean Water Sampling)	$100,000	$100,000	$100,000	$100,000	$100,000	$500,000
7	USGS Open File Report Preparation					$100,000	$100,000
8	Irrigation Materials	$250,000	$250,000	$250,000	$250,000	$250,000	$1,250,000
9	Pili Grass Delivery $2200/hr for 9.1 hours/day @ $20,000/day @12 days a year	$240,000	$240,000	$240,000	$240,000	$240,000	$1,200,000
10	Native Plants and Endangered Species Propagation	$100,000	$100,000	$100,000	$100,000	$100,000	$500,000
11	Hydroseeding Materials	$100,000	$100,000	$100,000	$100,000	$100,000	$500,000
12	Two (2) Explosive Ordnance Demolition (EOD) personnel[3]	$180,000	$180,000	$180,000	$180,000	$180,000	$900,000
Note	[1] Two NRS III @ $60,000/annum. Two NRS II @ $55,000/annum Five NRS I @ $55,000/annum (Includes 35% overhead)	[2]Admin person to administer project purchasing/ billing etc.	[3] EOD @ $90,000/annum				
Totals		$1,980,000	$1,980,000	$1,980,000	$1,980,000	$2,080,000	$10,000,000

Table 22. Estimate of the sources of technical and financial assistance needed over 5 years, 2008 to 2013.

The authorities to be relied upon to implement the Watershed Based Plan (WBP) are listed in Table 23.

	Authority
1	KIRC, State of Hawaii
2	USGS Pacific Islands Water Science Center, (PIWSC) Honolulu, HI
3	USGS Pacific Science Center, (PSC) Santa Cruz, CA
4	USDA Plant Materials Center, Ho'olehua, Moloka'i, HI

Table 23. Authorities to be relied upon to implement the Watershed Based Plan.

Personnel from the KIRC, State of Hawai'i will be instrumental in overseeing the success of the proposed NPS management measures and BMP's. The USGS PIWSC in Honolulu will monitor the stream gages, suspended stream sediment and the soil erosion pins. With coordination through their office, the T-LiDAR data will be obtained through USGS personnel from the mainland. The USGS PSC will continue to assist in collection and analysis of the turbidity monitor data as well as subsequent ocean water sample analysis. The USDA Plant Materials Center on Moloka'i will continue to supply the pili grass by propagating and baleing the material at their location.

e. Information, Education and Public Participation Component

The KIRC has an Outreach Specialist and a Volunteer Coordinator that disseminates information and both educate the public understanding of the project and encourage their participation. While on island, restoration volunteers are given cultural and historical education of Kaho'olawe in an informal outdoor setting. Listed below in Table 24 are 22 groups that have frequently come out to Kaho'olawe to participate in restoration work from 2003 to 2005.

	Group
1	Americorp
2	Breakthrough Adventures Ecology Group University of Hawaii at Hilo
3	Ethnic Studies University of Hawaii at Manoa
4	Hawai'i Preparatory Academy
5	Halau Lokahi Charter School
6	Haleakala National Park
7	Kamehameha High School, Maui , Oahu
8	Kua Ana Services University of Hawaii at Manoa
9	Lahaina Luna High School
10	Lanai High School
11	Maryknoll High School
12	Maui Invasive Species Committee
13	Maui Land and Pine - Pu'u Kukui Watershed
14	Maui Youth and Family Services

15	Pacific Whale Foundation
16	Punahou High School
17	Queen Liliuokalani Childrens Center
18	Seabury High School
19	Sierra Club – Oahu Chapter
20	USGS BRD Hawaii Volcanoes National Park
21	University of Hawai'i - Ethnic Studies
22	Youth Conservation Corps.

Table 24. A list of 22 groups that have come to Kaho'olawe to participate in restoration work from 2003 to 2005.

The volunteers will provide work for the restoration activities including planting and some of the other BMP's that are implemented in the watersheds.

In 2005, a poster entitled Watershed Restotration on Kaho'olawe, and an oral presentation on the former DOH Project Restoration, was given at the Hawaii Conservation Conference. The theme for the 2006 Hawaii Conservation Conference in Honolulu is "Mauka to Makai" and personnel from the KIRC Restoration Department will be presenting a poster on the preliminary results from the current DOH Project "AThree-Phase KIRC Project Extension".

An award winning DVD entitled Kaho'olawe: Breath of Our Ancestors "Ka Ha o Ko Makou Mau Kupuna" was produced by the KIRC and Hawaii Pacific University in 2003, and has been given out to various groups in the State of Hawaii. Listed in Table 25 are the 35 organizations that received the DVD at the Hawaii Conservation Conference in Honolulu Hawaii in 2005.

Number	**Organization**
1	US Army Environmental
2	Big Island Invasive Species Council
3	Bishop Museum
4	Conservation Council of Hawaii
5	CSU Pohakuloa Traing Area
6	Forest Research Extension Partnership
7	Haleakala National Park Service
8	Hawaii C's Consultants
9	Hawaii Department of Forestry and Wildlife
10	Hawaii Department of Land and Natural Resources
11	Hawaii Natural Area Reserves
12	Kaelepulu Wetland
13	Kauai Endangered Bird Project
14	LARIX
15	Leeward Community College
16	Maui Forest Bird Recovery
17	Maui Invasive Species
18	Na Ala Hele

Number	Organization
19	Native Hawaiian Plant Society
20	OSU
21	Stanford University
22	The Nature Conservancy
23	The Nature Conservancy Kauai
24	UH CCRT Seed Lab
25	UH College of Tropical Agriculture and Human Resources
26	UH Hilo
27	UH HINHP
28	UH HIP Imi Pono No Ka Aina
29	UH NREM Remote Sensing
30	UH REV Coral Ecology
31	USGS Biological Research Division/ Pacific Island Ecosystem Research Center
32	USGS Inventory &Monitoring
33	USGS Maui
34	USGS PBIN
35	Waimea Valley Audubon Center

Table 25. A list of the 35 organizations receiving the KIRC DVD, Breath of our Ancestors in 2005.

A NPS brochure was developed for the previous DOH project, Watershed Restoration at Pu'u Moa'ulanui, Kaho'olawe (Figure 50). This brochure has been handed out to multiple State and Federal agencies, and an updated NPS brochure will be developed for the current DOH project. This brochure was developed by the Restoration Department of the KIRC and covers the Project Scope, Backround, BMP's, Outplantings and Reintroductions, Lessons Learned and Cultural Education of the previous DOH project.

KAHO'OLAWE

Pu'u Moaulanui Restoration Project

PROJECT SCOPE

An Environmental Challenge

On Kaho'olawe an estimated 1.9 million tons of soil is deposited into the surrounding ocean each year as a result of erosion. Overland water flow is currently the dominant factor in erosion losses with subsequent sediment flow into the ocean.

Many of the streams on Kaho'olawe are intermittent where water flows after heavy rains, or ephemeral, where water flows over the surface in flash flood events. Both of these stream types carry sediment into the ocean and cover coral reefs. With coral reefs being the base for healthy ocean ecosystems, the restoration on land assists in restoring the surrounding ocean resources. The Pu'u Moa'ulanui restoration project focuses on capturing sediment in these stream channels and promoting the growth of vegetation, thus reducing sediment flow into the ocean. The near shore waters off the coast of Kaho'olawe experience silt plumes during high rainfall events, as well as on a daily basis. Corals observed in the surrounding ocean waters are generally limited to the robust species such as Lobe coral (*Porites lobata*) and Cauliflower coral (*Pocillopora meandrina*), that are relatively tolerant of silt-laden environments. The sediment runoff has been occurring for decades if not centuries.

The Hawaii State Department of Health (DoH), Clean Water Branch provided the Kaho'olawe Island Reserve Commission with a grant to reduce nonpoint source pollution. The goal of the watershed restoration project at Moa'ulanui is to reestablish a native Hawaiian dry forest ecosystem while reducing soil erosion.

Watershed restoration presents various challenges. In addition to erosion control measures, re-establishing native vegetation is a primary goal. The Pu'u Moa'ulanui restoration project employs various strategies to mitigate the problems Kaho'olawe presents for revegetation. Restoration of native plant species on Kaho'olawe is challenging due to five main factors:

I. A harsh climate, which includes low seasonal rainfall (10-25" per year), high solar radiation, high rate of evaporation, and strong persistent trade winds.

II. Severe soil erosion that has reduced available nutrients, organic matter, and microbial activity.

III. Invasive species that out-compete native species.

IV. Logistically difficult access to a remote island.

V. The presence of unexploded ordnance (UXO).

Figure 50. NPS Brochure developed for the previous DOH Project.

In the current DOH Project, the data from the stream gages and near shore ocean turbidity monitors will be made available to the public as a USGS Open File Report. These are located on the internet at http://pubs.usgs.gov/of/. This information will benefit other land mangers seeking to understand the relationship between precipitation and soil erosion in the state of Hawaii.

On the internet, the Bishop Museum Web site for Kaho'olawe was developed in conjunction with the Bishop Museum exhibition Kaho'olawe: Ke Aloha Kupa'a i ka Aina, and are projects of the Bishop Museum's Native Hawaiian Culture and Arts Program. (http://www.bishopmuseum.org/research/cultstud/kaho/index.htm) It contains photographs and cultural information about Kaho'olawe.

Finally, the KIRC maintains a web site at http://kahoolawe.hawaii.gov/ with information on open water schedules, upcoming events, bidding and employment opportunities.

f. Schedule

The schedule for implementing the NPS management measures are listed in Table 26.

	NPS Management Measure	**Year Begin**	**Year End**
1	Irrigation	2006	2013
2	Native Plantings, Mulching, Soil Amendments	2006	2013
3	Non-Native Species Control	2006	2013
4	Hydroseeding, Straw Blower	2006	2013
5	Hummock Restoration	2006	2013
6	Pili Rolls, Check Dams, Swales	2006	2013
7	Planter Box/C-Shapes	2006	2013

Table 26. Schedule for the7 NPS management measures.

Two (1,2) of these NPS management measures have already begun with the current DOH project. Pili Rolls, planter boxes and c-shapes will be constructed once the project evolves into the hard pan and Tier I clearance areas of the two watersheds. Check dams will be made stronger as the ones already built were not able to withstand the force of the stream water. Hydroseeding will have limited application as the 5 ton vehicle it is mounted on will only be able to traverse to the edge of the Tier II boundaries. However, any hydroseeded areas will be irrigated to ensure initial germination and growth of the native seed in the hydromulch medium. Non-native species control will be applied through out the watersheds especially targeting invasive species listed in the Non-native vegetation section of Chapter 4 on the Environment.

g. Milestones

Statistical T -Test results from the previous DOH Project, "Watershed Restoration at Moa'ulanui, Kaho'olawe Hawai'i " (ASO LOG 04-184) are listed in Table 27.

Taxa	Mean Cover (%) 2003	Mean Cover (%) 2005	Change (%)	t (0.05)	1-α
Chamaecrista nictitans	0.99	1.87	0.88	0.009	*99.10%
Digitaria insularis	3.72	7.72	4.00	0.011	*98.89%
Lantana camara	1.36	2.08	0.72	0.043	*95.67%
Leucaena leucocephala	4.49	7.88	3.39	0.0003	**99.97%
Litter	4.48	1.39	-3.09	0.0002	**99.97%
Soil	73.55	66.57	-6.98	0.001	**99.99%
All natives[1]	4.53	4.85	0.32	0.0493	*95.07%

Table 27. T-Test results of the significant differences in mean cover (%) from 2003 to 2005.

1 = Three native species observed in 2003, Ten native species observed in 2005
* = $\leq$ 0.05 (Significant)
** = $\leq$ 0.01 (Highly Significant

Mean plant cover (%) of three species in 2003 and ten species in 2005 increased significantly (α=0.493) reduced from Fall, 2003 to Spring, 2005 and mean cover (%) of bare soil decreased significantly (α=0.001) during the same time period. Mean cover (%) for several non-native species increased as well and indicates the absence of non-native species control. In the former DOH project the approach of use your aliens was adopted to avoid causing further soil erosion. A summary of the T-Test results of the significant differences in mean cover (%) for all natives, non-natives, and bare soil from 2003 to 2005 is illustrated in Figure 51.

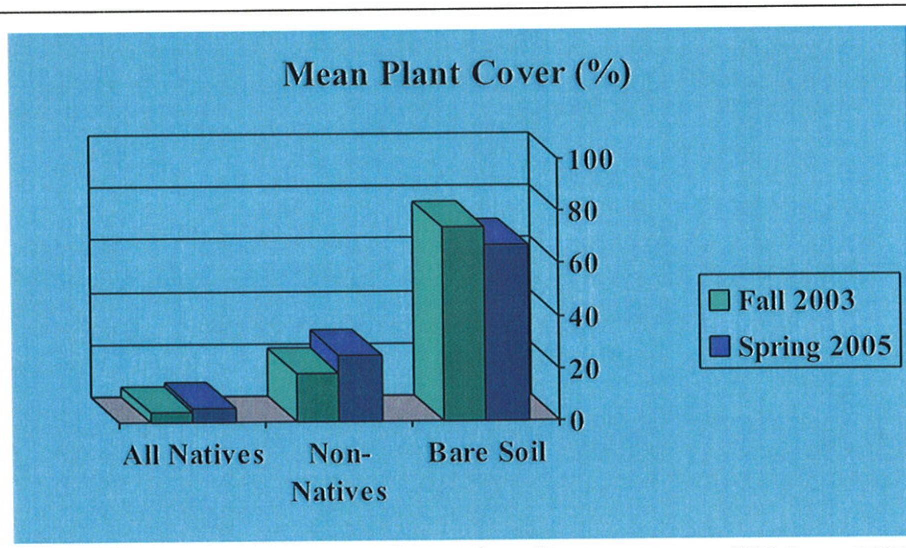

Figure 51. Summary of t-test results of mean cover (%) from 2003 to 2005.

Five vegetation plots, irrigation lines and pili rolls installed in the previous DOH project site are presented in Figure 52. Approximately 6000m of irrigation line were laid out, 2000m of Pili Rolls, 10 check Dams, and 100 swales. One Grid Map Unit (GMU) is 100m X 100m (UTM-NAD 83).

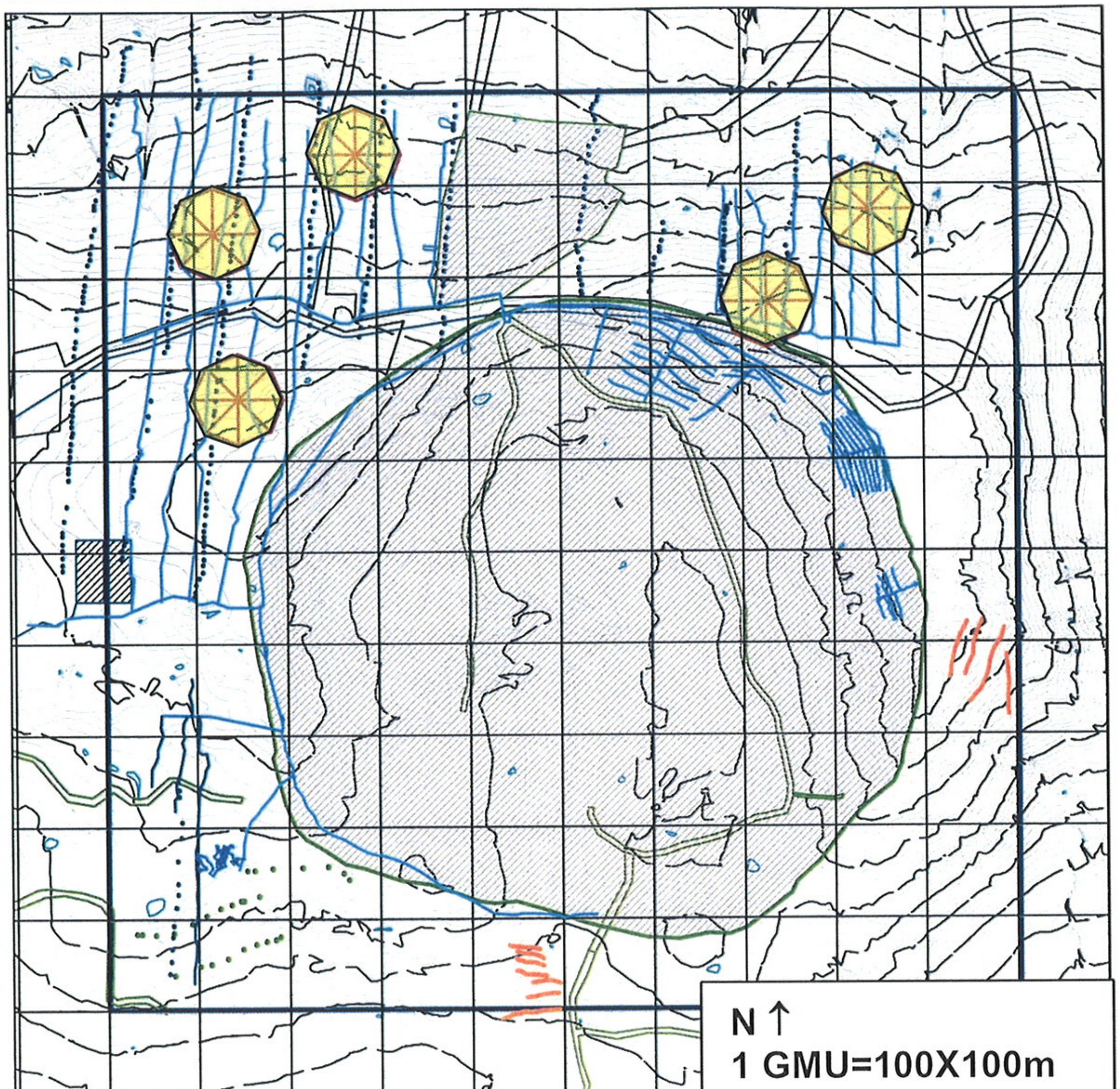

Figure 52. Five vegetation plots (yellow), irrigation lines (blue), and pili rolls (orange) installed in the previous DOH project 2003 to 2005.

A KIRC GIS (Microstation ver 7.0 J) map illustrating the most recent irrigation lines of the current DOH project is in Figure 53 below. Approximately 3000m of irrigation line have laid out to date. Green circles are 2600 gallon satellite water tanks.

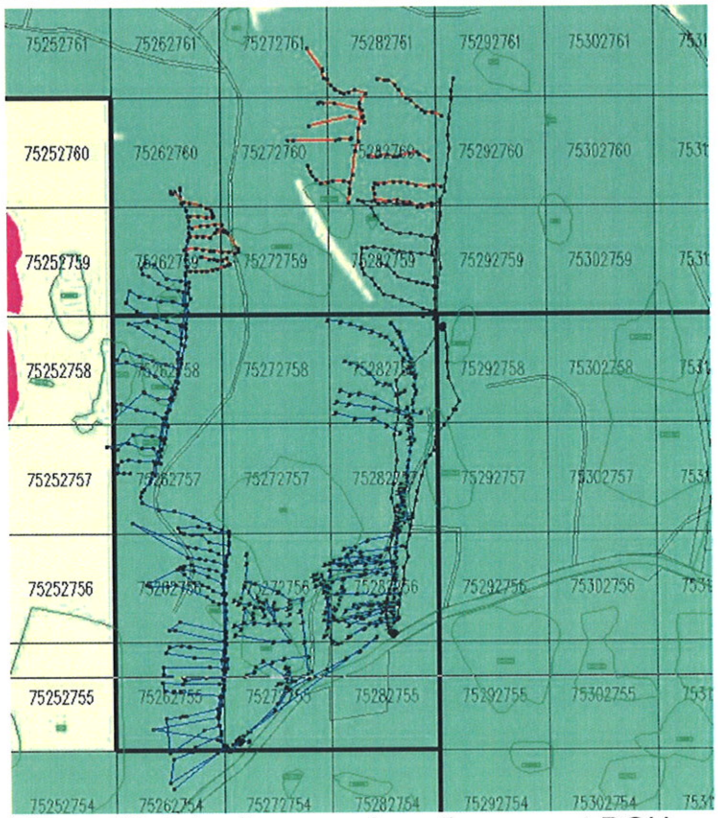

Figure 53. Irrigation map from the current DOH project.

h. Load Reduction Evaluation Criteria

Mean plant cover (%), native plant density, photo points, stream suspended sediment (mg/l), near shore ocean turbidity (NTU), and USGS soil erosion pin data, will be the set of criteria that will be used to determine whether substantial progress is being made towards attaining water quality standards. For example, the first turbidity spike recorded in Hakioawa Bay came in conjunction with a rain event on Kaho'olawe is presented in Figure 54. With restoration and time, one would expect a lower turbidity value with subsequent rainfall events. For example, in this 3.63cm event, a turbidity value of over 200 NTU was recorded at the Hakioawa monitor.

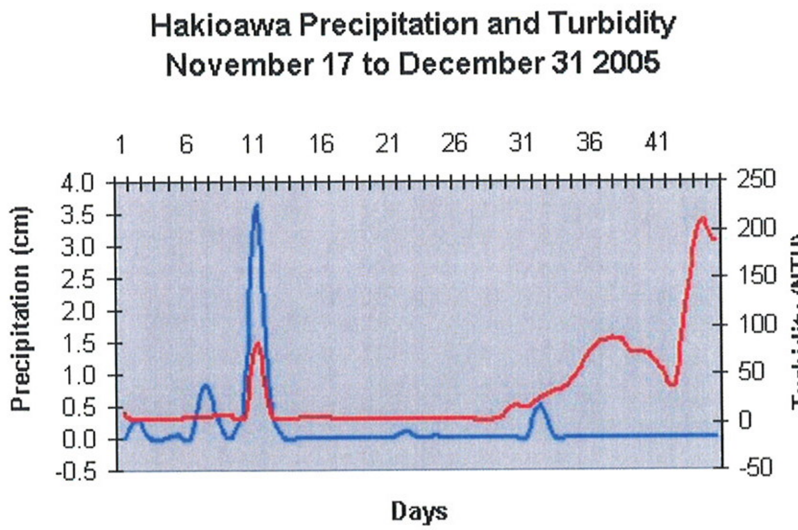

Figure 54. Precipitation at Hakioawa RAWS and Subsequent Turbidity Spike in Hakioawa Bay. Red = Turbidity (NTU) Blue = Precipitation (cm).

The turbidity spike was coincident with 3.63cm of precipitation on November 27, 2005. Unfortunately, there is little or no correlation with the turbidity that is evident from 31 days on. Attempts at correlating this trend with Mean significant wave height (m) from Buoy 51001 in the North Pacific proved to be futile (Figure 55).

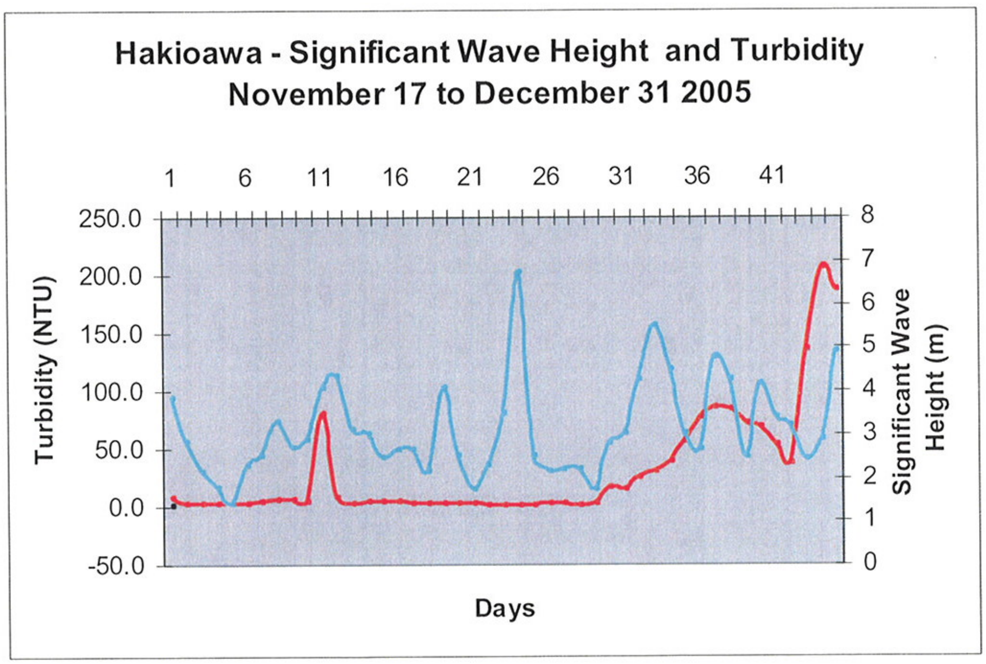

Figure 55. Mean Significant Wave Height from Buoy 51001 and Turbidity from November 17 to December 31, 2005.

Water samples taken at 1, 15 and ~30 feet at the ocean turbidity monitors will correlate near shore ocean suspended sediment (mg/l) with turbidity readings (NTU).

i. Monitoring Component

The following 8 monitoring components in Table 28 will be applied to evaluate the progress and effectiveness of the restoration efforts.

	Monitoring Component	**Subject**
1	40 Vegetation Sub-Plots	Native Plant Density
2	5 Vegetation Plots	Hydroseeding
3	Photo points	Native Plant Establishment and Growth
4	Turbidity Monitors	Suspended Sediment in Ocean
5	Ocean Water Sampling	Suspended Sediment in Ocean
6	USGS Stream Gages	Suspended Sediment in Streams/Stream Flow
7	T-LiDAR	Soil Erosion in Tier I and II Areas.
8	USGS Soil Erosion Pins	Soil Erosion in Tier I and II Areas

Table 28. Eight monitoring components to be used to evaluate the progress of restoration efforts.

The 40 vegetation subplots will be re-read in 2007 to observe any increase in native species density using presence and absence.

After application of hydroseeding in selected vegetation plots, some of the 50m transects will be re-read and compared to the 2005 data set to determine if the hydromulching application is effective in increasing native plant mean cover (%) and reducing mean cover (%) of bare soil.

Four (4) photo points have been taken in March 2006 and will be re-photographed in July 2006 for a 4-month growth comparison. Further photo documentation of planted native vegetation, for comparisons over time, will occur as the NPS management measures are implemented in the project site.

The two AQUATECH AQUA*logger* turbidity monitors in the near shore ocean environment off of Kaulana and Hakioawa Bays have been recording data since November 17, 2005, and will continue to obtain data until 2008.

To date, 6 water samples have been collected at 1 foot, 15 feet and ~30 feet by each of the two turbidity monitors off of Kaulana and Hakioawa Bays. These samples were shipped to the USGS Pacific Science Center (PSC) in Santa Cruz for suspended sediment (mg/l) analysis. Further sampling may continue in the future with possible chemical analysis.

Plans for collecting LiDAR data is underway with the USGS and several appropriate areas in the DOH project sites have already been identified for the initial readings.

USGS stream gage placement has been determined by USGS personnel in Hakioawa and Kaulana streams and these stations will be constructed beginning in July, 2006.

Finally, 12 soil erosion pins along 6 transects have been installed in Kaulana, Hakioawa and Papakanui headwaters in Tier I and Tier II areas for comparison of soil erosion rates in control (Tier I) and restoration treated (Tier II) sections of the project site. More pins and transects will be installed throughout 2006.

11- EPILOGUE

Endangered Species Propagation

Discovered as a new genus in 1992 (Gon et al., 1992), special consideration should be given to the only remaining one of two original plants, the endangered Palupalu o Kanaloa (*Kanaloa kahoolawensis*) (Figure 56).

Figure 56. Palupalu o Kanaloa (*Kanaloa kahoolawensis*) growing on Aleale seastack on Kaho'olawe's southeast shore.

Propagation of Palupalu o Kanaloa in the headwaters of Kaulana (Figure 54) should take place for the following reasons;

1. The danger of personnel accessing the sea stack, Aleale by Helicopter, where the last remaining individual is located is extremely high, and successful outplantings in the headwaters of Kaulana would reduce this risk to personnel.
2. A Federal Endangered Species permit would not be required because the outplanings would be derived from cultivated material.
3. The climate in the headwaters Kaulana on approximates the sea stack Aleale where the last remaining individual is located.
4. Monitoring of condition, flowering and fruiting can take place on a daily to weekly basis, as restoration personnel would already be in the vicinity of the outplantings.
5. Irrigation of the outplantings would be available 365 days of the year.

6. Systemic (endogenous) problems experienced with the tissue cultures in the micropropagation laboratory at Lyon Arboretum may not be present in the field.

7. Kaho'olawe is an Island Reserve protected from the casual visitor. The security of successful out plantings from the general public would be high as any personnel coming to the island would be under the direct supervision of KIRC staff.

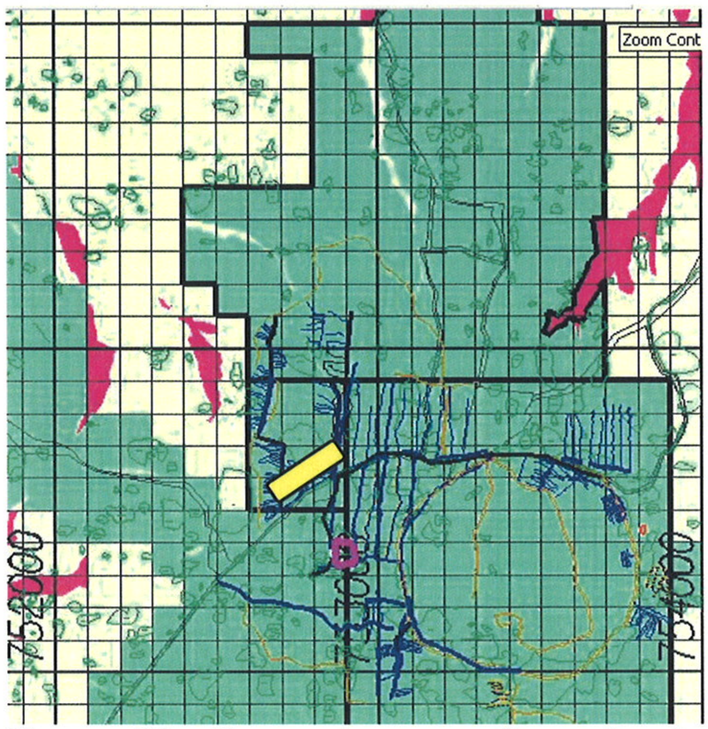

Figure 57. Proposed propagation site for Palupalu o Kanaloa (*Kanaloa kahoolawensis*) in the headwaters of Kaulana watershed on Kaho'olawe.

NOAA 5-year Plan

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) initiated a coral reef research program in 1999 to map, assess, inventory, and monitor U.S. coral reef ecosystems (Monaco et al. 2001). NOS and National Geodetic Survey (NGS) have acquired color aerial photography and hyperspectral imagery (HSI) for the near shore waters of the eight Main Hawaiian Islands. The images are being used to create maps of the region's marine resources including coral reefs and other important habitats for fisheries. Accurate habitat maps are necessary for resource managers to make informed decisions about the protection and use of these areas. A primary product of this effort is a benthic habitat map produced by visual interpretation of the remotely sensed image data. These benthic habitat mapping products have been generated by manual delineation of habitats from color aerial photographs, AURORA hyperspectral and IKONOS multispectral satellite digital imagery.

NOAA's 5-year plan includes the following statements which are appropriate to the future of environmental research in the Kaho'olawe Island Reserve. One of their four major Mission Goals is to "Protect, Restore, and Manage Use of Coastal and Ocean Resources through Ecosystem-Based Management." Regional watersheds affect water quality, which in turn affect habitats essential for all living organisms, as well as human health. "Near Term" actions are to establish regional research coordination and planning teams relevant to Large Marine Ecosystems and coastal regional observing systems, and (2) establish or enhance national research teams to address issues surrounding aquaculture, communities, coral reefs, invasive species, protection and restoration of habitats, protected species and fisheries. NOAA will work with federal, state, and regional science partners in developing the regional research strategies required to develop and implement these systems.

One of the NOAA research milestones for understanding impacts of climate variability and change on marine ecosystems in the Pacific Northwest is to track and improve the ability to forecast, the relationships among climate and variations in coral cover, bleaching, and anthropogenic impacts on coral reefs.

"Models will be constructed to assimilate new observational data, providing forecasts and diagnostic assessments of weather, climate, and conditions in the oceans well beyond those currently produced. These models will encapsulate our understanding of the complex physical and biological processes that constitute the Earth system. To understand, model, and predict the evolution of these processes will require new inter-disciplinary approaches that link climate, weather, water, land, ocean, and biochemical processes."

Two outcomes for the NOAA Ecosystems Mission Goal include;

- Healthy and productive coastal and marine ecosystems that benefit society
- A well-informed public that acts as steward of coastal and marine ecosystems

To evaluate the achievement of the outcomes, the following performance objectives have been developed:

- Increase number of fish stocks managed at sustainable levels
- Increase number of protected species that reach stable or increasing population levels
- Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood
- Increase number of invasive species populations eradicated, contained, or mitigated

• Increase number of habitat acres conserved or restored
• Increase portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues
•Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management.

Coastal Monitoring and Assesment (CCMA) Biogeography team completed an investigation in 2000 to consistently and comprehensively map the distribution of coral reefs and other benthic habitats throughout the main Hawaiian islands. Completion of this project represents a major milestone towards completion of the U.S. Coral Reef Task Force's recommendation to develop shallow-water coral reef ecosystem maps for all U.S. waters by 2007. This is the third set of major coral reef ecosystem maps produced with support from NOAA/NOS Coral Reef Conservation Program. However, the nearshore ocean waters of the Kaho'olawe Island Reserve are conspicuosly absent from this study.

End of Watershed Based Plan for Kaho'olawe

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Internet Resources

http://pubs.usgs.gov/of/
USGS Open File Reports

http://kahoolawe.hawaii.gov
Kaho'olawe Island Reserve Commission Web site

http://eastmauiwatershed.org/
East Maui Watershed Partnership

http://hawp.org/

Hawaii Association of Watershed Partnerships

http://www.hear.org/
Hawaii Ecosytems at Risk

http://hawaiihumpbackwhale.noaa.gov/
Hawaiian Humpback Whale National Marine Preserve

http://cramp.wcc.hawaii.edu/Study_Sites/Kahoolawe/An_Evaluation_of_the_Near shore_Coral_Reef_Resources_of_Kahoolawe/
Coastal Resources And Monitoring Project (CRAMP) paper on Kaho'olawe

http://nrc.noaa.gov/Docs/NOAA_5-Year_Research_Plan_010605.pdf
Research Planning at NOAA, 5-Year Research Plan

www.airborne1.com
Airborne LiDAR and LiDAR Accuracy, An Airborne 1 Perspective

http://www.itl.nist.gov/div898/handbook/index.htm/2006
Engineering Statistics Handbook

http://coralreefs.wr.usgs.gov/sediment.html
USGS Coral Reef Project

APPENDIX A

UXO found on Kaho'olawe

Type	Description
Bombs	2000-pound SAP bomb
	2000-pound MK 84 LDGP
	1000-pound MK 83 LDGP
	500-pound MK 82 LDGP
	250-pound MK 81 LDGP
	Fuel-Air explosive bomb
	40-pound fragment bomb
	Fire bomb
Guided Missiles	TOW surface attack (wireguided)
	Dragon anti-tank
	AGM-12 Bullpup
	AGM-45 Shrike
Submunitions	Butterfly bomblet
	BLU (baseball) bomblet
Pyrotechnics	MK 24 illuminating flare
	MK 45 illuminating flare
	5-inch projectile (illuminating)
Mortars	81 mm
	60 mm
Rockets	2.75 inch rocket
	66-mm light antitank
	weapon (LAW)
	3.5-inch bazooka
	5-inch HVAR rocket
	5-inch Zuni rocket
	4.5-inch barrage rocket
	4.2-inch depth charge
	7.2-inch depth charge
Grenades	40-mm
Small Arms	.22 caliber
	.45 caliber
	5.56-mm
	7.62-mm
	12 gauge shotgun
Projectiles	20-mm
	3-inch
	5-inch
	106-mm
	105-mm
	8-inch
	16-inch
	20-mm

APPENDIX B

Species list for all coral species observed at stations on Kaho'olawe (Cox et al., 1995).

Order	Family	Taxa
Scleractinia	Pocilloporidae	*Pocillopora damicornis* Linneaus, 1758
		Pocillopora meandrina Dana, 1846
		Pocillopora eydouxi Edwards and Haime, 1860
		Pocillopora ligulata Dana, 1846
	Acroporidae	*Montipora verrucosa* sensu Vaughan, 1907
		Montipora patula Verrill, 1864
		Montipora dilitata Studer, 1901
		Montipora flabellata Studer, 1901
		Montipora studeri
	Poritidae	*Porites compressa* Vaughan, 1907
		Porties lobata Dana, 1846
		Porites evermanni Vaughan, 1907
		Porites rus Forskål, 1775
	Siderastreidae	*Psammocora nierstraszi* van der Horst, 1921
		Psammocora stellata Verrill, 1864
	Agariciidae	*Pavona varians* Verrill, 1864
		Pavona duerdeni Vaughan, 1907
		Pavona maldivensis Gardiner, 1905
		Gardineroseris planulata Dana, 1846
	Fungiidae	*Fungia scutaria* Lamarck, 1801
	Faviidae	*Leptastrea bottae* Edwards and Haime, 1849
		Leptastrea purpurea Dana, 1846
		Cyphastrea ocellina Dana, 1864
Alcyonacea	Alcyoniidae	*Sinularia abrupta* Tixier-Durivault, 1970

APPENDIX C

From KIRC Ocean Resource Plan

Common Intertidal Species

Hawaiian Name	Common Name	Taxa
'ohiki	ghost crab	*Ocypode ceratophthalma*
Papa'i	mole crab	*Emerita pacifica*

Invertabrates (Sandy bottom)

Hawaiian Name	Common Name	Taxa
'a'ala'ula (wawae'iole)	Green	*Codium reediae*
'aki'aki	Red	*Ahnfeltia concinna*
Alani	Brown	*Dictyota sp.*
huluhuluwaena	Red	*Grateloupia filicina*
limu kala	Brown	*Sargassum echinocarpum*
lipe'epe'e	Red	*Laurencia succisa*
Lipoa	Brown	*Dictyopteris plagiogramma*
manauea	Red	*Gracilaria coronopifolia*
mane'one'o		*Laurencia nidifica*
pahe'e	Green	*Porphyra sp.*
palahalaha	Green	*Ulva fasciata*
wawae'iole	Green	*Codium edule*

Macroalgae (Hard Bottom)

Hawaiian Name	Common Name	Taxa
'a'ama	crab	*Grapsus grapsus*
ha'uke'uke	shingle sea urchin	*Colobocentrotus atratus*
'opihi 'alinalina	yellow foot limpet	*Cellana sandwicensis*
'opihi makaiauli	black foot limpet	*Cellana exarata*

Invertabrates (Hard bottom)

Hawaiian Name	Common Name	Taxa
aholehole (juvenile)	flagtail	*Kuhlia sandvicensis*
hinalea (juvenile)	wrasses	
kupip'	blackspot sergeant major	*Abudefduf sordidus*
mamo (juvenile)	sergeant major	*Abudefduf abdominalis*
manini (juvenile)	a surgeonfish	
pao'o ('o'opu)	lennies	*Istiblennius zebra*
pao'o ('o'opu)	blennies	*Entomacrodus marmoratus*

Fish (Hard bottom)

Common Subtidal Species

Hawaiian Name	Common Name	Taxa
papa'i kua loa	kona crab	*Ranina ranina*
pu	helmet shell	*Cassis cornuta*

Invertebrates (Sandy bottom)

Hawaiian Name	Common Name	Taxa
aholehole	flagtail	*Kuhlia sandvicensis*
'ama'ama	grey mullet	*Mugil cephalus*
kaku	barracuda	*Sphyraena barracuda*
laenihi	sand wrasse or nabeta	*Xyrichtys pavo*
lai	leatherback	*Scrombroides lysan*
moi	threadfin	*Polydactylus sexifilis*
'o'io	bonefish	*Albula vulpes*
'opelu	mackerel scad	*Decapterus macarellus*
papio	juvenile jacks	*Caranx sp. (family Carangidae)*
uku	grey snapper	*Aprion virescens*
weke	yellowstripe goatfish	*Mulloides flavolineatus*
weke pueo	nightmare goatfish	*Upeneus arge*

Fish (Sandy bottom)

Hawaiian Name	Common Name	Taxa
'a'awa	tableboss	*Bodianus bilunulatus*
aholehole	flagtail	*Kuhlia sandvicensis*
akule	bigeye scad	*Selar crumenophthalmus*
'ala'ihi	red squirrelfish	*Adioryx xantherythrus*
'ama'ama	grey mullet	*Mugil cephalus*
'api	whitespot surgeonfish	*Acanthurus guttatus*
'awela (hou)	Christmas wrasse	*Thalassoma trilobatum*
'aweoweo	bigeye	*Heteropriacanthus cruentatus*
hahalalu (halalu)	juvenile akule	*Selar crumenophthalmus*
hilu	yellowstripe coris	*Coris flavovittata*
hinalea	wrasses	
hinalea lauwili	saddleback wrasse	*Thalassoma. duperrey*
hou	surge wrasse	*Thalassoma purpureum*
humuhumu 'ele'ele	black triggerfish	*Melichthys niger*
humuhumu hi'u kole	pinktail triggerfish	*Melichthys vidua*
humuhumu lei	lei triggerfish	*Sufflamen bursa*
humuhumu mimi	bridled triggerfish	*Sufflamen fraenatus*
'iao	silversides	*Pranesus insularum*
kahala	amberjack	*Seriola dumerilii*

Hawaiian Name	Common Name	Taxa
kaku	barracuda	*Sphyraena barracuda*
kala holo	sleek unicornfish	*Naso hexacanthus*
kala	bluespine unicornfish	*Naso unicornis*
kala lolo	spotted unicornfish	*Naso brevirostris*
kikakapu	butterfly fish	*Chaetodon spp.*
kole	goldring surgeonfishes	*Ctenochaetus strigosus*
kole	black surgeonfish	*Ctenochaetus hawaiiensis*
kumu	whitesaddle goatfish	*Parupeneus porphyreus*
kupoupou	cigar wrasse	*Cheilio inermis*
lai	leatherback	*Scrombroides lysan*
lauhau	fourspot butterfly fish	*Chaetodon quadrimaculatus*
lauhau	teardrop butterfly fish	*Chaetodon unimaculatus*
lau'ipala	yellow tang	*Zebrasoma flavescens*
lauwiliwili	milletseed butterfly fish	*Chaetodon miliaris*
ma'i'i'i	brown surgeonfish	*Acanthurus nigrofuscus*
maiko	bluelined surgeonfish	*Acanthurus nigroris*
maikoiko	whitebar surgeonfish	*Acanthurus leucoparieus*
malamalama	lined coris	*Coris ballieui*
malu	sidespot goatfish	*Parupeneus pleurostigma*
maneoneo	sailfin tang	*Zebrasoma velifrum*
manini	convict tang	*Acanthurus triostegus*
moano	manybar goatfish	*Parupeneus multifasciatus*
moano kea	blue goatfish	*Parupeneus cyclostomus*
me lua	Pfluger's goatfish	*Mulloidichthys pflugeri*
mu	Big Eye Porgy, emperor fish	*Monotaxis grandoculis*
munu	doublebar goatfish	*Parupeneus bifasciatus*
na'ena'e	orangebar surgeonfish	*Acanthurus olivaceus*
nehu	anchovy	*Stolephorus purpureus*
nenue	chub or rudder fish	*Kyphosus biggibus*
nohu	rockfish, scorpionfish	*Scorpaenopsis cacopsis*
nohu 'omakaha	rockfish, scorpionfish	*Scorpaenopsis diabolus*
nunu	trumpetfish	*Aulostomus chinensis*
'omilu	blue trevally	*Caranx melampygus*
'opelu	mackerel scad	*Decapterus macarellus*
paki'i	flounder	*Bothus pantherinus*
paku'iku'i	achilles tang	*Acanthurus achilles*
palani	eyestripe surgeonfish	*Acanthurus dussumieri*
palukaluka	redlip parrotfish	*Scarus rubroviolaceus*
pa'opa'o	yellow ulua	*Gnathanodon speciosus*
papio	juvenile jacks	*Caranx sp. (family*

Hawaiian Name	Common Name	Taxa
		Carangidae)
papio	three spot papio	*Caranx orthogrammus*
ponuhunuhu	stareye parrotfish	*Calatomus carolinus*
po'opa'a	hawkfish	*Cirrhitus pinnulatus*
po'ou	ringtail wrasse	*Chelinius unifasciatus*
pualu	yellowfin surgeonfish	*Acanthurus xanthopterus*
pualu	ringtail surgeonfish	*Acanthurus blochii*
puhi lau milo	undulated moray eel	*Gymnothorax undulatus*
puhi 'oni'o	whitemouth moray eel	*Gymnothorax meleagris*
puhi paka	yellowmargin moray eel	*Gymnothorax flavimarginatus*
puhi uha	white eel	*Conger cinereus*
hu 'ahu'ula (uhu uliuli)	spectacled parrotfish	*Scarus perspicillatus*
uhu	parrotfish	*Scarus sordidus, S. psittaceus*
uku	grey snapper	*Aprion virescens*
ulua	black ulua	*Caranx lugubris*
ulua	pig ulua or butaguchi	*Pseudocaranx dentex*
ulua aukea(?)	white ulua	*Caranx ignobilis*
ulua kihikihi	kagami or threadfin ulua	*Alectis indica*
umaumalei	orangespine unicornfish	*Naso lituratus*
uouoa	false mullet	*Neomyxus chaptalii*
'upapalu	cardinalfish	*Apogon kallopterus*
'u'u	menpachi or soldierfish	*Myripristes amaenus*
'u'u kane pou	spiny squirrelfish	*Adioryx spinifer*
wahanui	gurutsu	*Alphareus furcatus*
weke	yellowstripe goatfish	*Mulloides flavolineatus*
weke 'ula (red weke)	yellowfin goatfish	*Mulloidicthys vanicolensis*
	roi, blue-spotted grouper	*Cephalopholis argus*
	ta'ape, bluelined snapper	*Lutjanus kasmira*
	to'au, snapper	*Lutjanus fulvus*

Fish (Hard bottom)

Hawaiian Name	Common Name	Taxa
'aha'aha	needlefish	*Belone platyura*
'ahi	yellowfin tuna	*Thunnus albacares*
aku	skipjack tuna	*Katsuwonus pelamis*
hapu'upu'u	grouper	*Ephinephalus quernus*
kahala	amberjack	*Seriola dumerilii*
kalekale	von Siebold' snapper	*Pristipomoides sieboldii*
kamanu	rainbow runner	*Elagatis bipinnulatus*
kawakawa	bonito	*Euthynnus affinis*

Hawaiian Name	Common Name	Taxa
kumu	whitesaddle goatfish	*Parupeneus porphyreus*
la'i	leatherback	*Scrombroides lysan*
mahimahi	dolphin fish	*Coryphaena hippurus*
malolo	flying fish	*Cypselurus simus*
malolo	flying fish	*Oxyporhamphus micropterus*
moano kea	blue goatfish	*Parupeneus cyclostomus*
mu	emperor fish	*Monotaxis grandoculis*
ono	wahoo	*Acanthcybium solandri*
'opakapaka	brown snapper	*Pristipomoides filamentosus*
'opelu	mackerel scad	*Decapterus macarellus*
papio	juvenile jacks	*Caranx sp. (family Carangidae)*
papio	three spot papio	*Caranx orthogrammus*
'ukikiki	gindai or snapper	*Pristipomoides znatus*
uku	grey snapper	*Aprion virescens*
'ula'ula koa'e	onaga or red snapper	*Etelis coruscans*
'ula'ula	ehu or red snapper	*Etelis carbunculus*
ulua	black ulua	*Caranx lugubris*
ulua	pig ulua or butaguchi	*Pseudocaranx dentex*
ulua aukea(?)	white ulua	*Caranx ignobilis*
ulua kihikihi	kagami or threadfin ulua	*Alectis indica*
weke 'ula (red weke)	yellowfin goatfish	*Mulloidicthys vanicolensis*

Fish Offshore

APPENDIX D. ADDENDUM TO THE ASSESSMENT AND PROTECTION PLAN FOR THE KAULANA AND HAKIOAWA WATERSHEDS ON KAHO’OLAWE, HAWAI’I

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 Assessment and Protection Plan for the Kaulana and Hakioawa Watersheds on Kaho'olawe, Hawai'i to include activities and additional guidance related to the removal of invasive plants and animals, as well as the reintroduction of native species. In addition to including these activities in the menu of best management practices (BMPs) that are eligible for 319 funding, this addendum provides an approach for calculating the pollutant reductions associated with these restoration activities. These pollutant reductions can be used by project managers and sub-grantees to develop individual project plans and by HDOH to calculate annual pollutant reductions for the broader NPS program.

Pollutant Loading from Invasive Species

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

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

Pollution Control Practices

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

Table 1 below includes BMPs that can address pollutant loading caused by invasive species.[2] As shown by the large number of potential BMPs, vegetative plantings are a common element of many BMPs; ensuring that native species are used (and in the

[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.

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

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

Calculating Pollutant Reductions

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

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

Description of the InVEST Model

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

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

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

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

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/

Soil Erodibility: A map showing the soil erodibility in the watershed. Soil erodibility, also called K factor, is the likelihood of soil particles to erode and be transported downstream by precipitation or runoff. The soil erodibility raster must be in units of t · h · ha / (ha · MJ · mm).	Raster	Soil data, including K factors, is available from the Soil Survey Geographic Database (SSURGO).[9] This database provides raster data of soil type in an area of interest, and a table showing the K factor of each soil type. Raster data of K factors in a projected coordinate system will have to be generated by combining the soil raster data and the K factor table.
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.

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

Other Required Data Inputs		
Input Name and Description	**Data type**	**Suggested Input Value**
Threshold Flow Accumulation: The minimum number of pixels that flow into another pixel for it to be classified as a stream.	Number of pixels	This value should be determined by the user via trial and error. Users should test different values until the streams on the output maps resemble the streams in the watershed.
Borselli k Parameter: A calibration parameter in the sediment delivery ratio equation.	Number	This value is based on watershed location. Table 3 shows the Borselli k Parameter by location.
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	.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.

indicates best 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
Kau Basalt	0.001	Koloa Volcanics	1
Laupahoehoe Volcanics	0.1	Paniau Basalt	0.1
Ninole Basalt	1	Waimea Canyon	0.1
Pololu Volcanics	1	--	--
Puna Basalt	0.001	--	--

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

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

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

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

It is crucial that multiple lines of evidence are considered when determining where BMPs should be implemented. The normalized difference vegetation index (NDVI)[19] is a satellite-based measurement that could be useful in identifying areas with minimal vegetation which may be susceptible to increased erosion. The NDVI quantifies vegetative health and density. NDVI values closer to positive 1 indicate the presence of abundant and healthy vegetation, and a value closer to 0 indicates there is less vegetation (NASA, 2025). Looking at NDVI data in a raster format would allow a user to visualize areas within the watershed that have little vegetation or unhealthy vegetation, indicating that the area could benefit from BMP implementation. If the resolution of the NDVI data is a lower resolution, it may be

[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.

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:

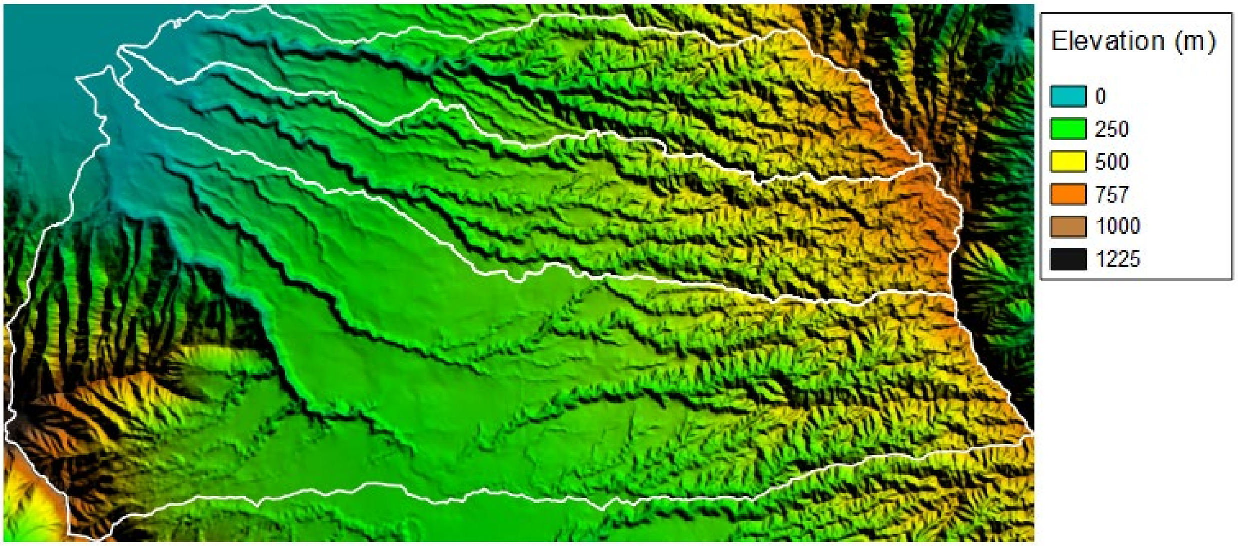
- The P factors in the biophysical table should be decreased for each land use/land cover type where an erosion reduction practice will be implemented.
- Alternatively, the land cover/land use raster should be edited to show how the land use/land cover would change with erosion reduction practices implemented.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

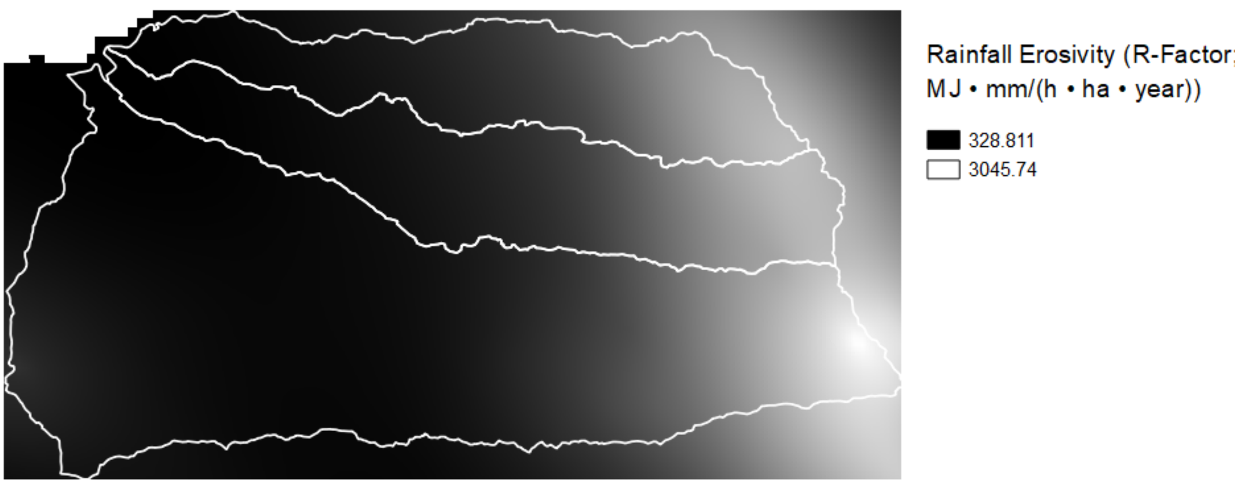
<u>**Example Use of the Procedure**</u>

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

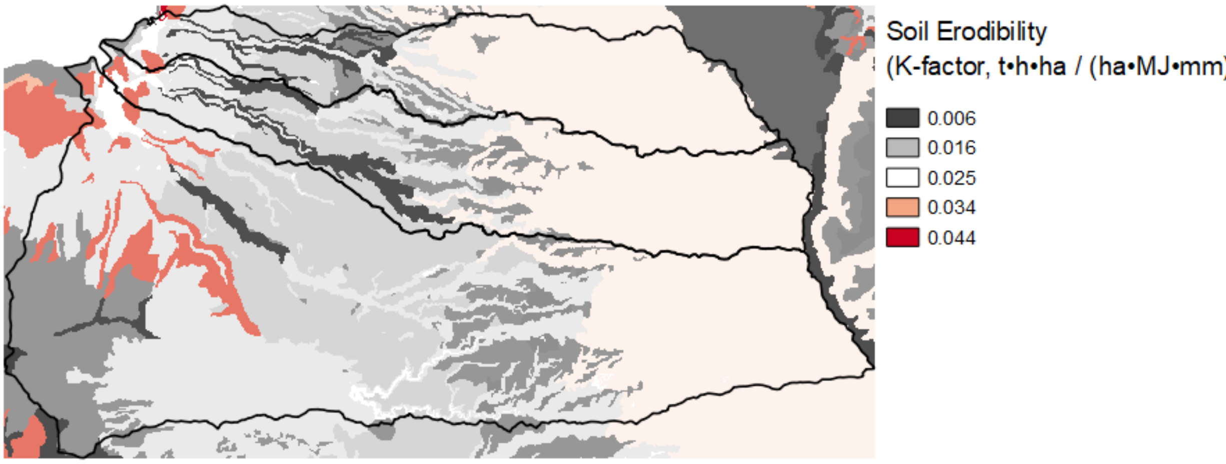
- Elevation Map: A DEM raster showing elevation in meters in the Kaiaka Bay and the surrounding area. This raster is a valid input for the InVEST model because the elevation is in meters and it extends beyond the Kaiaka Bay watershed boundary.



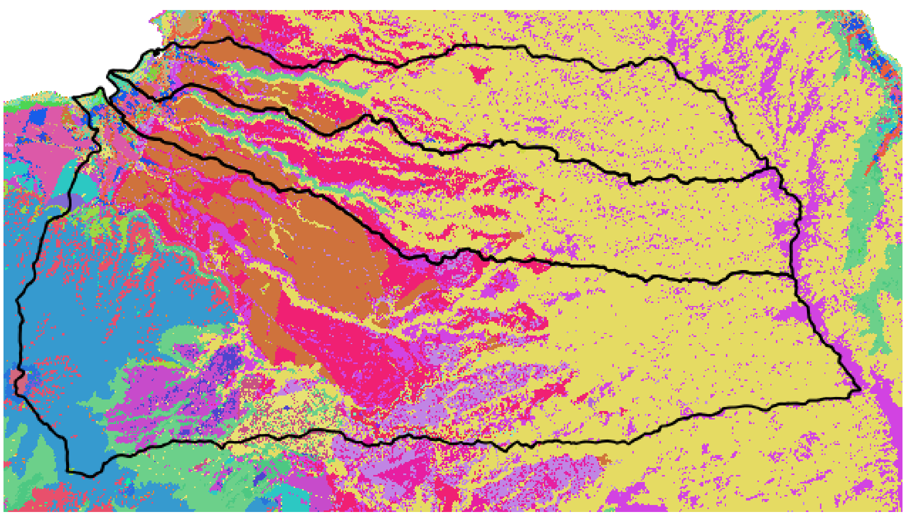
- Rainfall Erosivity: A rainfall erosivity map in raster format showing the rainfall erosivity throughout the Kaiaka Bay watershed in MJ • mm/(h • ha • year), the units required by the model.



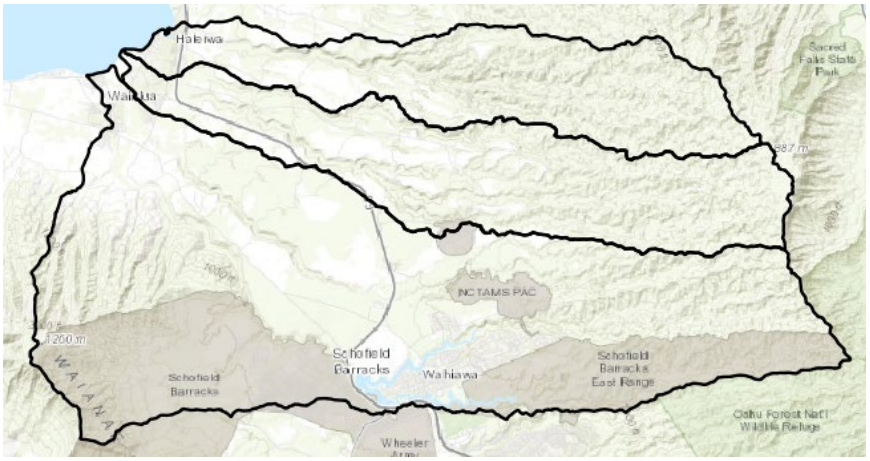
- Soil Erodibility: A map showing soil erodibility, or K factors, within the Kaiaka Bay watershed in raster format. The values in the raster format are in the proper units for the model, t • h • ha / (ha • MJ • mm).



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



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



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

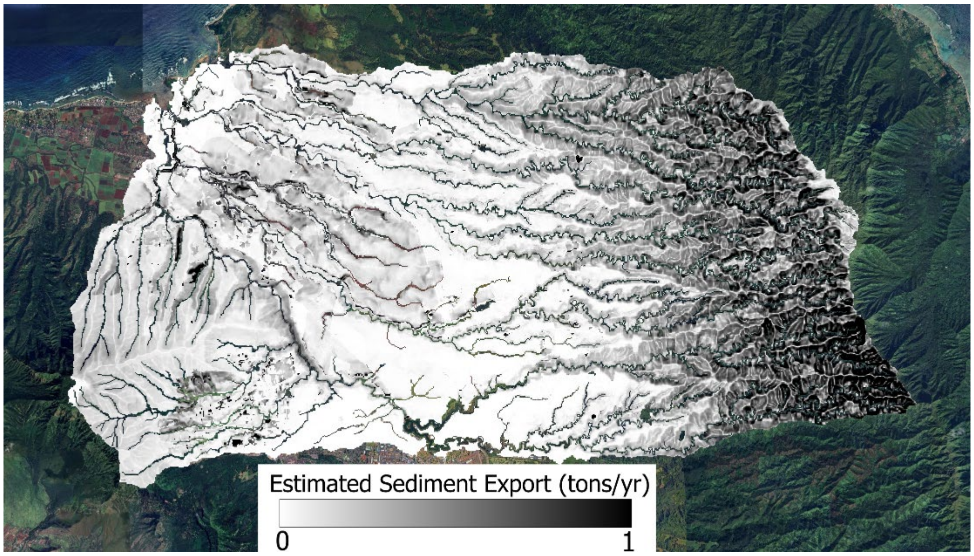
- Borselli k Parameter: The Borselli k parameter for this model run is 2.5, the value for all watersheds on Oahu.

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

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

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

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



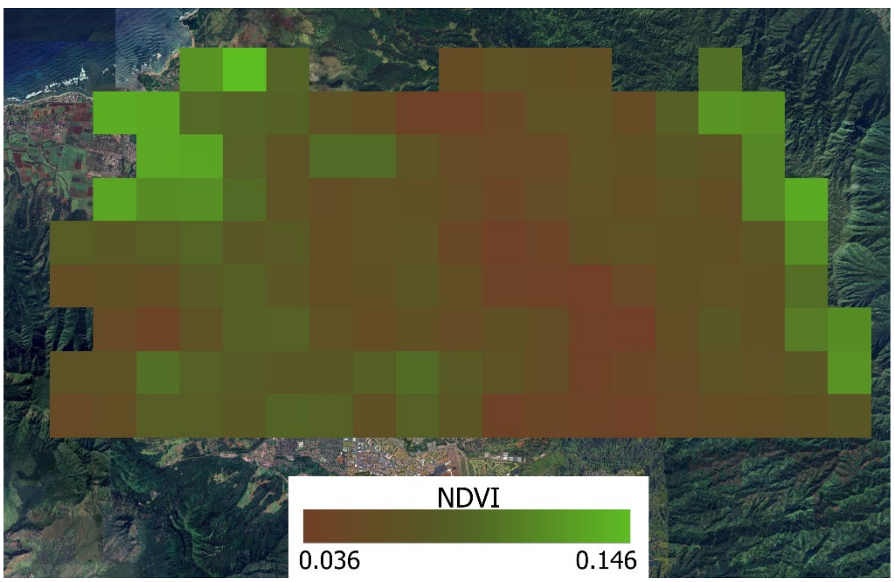
This raster indicates that the model expects the highest amount of sediment export to occur at the higher elevations of the watershed, but as discussed in the Step-by-Step Procedure section, the InVEST model tends to overestimate sediment export in high elevation areas. For this reason, multiple lines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

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

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

Class	Edge of Stream Sediment Load (lbs/acre/year)
Estuarine Scrub/Shrub Wetland	0.23
Unconsolidated Shore	0.00
Bare Land	4.42
Open Water	0

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



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

InVEST model run, the NDVI index raster, satellite images, drone footage, interviews and documentation from someone on site should all be carefully considered when determining where BMPs should be implemented.

Useful Resources and Materials

To supplement the information included in this 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