FINAL

Pelekane Bay Watershed Sediment Runoff Analysis

Contract No. W9128A-06-D-0001
South Kohala, Hawai'i

Prepared For:

U.S. Army Corps of Engineers
Honolulu Engineer District

Prepared By:

Group 70 International, Inc.
Honolulu, Hawai'i

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innovation through engineering & scientific excellence

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EXECUTIVE SUMMARY

Land-based sources of pollutants, such as sediment and nutrients, are one of several factors threatening the quality of coastal waters and coral reef ecosystems in Hawai'i. The marine environment and coral reefs of Pelekane Bay have been stressed because of diminished water quality. Pelekane Bay, located on the north-western coast of the island of Hawai'i, has been subjected to large-scale alterations in the watershed over the last 200 years and the construction of the Kawaihae Harbor. In 1992, the Mauna Kea Soil and Water Conservation District (MKSWCD), an agency of the State of Hawai'i, initiated the *Pelekane Bay Watershed Management Project*, and in result over the years many management plans, programs, and monitoring activities have been implemented.

The purpose of this study was to 1) estimate average annual sediment yield; 2) estimate sediment yield from historical storm events; 3) characterize Pelekane Bay sediment deposit; and 4) define critical watershed issues.

An erosion prediction and hydrologic model, N-SPECT, was used to determine the amount of runoff and sediment yield for the watershed. The watershed-scale model includes the parameters of rainfall, terrain characteristics, soil type, and land cover. Rain gauge data provided historical data to simulate realistic local rain depth, duration and intensity data.

The average rainfall in the modeled storms varied from 0.67 to 3.99 inches and displays an exponential capability of larger storms to cause more erosion. Model results showed that approximately 322 tons of sediment was delivered to Pelekane Bay during the largest storm, where 3.99 average inches of rainfall occurred. At half this average rainfall amount of 2.06 inches, less than a tenth (29.8 tons) the sediment load was delivered. Direct model results for annual sediment load (erosion) to Pelekane Bay were higher than judged to be reasonable (~15,000 tons average per year) and an alternate approach to estimate annual load was used. Annual rainfall records for the area were used to create an average rainfall year including fractional day percentages for storms with longer return periods. A sediment production regression was developed from model runs and this regression was applied to the "average" rainfall year to yield an annual average sediment load of 4,222 tons. Of this erosion quantity, 3,502 tons (83%) was the result of runoff from storms with greater than 1-year return periods, i.e. very large and relatively rare storms were responsible for the largest quantity of sediment erosion in the watershed. The total quantity of material eroded to Pelekane Bay in the past half century is estimated to be 50 times the annual load (4,222 tons) or approximately 211,100 tons.

As part of the study, a bathymetry survey was also conducted to determine the physical impact of this sediment load to Pelekane Bay. The total quantity of accumulated sediments within the surveyed area of Pelekane Bay was measured to be approximately 1,264,000 cubic feet, or 46,800 cubic yards, with an estimated weight (@ 1.33 tons / cy) of 62,300 tons. Deposition of sediments can be expected to continue within Pelekane Bay as the delta continues to build seaward until it reaches an equilibrium point where long shore currents transport light sediments away, and heavier sediments begin contributing to the pre-historic sand channel / stream bed through the reef to the deep ocean slopes of the island.

In summary, the analyses demonstrated that larger storms, with return periods greater than one year, had a disproportionately large impact upon sediment erosion as compared to smaller storms. Erosion was also found to occur along parallel rills and gullies (as opposed to quickly coalescing into dry stream beds with protective stone beds). Stopping the upward development of the rills and gullies would appear to be a good strategy. In addition, the quantity of rainfall in the lower, less vegetated, more arid portions of the watershed appears to be more directly correlated with erosion as compared to similar rainfall quantities in the upper watershed, where vegetation cover is more dominant. Therefore, erosion prevention measures should concentrate in the lower watershed area as these soils have the greatest potential for erosion during the large storm events.

Recommended watershed management activities for Pelekane Bay Watershed include installing best management practices; community educational efforts to promote local stewardship of the watershed; implementation of existing resource management native species re-vegetation and sediment management plans; improving grazing management; and implementation of monitoring activities to measure the effectiveness of watershed restoration and protection efforts. The results of this study can be used as a screening tool to assist with watershed management planning for erosion control and resource management for Pelekane Bay Watershed. Further use of N-SPECT for additional research and studies is recommended to help understand and predict the impacts of management decisions on water quality and ultimately the implications of different policy scenarios.

APPENDICES

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

(Ann)AGNPS	Annual Agricultural Nonpoint Source Pollution Model
BIWCG	Big Island Wildfire Coordinating Group
BMP	Best Management Practices
CES	University of Hawai'i, Cooperative Extension Service
CN	Curve number
CRAMP	Hawai'i Coral Reef Assessment and Monitoring Program
DEM	Digital Elevation Model
DHHL	State of Hawai'i, Department of Hawaiian Home Lands
DLNR	State of Hawai'i, Department of Land and Natural Resources
DOH	State of Hawai'i Department of Health
EPA	U.S. Environmental Protection Agency
Flo-2D	Flow 2D Hydraulic Model with sediment transport module
ft	Feet
GIS	Geographic Information Systems
HAWP	Hawai'i Association of Watershed Partnerships
hr	Hour
KDDH	Kawaihae Deep Draft Harbor
kg	Kilograms
L	Liter
LIDAR	Light Detection and Ranging
m	Meter
mg	milligram
min	Minute
MKSWCD	Mauna Kea Soil and Water Conservation District
MUSLE	Modified Universal Soil Loss Equation
N	North
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Services
NRCS	Natural Resource Conservation Service
N-SPECT	Nonpoint Source Pollution and Erosion Comparison Tool
NWS	National Weather Service
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RUSLE	Revised Universal Soil Loss Equation
SHOALS	Scanning Hydrographic Operational Airborne LIDAR Survey
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
W	West
WEPP	Watershed Erosion Prediction Project
WHWMO	West Hawai'i Wildfire Management Organization
WRDA	Water Resources Development Act
yr	Year

TABLE OF CONVERSIONS

Unit	Multiplied by	Equals to
Length		
inches	2.54	centimeters
foot	30	centimeters
yards	0.91	meters
miles	1.6	kilometers
Area		
sq. inches	6.5	sq. centimeters
sq. feet	0.09	sq. meters
sq. yards	0.8	sq. meters
sq. miles	2.6	sq. kilometers
acres	0.4	hectares
Mass (Weight)		
ounces	28	grams
pounds	0.45	kilograms
short ton	0.9	metric ton
Volume		
teaspoons	5	milliliters
tablespoons	15	milliliters
fluid ounces	30	milliliters
cups	0.24	liters
pints	0.47	liters
quarts	0.95	liters
gallons	3.8	liters
cubic feet	0.03	cubic meters
cubic yards	0.76	cubic meters
Temperature		
Fahrenheit	Subtract 32, then multiply by 5/9ths	Celsius

1. INTRODUCTION

1.0 INTRODUCTION

1.1 AUTHORITY

This study is being conducted under Section 1135 of the Water Resources Development Act (WRDA 1986 PL99-662), Ecosystem Restoration for the United States Army Corps of Engineers (USACE), Honolulu District. The Mauna Kea Soil and Water Conservation District (MKSWCD) is the local sponsor.

1.2 STUDY AREA LOCATION

Pelekane Bay is located immediately south of the Kawaihae Deep Draft Harbor, in the South Kohala District, on the northwest coast of the island of Hawaiʻi *(Figure 1.1 and 1.2)*. The watershed is located on the slopes of Kohala Mountain, extending from the Kohala Forest Reserve at the top of the mountain down to Pelekane Bay, just south of Kawaihae Harbor. The watershed is about 10,000 acres in size and has an elevation range from sea level to 5,300 feet. The watershed is bordered by the Makahuna Gulch to the north and Highway 19 (Kawaihae Road) to the south. There are 6 named gulches within the watershed – Makahuna, Palihae, Luahine, Waiakamali, Makeāhua, and Pauahi (MKSWCD, 2005). There are no perennial streams, other than within the Kohala Forest Reserve. Streamflow is limited to flows in the gulches and overland during rainfall events in all but the highest parts of the watershed. The watershed is typically dry except during periods of heavy rainfall. Today, Parker Ranch is the primary user of the land, mostly for cattle grazing *(Figures 1.3 and 1.4)*.

1.3 PROBLEM STATEMENT

According to the State of Hawaiʻi Department of Health (DOH), Pelekane Bay has been identified as an impaired water body on DOH's 2004 Section 303(d), List of Impaired Waters due to high levels of turbidity from sediment runoff and accumulation. In addition, the Pelekane Bay Watershed was identified in the Hawaiʻi Unified Watershed Assessment Plan as a Category 1 Priority Watershed, one of the State's watersheds in most urgent need of restoration (DOH, 2004). Erosion control and resource management for coral reef protection, enhanced recreational usage and historic/cultural preservation have been identified as crucial restoration action strategies for Pelekane Bay.

In 2003, water samples were collected from three sites at Pelekane Bay by DOH, including Pelekane Beach, Pelekane North and Pelekane South. According to DOH, the samples recorded were not in compliance with State water quality standards for turbidity *(Tables 1.1 and 1.2)*. Pelekane Beach is considered estuary waters because of its salinity of less than 32 parts per thousand (ppt) and turbidity was recorded at almost 18 times the allowable water quality standard (26.5 vs. 1.5 standard). Pelekane North and South are both considered embayment waters, according to DOH. Water samples from Pelekane North and South were also not in compliance with State water quality standards for turbidity (DOH, 2004).

Table 1.1 Pelekane Bay Coastal Water Quality Monitoring Results (DOH, 2003)

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

Table 1.2 Hawai'i Water Quality Standards for Embayment and Estuary Waters for Turbidity

Parameter	Standard	Geomean*	10%**	2%***
Turbidity (NTU)	Wet	1.5	3	5
	Dry	0.4	1	1.5

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

1.4 STUDY OBJECTIVES

The objectives of this study are as follows:

- Estimate Average Annual Sediment Yield. Estimate the average annual sediment yield into Pelekane Bay as a result of rainfall-runoff from contributing drainage areas. *(Section 3.0 & 4.0)*
- Estimate Sediment Yield from Historical Storm Events. Provide an estimate of sediment yield into Pelekane Bay for historical storm events since the development of Kawaihae Harbor coral flats in the 1950's. The estimate will be calculated based on available existing information equal to or exceeding the 10-year, 1-hour rainfall intensity. In addition, sediment yield for at least two, 2-year, 24-hour rainfall events will be analyzed. The selection of specific storm events to be evaluated for the model will be verified in the initial phase. *(Section 3.0 & 4.0)*
- Characterize Pelekane Bay Sediment Deposit. Provide a preliminary estimate of the extent and volume of accumulated sediment in Pelekane Bay and associated sand bar by conducting a limited bathymetric survey to verify existing SHOALS data and obtain sediment samples from cores in representative locations. Conduct sampling and analysis of selected sediment core samples to characterize material grain size. *(Section 5.0)*
- Define Critical Watershed Issues. Provide a summary of critical watershed issues relating to resource conditions, human activities, recognized problem conditions, further study requirements, mitigation project definition, and management recommendations for improving the Pelekane Bay Watershed. *(Section 7.0)*

1.5 PLANNING APPROACH: GIS-BASED SEDIMENT RUNOFF ANALYSIS

The National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center has developed a spatially distributed (raster-based) pollutant and sediment yield model called the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT). To meet the objectives of this study, N-SPECT was applied and used to examine the relationship between parameters including rainfall, terrain characteristics, soil types, vegetation cover and existing drainage routes and systems in order to assess spatial patterns of runoff and erosion. N-SPECT is a geographic information systems (GIS) tool implemented in ESRI ArcGIS software and requires Spatial Analyst extension.

The N-SPECT model recently adapted for Hawai'i's geology and rainfall patterns was selected over a variety of other runoff models because of its relative ease of use and adaptive GIS platform. To minimize the amount of modeling required to predict average future annual sediment loads, a modeling option was used that creates a statistically average rainfall year. The synthetic rainfall year was calculated since 1950, obtained from the Rainfall-Frequency Atlas of the Hawaiian Islands (US Weather Bureau, 1962). Surface runoff was calibrated with the rainfall data for major storm events equal to or exceeding the 10-year, 1-hour rainfall intensity in addition to 2-year, 24-hour rainfall events. For each specific storm and annual sediment yield calculation, the input parameters were varied according to the rainfall event on the date of the storm. Runoff calibration was followed by sediment calibration.

To document the long term physical impact of sedimentation on Pelekane Bay the present-day bathymetry of the bay was compared to the bathymetry measured prior to the construction of Kawaihae Deep Draft Harbor (KDDH) in 1962. Sediment and mud core samples were obtained and tested for grain size analysis to help understand the distribution of sediments carried by runoff into the bay.

The results of N-SPECT analyses are intended to be used as screening tools to help assist with watershed management planning for resource managers, land owners, government and local decision makers. Outputs of the N-SPECT analyses can help resource managers and planners target areas needing further management and attention for Pelekane Bay Watershed. In conclusion, an assessment of critical watershed issues defined for Pelekane Bay Watershed is provided, which includes recommendations on erosion control, grazing management and vegetation restoration. As a part of this assessment, meetings and coordination with stakeholders, Federal, State and County agencies, and direct communication with land owners, organizations and individuals with interests in the watershed were conducted.

Working in concerted effort with Mauna Kea Soil and Water Conservation District (MKSWCD), the objectives of this study are consistent with that of the U.S. Environmental Protection Agency (EPA) and the Water Quality Division of the State of Hawai'i Department of Health (DOH).

1.6 INITIATIVES TO PROTECT PELEKANE BAY

In 1992, MKSWCD initiated the *Pelekane Bay Watershed Management Project*, as part of the *Kawaihae Coral Reef Transplant Project*, in order to reduce soil erosion in the watershed by improving land management practices and restoring vegetation cover. The MKSWCD was funded through a variety of grants. In 1994 and 1998, the State of Hawai'i Department of Health (DOH) funded installation of best management practices to reduce polluted runoff and community education efforts to promote local stewardship of the watershed. Additional funding from United States Department of Agriculture's (USDA) Natural Resource Conservation Service (NRCS) supported development of the Pelekane Bay Coordinated Resource Management Plan (MKSWCD, 1998), as well as fire management, native species re-vegetation and sediment management plans (MKSWCD, 2001 (A, B, & C). In 2005, the Pelekane Bay Watershed Management Plan was prepared, which includes a *Watershed Assessment and Inventory* (MKSWCD, 2005). The 2005 plan also provides an update to the comprehensive watershed management program of the Coordinated Resource Management Plan (1998) and *Pelekane Bay Watershed Management Project*. Today, the district has also undertaken a number of monitoring activities to measure the effectiveness of their watershed restoration and protection efforts, such as erosion monitoring, vegetative cover monitoring, stubble height monitoring, and water quality monitoring.

Agencies and land owners currently involved with watershed management for the Pelekane Bay Watershed include:

- Mauna Kea Soil and Water Conservation District (MKSWCD)
- Queen Emma Land Company, land owner
- Parker Ranch, lessee
- USDA's Natural Resources Conservation Service (NRCS)
- U.S. Geological Survey (USGS)
- U.S. Army Corps of Engineers (USACE)
- National Oceanic Atmospheric Administration (NOAA)
- University of Hawaiʻi, Cooperative Extension Service (CES)
- University of Hawaiʻi, Water Resources Center
- Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP)
- University of Hawaiʻi at Hilo
- State of Hawaiʻi, Department of Land and Natural Resources (DLNR)
- State of Hawaiʻi, Department of Health (DOH)
- State of Hawaiʻi, Department of Hawaiian Home Lands
- County of Hawaiʻi, Planning Department
- National Park Services (NPS), Puʻukoholā Heiau National Historic Site
- Kohala Mountain Watershed Partnership
- Waimea Community Association

Figure 1.1 Location Map, Pelekane Bay Watershed

Figure 1.2 Aerial Photo of Pelekane Bay, USACE 2004

Figure 1.3 Pelekane Bay Watershed Looking Towards Kawaihae Harbor and Pelekane Bay to the Left

Figure 1.4 Kawaihae Harbor (right), Small Boat Harbor (left), Looking from the Trail Adjacent to Puʻukoholā Heiau

2.0 BACKGROUND AND EXISTING CONDITIONS

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2.1 PAST AND PRESENT LAND USE

In the past, Pelekane Bay was a historical and cultural center for native Hawaiians, as well as a breeding ground for many indigenous reef fish species. In ancient Hawai'i, the traditional system of land and water tenure and management centered on the *ahupua'a*, a wedge of land that extended from the mountains to the ocean and often followed natural watershed divisions. Land and water resources were under the control of the *ali'i* (chief), providing an efficient means of constructing land and water infrastructure. On the leeward side of Kohala Mountain, the Hawaiians terraced and farmed the land in dry land agriculture, carrying water to these drier lands in *auwai* (irrigation ditch or canal), as evidenced by the remnants of extensive rock work still visible today (Vitousek *et al.* 2004). This area is known as the Kohala Field System.

Early historical accounts indicate that the upper slopes of the Kawaihae watershed was comprised of dense hardwood forests in contrast to the dry relatively barren coastal zone. Water flowed continuously from the two major gulches, Makeāhua and Makahuna, which drain the majority of the watershed and enter the ocean at Pelekane Bay. Beginning in the early 1800's, sandalwood was extensively harvested from the upper slopes of the watershed (Kawaihae Uka) and in the Waimea area. This activity lasted into the 1830's resulting in extensive deforestation. In addition to large-scale removal of upland forests, cattle were introduced by Captain George Vancouver in 1793. The cattle, protected by a kapu, rapidly increased in numbers, running wild and grazing the land. By the 1850's the number of wild cattle was estimated at 10,000 head. Since the late 19th century the land has been used for cattle operations through leases and subleases to Kahuā and Parker Ranches.

Construction of Kawaihae Deep Draft Harbor was completed in 1962 and enlarged in 1973 for the State of Hawai'i by the U.S. Army Corps of Engineers (USACE) *(Figure 2.1 and 2.2)*. The harbor was constructed on a shallow coral reef foundation that extended 4,000 feet offshore and laterally more that a mile along the coast. The large fringing reef adjacent to Pelekane Bay was dredged and deposited adjacent to harbor, which created a filled area, referred to as the "coral flats." In 1969, as part of Project Tugboat, the Army's Nuclear Cratering Group used high explosives to excavate the small-boat harbor located 980 feet north of Pelekane and to widen the harbor's entrance and basin. In 1998, the construction of the Kawaihae Small Boat Harbor project by the USACE for the State, including a breakwater, basin, and channel features, was completed. The project involved the use of transplantation of corals as a means to mitigate the damage to coral reefs, which were monitored by the University of Hawai'i, Institute of Marine Biology. The large-scale transplantation of coral was successful with little mortality caused by the transplanting process itself. The KDDH inner basin is protected by an 850-foot long breakwater, which extends southeast from the main harbor.

Parker Ranch is the primary land user in the Pelekane Bay Watershed and has been since the early 1900's. The Ranch leases land from Queen Emma Land Company and the State of Hawai'i for cattle grazing *(Figure 2.3)*. Queen Emma Land Company, a nonprofit organization, owns about 60% of the watershed. The State of the Hawai'i, through the Departments of Land and Natural

Resources (DLNR), and Hawaiian Home Lands (DHHL), is the second largest land owner. The remaining lands are held by a number of smaller landowners.

Issues relating to watershed restoration for Pelekane include management of existing land uses, the ability to implement corrective actions in the watershed, and maintenance of partnerships in watershed management and restoration projects. Currently, the major land owners of Pelekane Bay Watershed are partners with the Kohala Mountain Watershed Partnership, which is part of the Hawai'i Association of Watershed Partnerships (HAWP). The HAWP was established in 2003 to build public and private support for watershed protection. More than 50 public and private partners — representing nine watershed partnerships and six islands — belong to the Association.

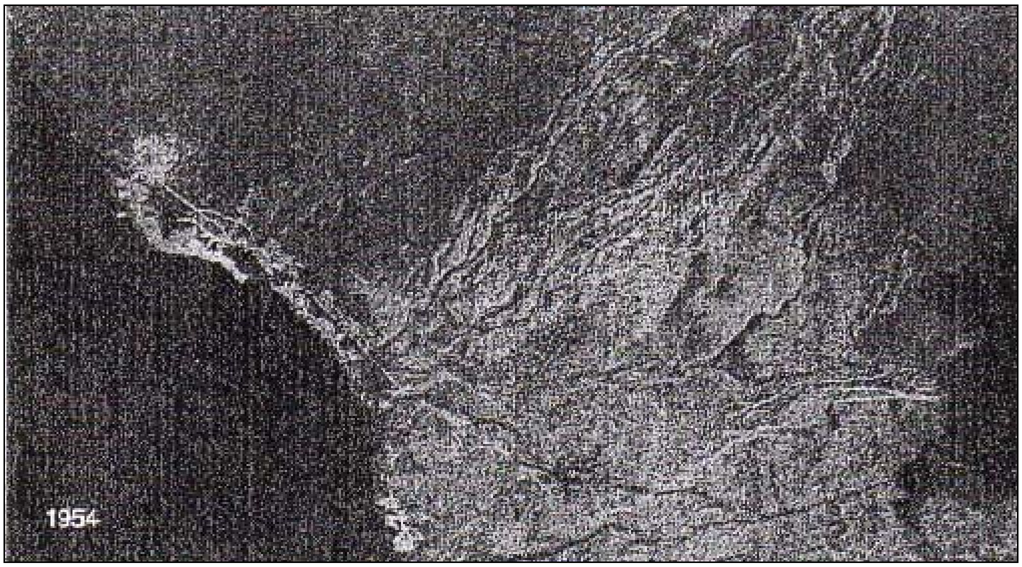


Figure 2.1 Kawaihae Bay Pre-Harbor Construction 1954 (Air Surveys Hawai'i, 1954).

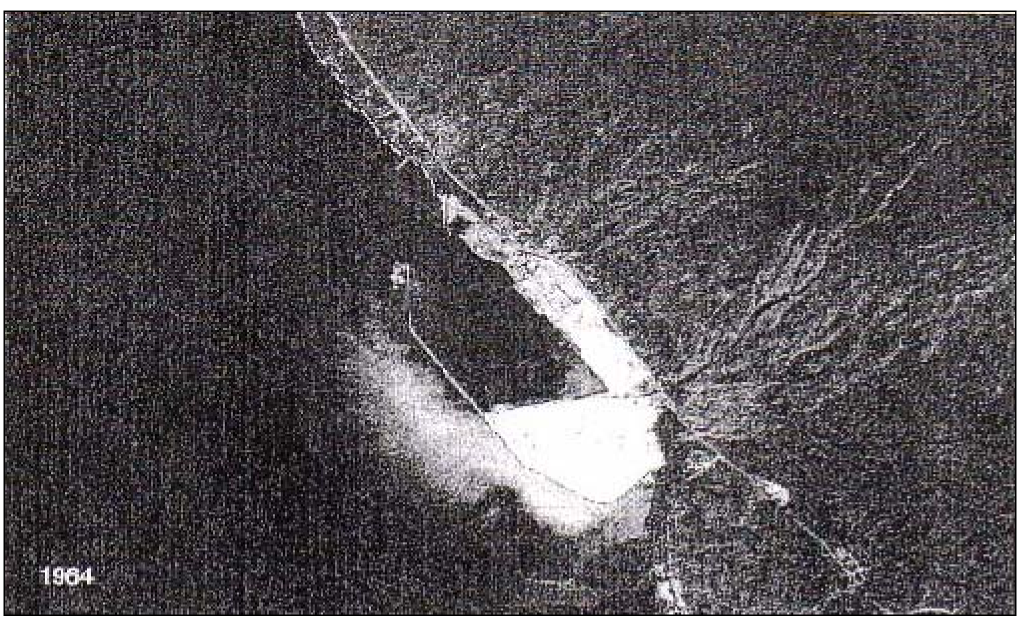


Figure 2.2 Kawaihae Deep Draft Harbor Post-Construction 1964 (Air Surveys Hawai'i, 1964).

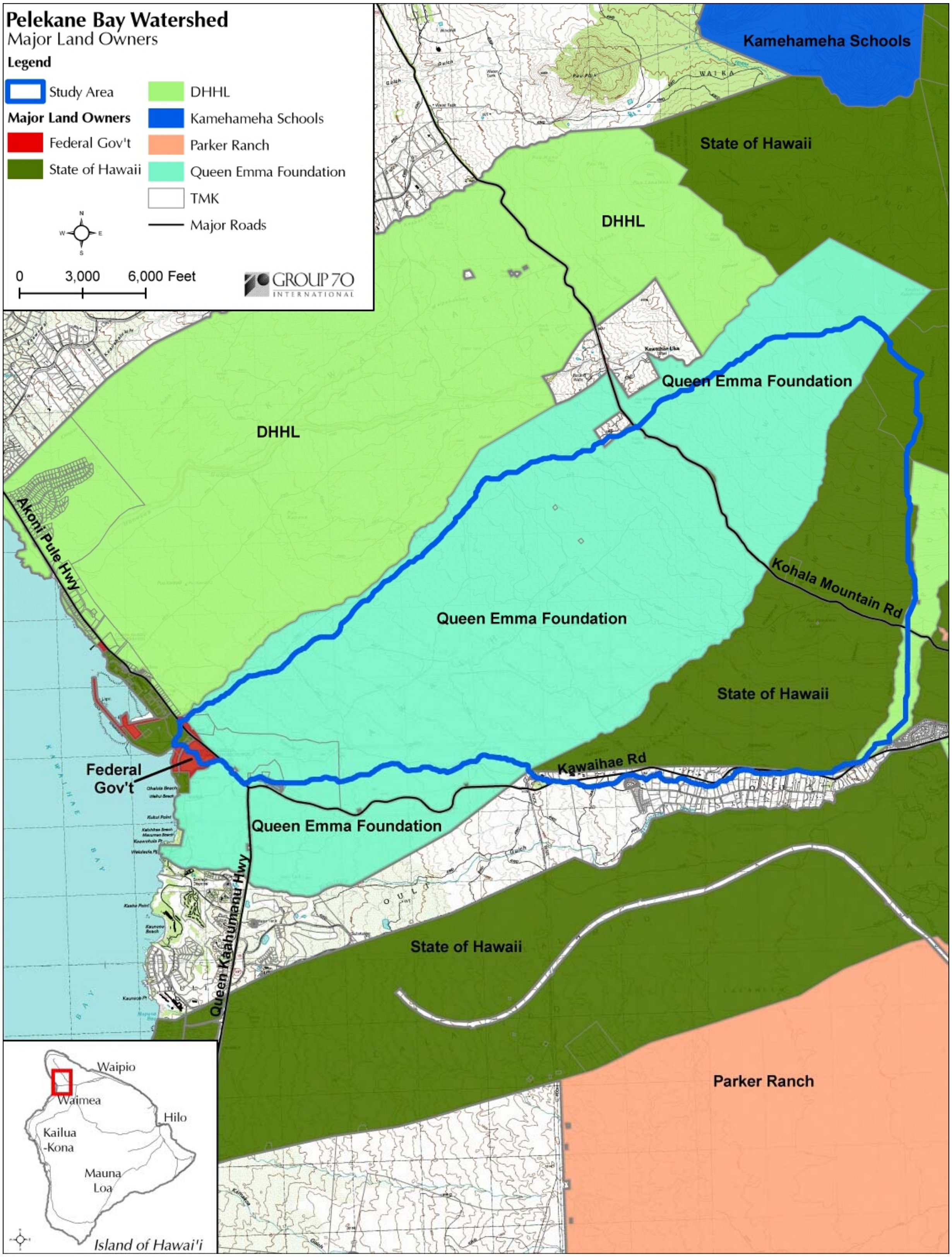


Figure 2.3 Major Land Owners, Pelekane Bay Watershed

2.2 HISTORIC AND CULTURAL RESOURCES

Four historic sites, Puʻukoholā Heiau *(Figure 2.4)*, Mailekini Heiau, Hale o Kapuni Heiau and the John Young Homestead are located at Pelekane Bay. Built around 1790-91 by Kamehameha I, Puʻukoholā Heiau "Hill of the Whale" was constructed for ceremonies related to war and was a place of worship central to Hawaiian religious beliefs *(Figures 2.5)*. Puʻukoholā Heiau is considered the most important structure associated with Kamehameha's foundation of the kingdom of Hawaiʻi. As part of the Puʻukoholā Heiau site, the John Young Homestead contains three Western style stone buildings and a number of traditional Hawaiian structures. During Kamehameha's reign, John Young became an advisor to King Kamehameha and was granted land by the king at Kawaihae, adjoining Puʻukoholā, for a home. Today, the remains of John Young's Homestead may be toured at the site. Located immediately below Puʻukoholā Heiau is another heiau, Mailekini Heiau, which existed prior to the construction of Puʻukoholā, and is an older site probably representing the island warfare of the period prior to 1790 and constructed by the district ruling chief. During the Kamehameha era, Mailekini was fortified as a fort and remains restored today. Submerged just offshore below Mailekini Heiau are the ruins of another sacred site, the Hale o Kapuni Heiau. Hale o Kapuni Heiau is believed to have been dedicated to the shark gods. According to historical descriptions, when the tide was low, big boulders used to come out and sacrifices would be laid to be devoured by the shark gods. The underwater heiau, now covered by silt, has never been located or documented through underwater archeology. In 1972, the Puʻukoholā Heiau National Historic Site was declared and these historic sites are managed by the National Park Service (NPS) *(Figures 2.6)*.

Figure 2.4 Puʻukoholā Heiau National Historic Site, Pelekane Bay (National Park Service, 2004)

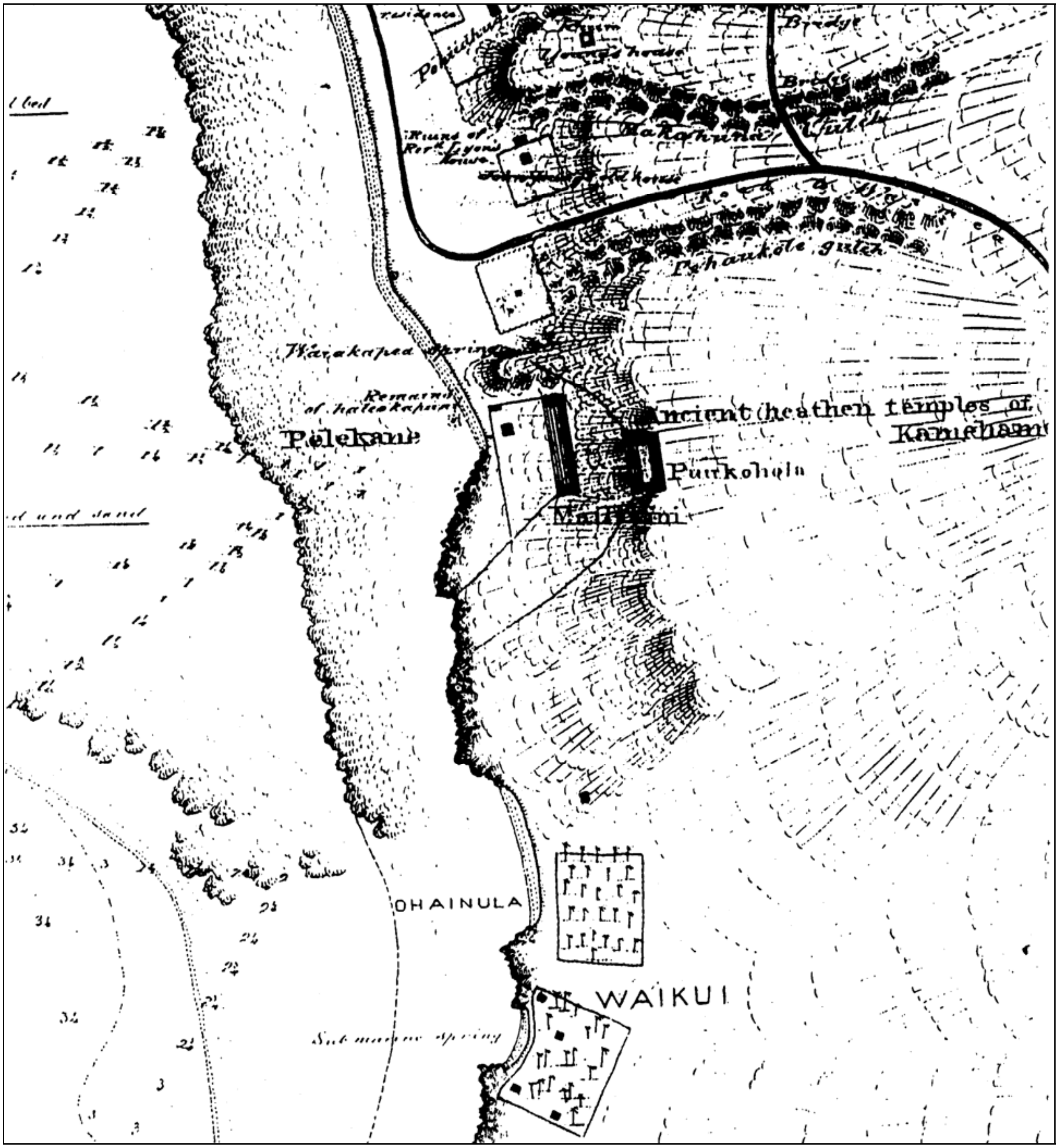


Figure 2.5 Portion of Historical Map of Kawaihae, July 1883, showing Pelekane (Kelly, 1974).

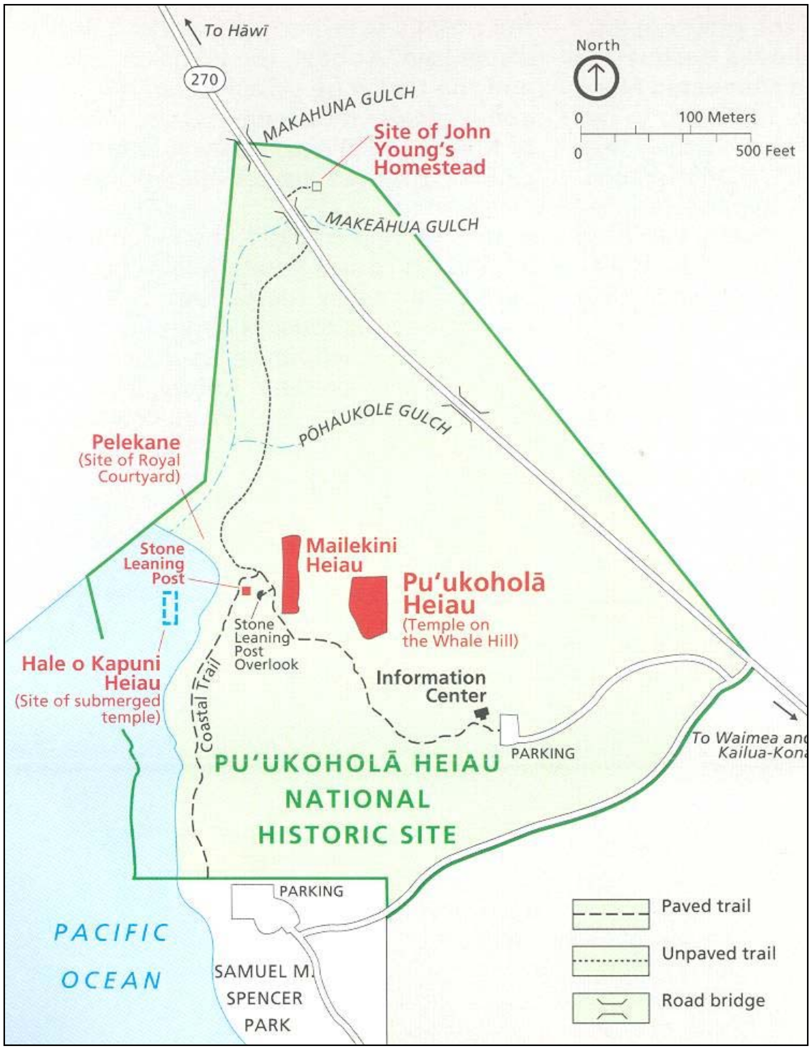


Figure 2.6 Pu'ukoholā Heiau National Historic Site, showing the former location of Hale O Kapuni Heiau in Pelekane Bay (National Park Service, 2002).

2.3 CLIMATE

The general climate of Pelekane Bay Watershed is very arid. Average annual temperature in the area ranges between 55 degrees F and 95 degrees F, and relative humidity ranges from between 71 and 77 percent year round. Average annual rainfall is about 5 inches adjacent to Kawaihae Harbor, and up to 150 inches a year at the summit of Kohala Mountain *(Figure 2.7)*. Most of the annual precipitation occurs during the winter months (November to March) in the upper watershed. Seasonal Kona storms and local convection rainfall events can generate large amounts of rainfall over short time periods. According to DLNR's Commission on Water Resources Management, drought conditions in recent years have exacerbated the dry conditions in the lower watershed (MKSWCD, 2005).

2.4 TERRAIN CHARACTERISTICS

The Pelekane Bay Watershed ranges in elevation from 5,300 feet to sea-level over a distance of approximately 8 miles, which is typical of Hawai'i's watersheds. Pelekane Bay Watershed has moderately steep slopes, about 13%. Generally, slopes vary from 10% to 17%. The terrain is rough and bisected by deep gulches *(Figure 2.7)*.

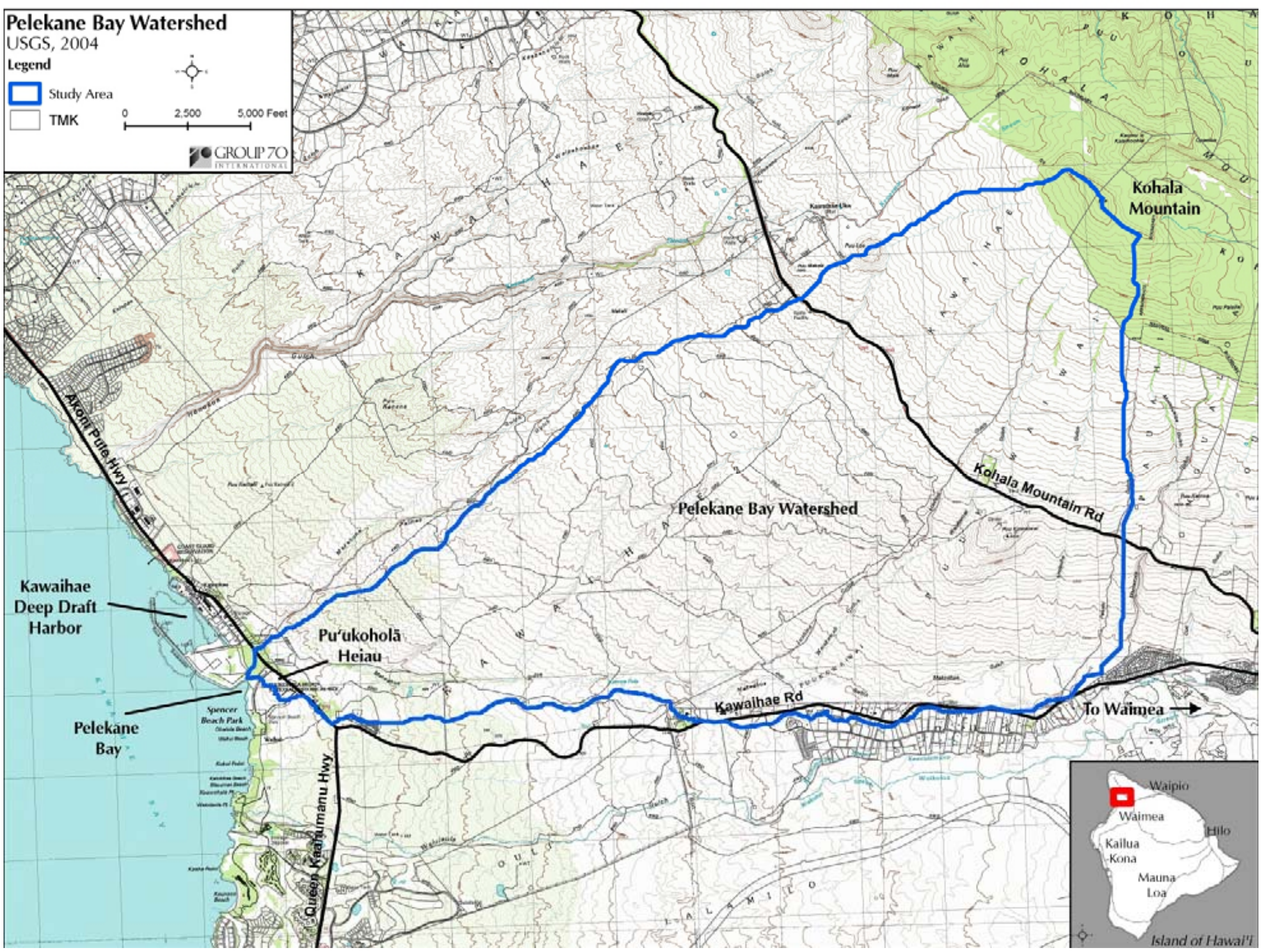


Figure 2.7 USGS 2004, Pelekane Bay Watershed

2.5 SOIL TYPES

Pelekane Bay Watershed is characterized by highly permeable volcanic rocks and soils, which are considered highly erodible *(Figure 2.8)*. The soils are also characterized as hydrophobic, which in arid conditions increases runoff potential (MKSWCD, 2001 (C)). Rugged terrain, steep slopes, and numerous rills, gullies, and gulches, combined with the primary land use of cattle ranching gives this watershed a high potential for erosion. Currently, NRCS is updated the Pelekane Bay Watershed soils map to include more soil types.

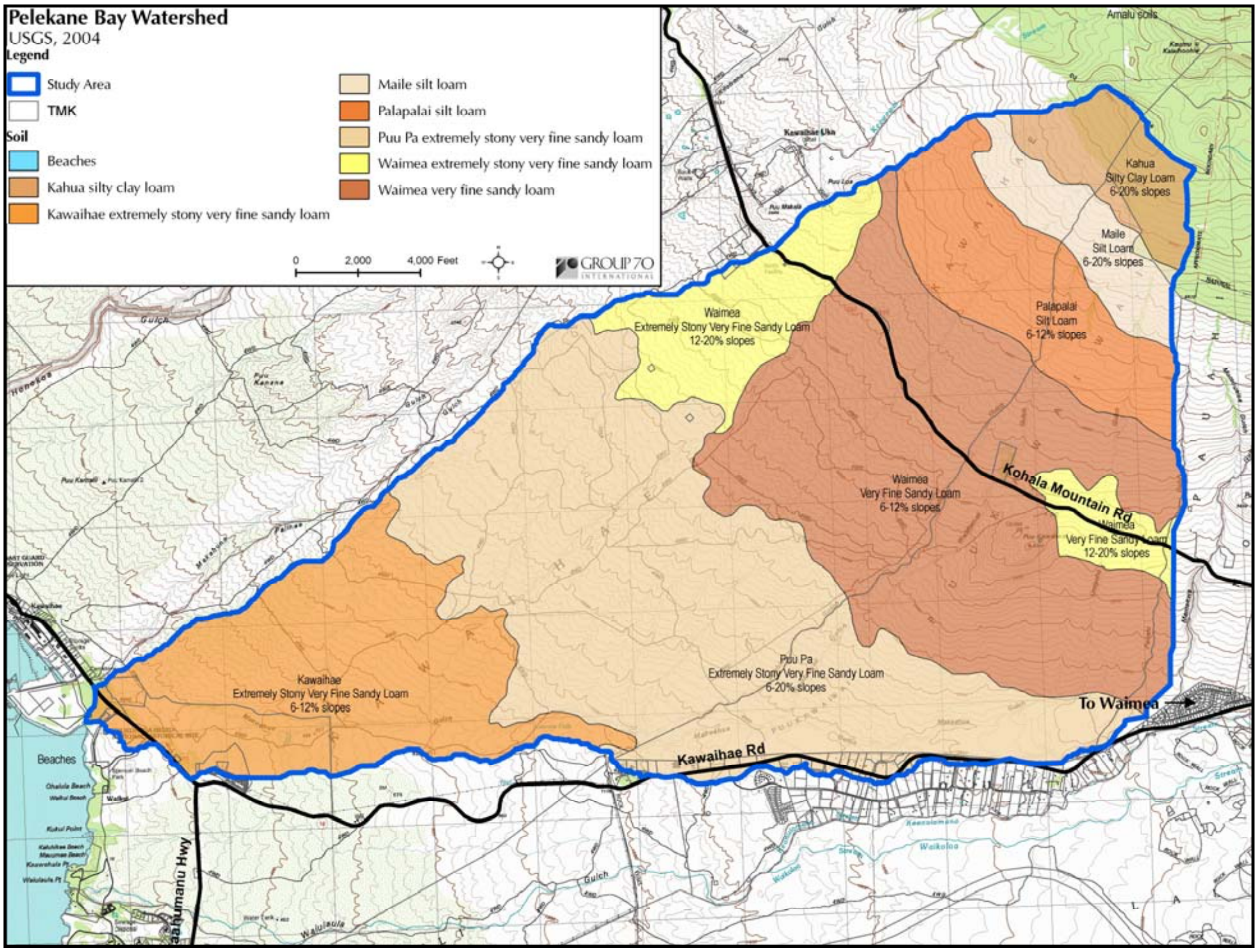


Figure 2.8 NRCS Soil Type 2007 Data, Pelekane Bay Watershed

2.6 VEGETATION COVER

Today, vegetation in the watershed includes native and introduced rangeland grass species, remnants of native plant communities, and invasive alien species of shrubs and trees (MKSWCD, 2005). As mentioned previously, human alterations to the environment of the watershed have altered the landscape of Pelekane Bay Watershed. Early Hawaiian settlers altered the lands by developing large, irrigated agricultural systems, using auwai, mostly for taro and sweet potato. In the 1800's, sandalwood was extensively harvested from the upper slopes of the watershed resulting in extensive deforestation. In addition to large-scale removal of upland forests in the 1800's, cattle were introduced and the land was fenced for livestock *(Figure 2.9)*. Many fires have also occurred within the watershed, resulting in depleted soil quality and barren landscape.

Figure 2.9 Vegetation Cover in Pelekane Bay Watershed, Looking towards Pelekane Bay

2.7 DRAINAGE ROUTES AND SYSTEMS

The gulches identified in the Pelekane Bay Watershed include Palihae, Luahine, Waiakamali, Umipoho and Pauahi, which are all tributary to Makeāhua Gulch and outlet into Pelekane Bay *(Figure 2.10)*. There are currently no perennial streams on leeward Kohala. Streamflow is limited to flows in the gulches and overland during rainfall events in all but the highest parts of the watershed.

The watershed is typically dry except during periods of heavy rainfall, where gulches receive sediment-laden runoff from overland sources and are subject to flashy flows *(Figure 2.11)*. Under normal conditions, there is a berm at the mouth of the watershed and no streamflow into the ocean. During intense rainstorms, the flows breach the sand berm at the mouth of the watershed and deliver sediment runoff into the bay.

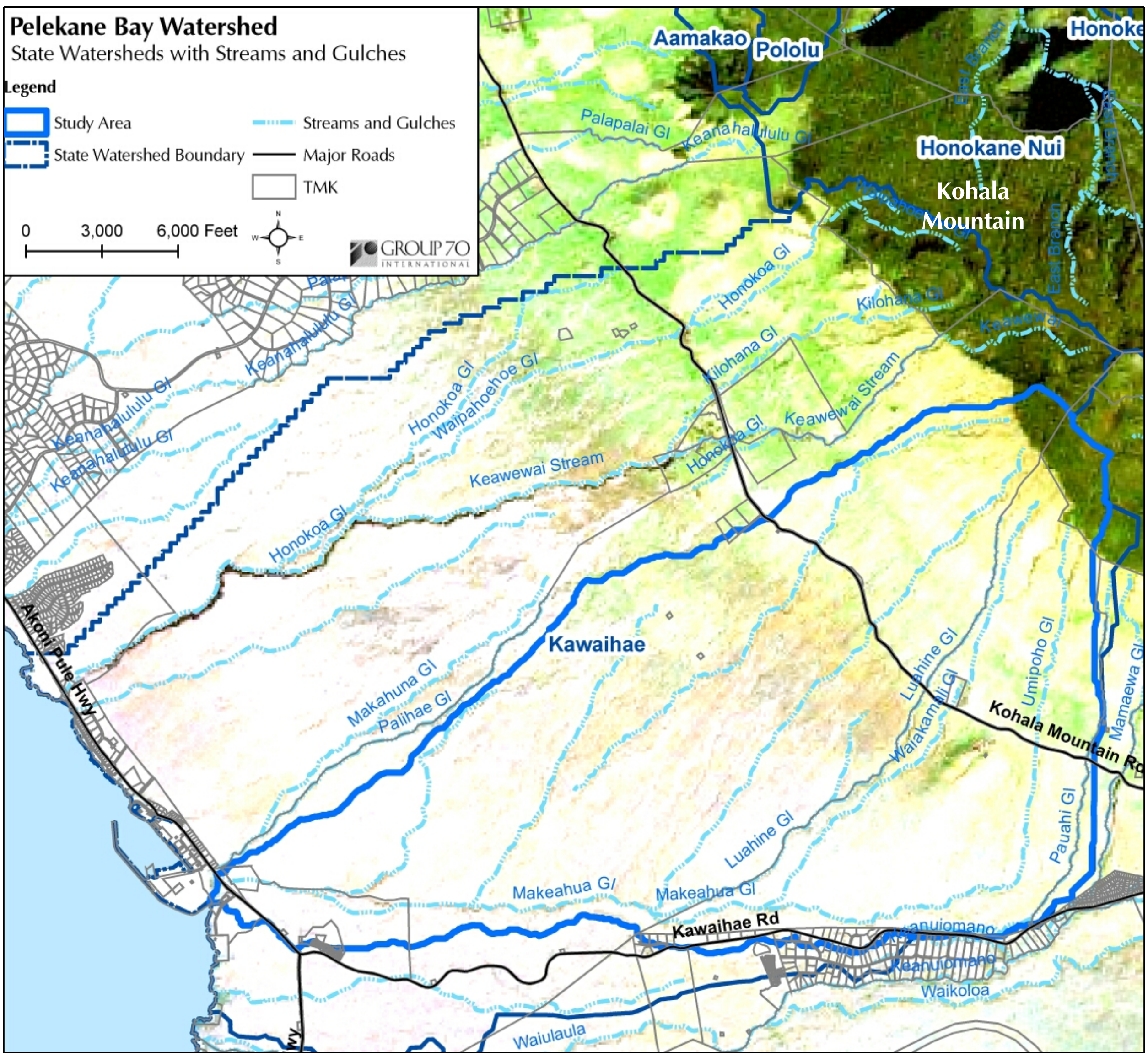


Figure 2.10 Watersheds with Streams and Gulches, Pelekane Bay Watershed

Figure 2.11 Photo of Makeāhua Gulch output into Pelekane Bay on March 9, 2003 Storm, Photo taken by Carolyn Stewart (MKSWCD, 2005).

2.8 WATER QUALITY AND MARINE ENVIRONMENT

In the 1998 Hawai'i Unified Watershed Assessment Plan, Pelekane Bay Watershed was characterized as a Category I – Watershed in Need of Restoration (DOH, 1998). These watersheds are defined as not meeting clean water or other natural resource goals. In 2004, Pelekane Bay was listed as impaired by the Department of Health's 2004 Section 303(d), List of Impaired Waters, due to high turbidity and suspended solids (DOH, 2004). According to DOH, turbidity levels at Pelekane Bay were recorded at almost 18 times the allowable State of Hawai'i water quality standard, 26.5 vs. 1.5 standard *(Refer to Tables 1.1 and 1.2).*

Increased erosion and the natural funneling of water by gulches into Pelekane Bay have resulted in chronic instances of high sediment runoff into the ocean. Sediment retention in Pelekane Bay has been attributed to the lack of nearshore circulation caused by the construction of Kawaihae Harbor in 1962 (Tissot, 1998 and Jokiel, 1995). Subsequent sediment deposition is alleged to be responsible for both the poor water quality and the long term sedimentation of the bay.

Studies have indicated that major changes have taken place in the marine environment of Pelekane Bay. For instance, according to Brian Tissot's study, Changes in the Marine Habitat and

Biota of Pelekane Bay, Hawai'i, Over a 20-year Period, there have been striking declines in the abundance of all plants and animals associated with major changes in species diversity and composition. In his study, Tissot notes that, "it is likely that the community is changing in response to long-term sedimentation stress associated with chronic terrestrial run-off and reduced ocean circulation in Pelekane Bay (Tissot, 1998)."*(Figure 2.12)*

Figure 2.12 Aerial Photo of Pelekane Bay (Tissot, 1998).

3.0 METHODOLOGY

3.0 METHODOLOGY

The main deliverables from this project evolve primarily from using a sedimentation model. The two main objectives of this portion of the study are to 1) estimate the average annual sediment yield into Pelekane Bay as a result of rainfall-runoff from contributing drainage areas and 2) provide an estimate of sediment yield into Pelekane Bay for historical storm events since the development of Kawaihae Harbor coral flats in the 1950's. To assure that the model meets the objectives and accurately represents site conditions, several potential models were evaluated. Attributes of the models evaluated are present in the following *Table 3.1*.

Table 3.1 Comparison of Models

	MODEL EVALUATION MATRIX				
MODEL	RUSLE2	(Ann)AGNPS	WEPP	Flo-2D	N-SPECT
Empirically Based	X	X			X
Process Based	X		X	X	X
Single-Event Based		X	X	X	X
Continuous or Long Term Average	X	X	X		
Lumped Parameter	X			X	X
Distributed Parameter	X	X	X		
Field Scale (Small)	X	X	X	X	X
Watershed Scale (Medium)	X	X	X	X	X
Regional Scale (Large)					
Applicable to Sheet and Rill Flow	X	X	X		
Applicable to Concentrated Flow			X	X	X
Limited Data Requirements					X
Moderate Data Requirements			X	X	
Extensive Data Requirements	X	X			
Limited User-Friendly Data Available				X	
Moderate User-Friendly Data Available		X	X		X
Extensive User-Friendly Data Available	X				
Graphical User Interface	X	X	X	X	X
Moderate Level of Testing/Validation			X	X	X
Extensive Level of Testing/Validation	X	X			
Supported by USDA	X	X	X		in process
Soil Loss Output					X
Sediment Yield Output	X	X	X		
Applicable to Urban Watersheds	X	X	X	X	

RUSLE: Revised Universal Soil Loss Equation
(Ann)AGNPS: Annual Agricultural Non-Point Source Pollution Model
WEPP: Watershed Erosion Prediction Project
Flo-2D Flow 2D Hydraulic Model with sediment transport module
N-SPECT Nonpoint-Source Pollution Erosion and Comparison Tool

While models such as WEPP, RUSLE, and AGNPS have become standard in many hydrological applications, their high degree of difficulty and moderate to extensive data requirements make them unwieldy in many applications. RUSLE1 has a maximum watershed length of 1000-feet which would require many multiple watershed analyses all tied together. RUSLE2 applies only to sheet/rill erosion, which although common in the Pelekane Bay Watershed, is not dominant over the entire watershed. N-SPECT uses MUSLE and has the same length/slope limitations as RUSLE2. WEPP can do both annual and individual storm sediment calculations, but the soil and weather data for Hawai'i is limited and calculations for individual rills and gullies are overly complex for such a large watershed. AnnANGPS has very limited weather station data that must be obtained from the model supplier. Flo-2D is primarily a hydrologic two-dimensional flow model with an untested sub-program added to calculate sediment carrying capacity.

After evaluating each of these models with a number of factors and agency coordination, the Nonpoint Source Pollution Erosion and Comparison Tool (N-SPECT) was selected as the most appropriate for this watershed. N-SPECT was developed by NOAA Coastal Services as a Nonpoint Source Pollution and Erosion Comparison Tool. The model was developed to assess the impacts of land cover, soil type, topography, and rainfall on runoff, non-point source pollution, and erosion. A quality of primary interest to the client is the basis of N-SPECT within a geographic information system (GIS) format. As GIS has become an information tool commonly used by land managers, the ability to extent its usefulness into runoff and pollution modeling is seen as a great advantage. N-SPECT, which is an ESRI ArcGIS based model, can operate on event-based time scales. The annual time scale option for this program was evaluated as part of this project and does not appear reliable. The results of N-SPECT analyses are intended to be used as screening tools to help resource managers and planners target areas for management and predict the impacts of management decisions on water quality and, potentially, on nearshore coral health (NOAA, 2005).

3.1 N-SPECT MODEL

For the purposes of this study, the N-SPECT model was chosen to predict runoff and sediment loads because it was relatively simple and has been developed for sedimentation and pollution transport in Hawai'i (NOAA, 2004). Initial meetings with NRCS, determined that N-SPECT would be an appropriate model for Pelekane Bay Watershed based on characteristics of the watershed (slope, size, land cover, climate, etc.), which were comparable to other watersheds being studied using the N-SPECT model at that time. The MKSWCD intends to use the N-SPECT model in future applications and expressed a preference for the use of this model. The GIS program ArcView 3.3 was used to create spatially distributed rainfall grids. AutoCAD was used to determine the exact location of the watershed on NOAA rainfall frequency maps. These rainfall grids were re-projected into Global Mapper, imported into ArcGIS-ArcView 9.1 and integrated with digital terrain, soil type, and vegetation cover models from existing GIS databases.

This project relies upon a presumption that the storms selected for modeling are representative, and that the model used to emulate storm impacts gives a true representation of real conditions. The storms selected are representative of the spectrum of storms impacting the watershed. The quality of the model output is limited by the hydrologic assumptions inherent to a single step (non-iterative) model and the quality of the data that is inputted. Selection criteria and sources of data entered in to the model are described below. Storm Type I was used for the model runs. The rainfall distribution of the selected storms and the Storm Type I distribution is plotted in the following *Figure 3.1*. The description provided in the N-SPECT documentation indicates that this storm type is the best fit for typical Hawai'i rainfall events (NOAA, 2005).

The following physical processes are not supported by the N-SPECT model:

- Atmospheric Deposition
- Groundwater Processes
- Stormwater Drainage
- Stream Diversions
- Snow Melt
- Landslides
- Runoff Routing/Timing
- Sediment Redeposition
- Pollutant Fate

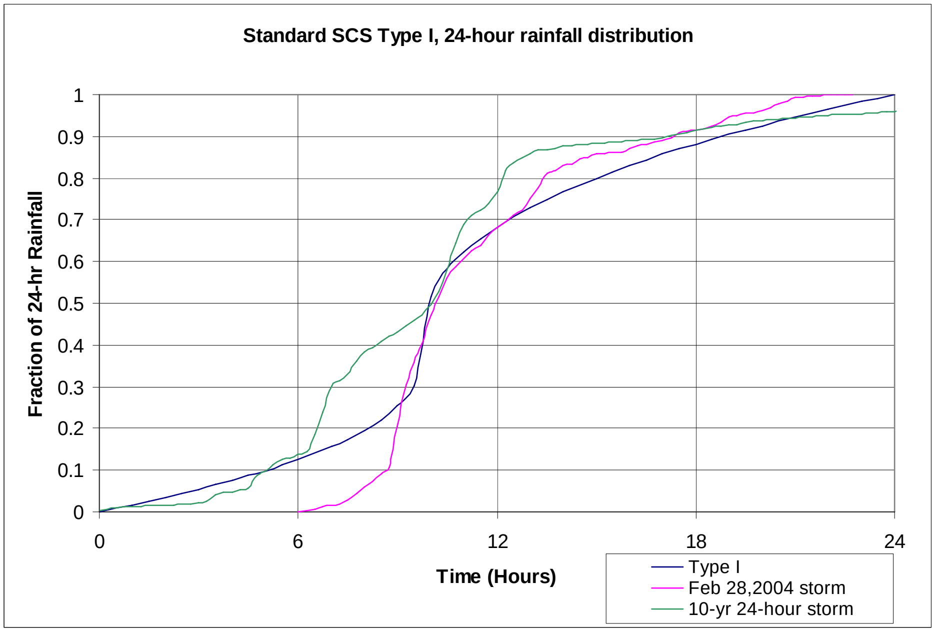


Figure 3.1 Comparison of Selected Storm Rainfall Distribution for Pelekane Bay Watershed versus Standard SCS Type I, 24-hour Rainfall Distribution

N-SPECT uses the SCS Curve Number Method to estimate retention, initial abstraction, and runoff depth according to the following equations:

Equation 1:

$$Q = (P - I_a)^2 / [P - I_a) + R],$$

Where:

I_a	=	Initial Abstraction (inches) = 0.2 * R
R	=	Potential Maximum Retention = (1000 / CN) -10
Q	=	Runoff (in)
P	=	Precipitation, Rainfall (in)
CN	=	Curve Number

Note that the equation does not account for land slope, storm duration or intensity. The equation also is limited by a 0.2 ratio, which is a fixed component of the N-SPECT model. Abstraction is a measure of the initial absorptive capacity of the surface before any runoff will occur and is a function of the maximum retention capacity of the soil and land cover type. By defining both retention and abstraction in terms of the curve number (CN), the runoff becomes a sole function of the rainfall and curve number. The curve number represents the infiltration capacity of the soil and ranges from 0 to 100 with 0 being no runoff and 100 indicating no infiltration. N-SPECT includes default curve number values for use with land cover and soil type data sets (Refer to *Table 3.2*). Curve numbers for the Pelekane Bay Watershed tend to be very low indicating a high tendency for rainfall to infiltrate to groundwater. A sensitivity analysis was done by varying the values for all of the curve numbers used in the model by +/-10% and +/- 0.01 for a single storm event.

Any runoff from a grid cell is converted from inches to cubic feet and transferred to the input of the adjacent cell with the lowest elevation. In this manner excess runoff is transferred down slope and concentrated into cells which then form the digital stream beds for the transfer of the majority of runoff down slope. The output units of runoff from N-SPECT are hard coded to be in cubic meters.

Sediment concentration and mass delivered is calculated using the Modified Universal Soil Loss Equation (MUSLE) with constants specific to Hawaiʻi;

Equation 2: $S = 18.943 * (Q * q_p)^{0.877} * Kf * C * P_f * L§,$

Where:

S	=	Sediment Yield from an Individual Storm (tons)
Q	=	Storm Runoff Volume (ac-ft)
q_p	=	Peak Runoff Rate (cfs)
Kf	=	Soil Erodibility Factor
C	=	Cover Management Factor
P_f	=	Supporting Practices Factor
L	=	Slope Length Factor
§	=	Slope Steepness Factor

The storm volume (Q) is derived from *Eq* 1 above. The peak runoff rate (q_p) is calculated as a function of the curve number (CN), slope from the digital terrain, and length of the model cell unit. The values of Kf, C, and P_f are derived from tables in the model specific to soil type and land cover specific to Hawaiʻi (*Table 3.2*).

In summary, the N-SPECT model constructs a constant watershed "equation" from datasets of topography, soil type, and land cover (all of which are related to curve number), and applies a single variable of rainfall quantity over this model to calculate both runoff and sediment erosion in a single step analysis process. It appears MUSLE does not account for bed load transport and accounts for only suspended loads. Once the watershed constants are in place within each cell, the rainfall quantity and distribution over the watershed become the only variable factors. The RUSLE and sediment delivery ratio for annual erosion were also applied with the N-SPECT model, but the results were determined not likely to represent the actual conditions seen on site.

Table 3.2 N-SPECT Model Curve Number (CN) Values

CCAP Landcover							
Value	***Name***	***CN-A***	***CN-B***	***CN-C***	***CN-D***	***Cover Factor***	***Wet***
2	High Intensity Developed	0.89	0.92	0.94	0.95	0	0
3	Low Intensity Developed	0.61	0.75	0.83	0.87	0.03	0
4	Cultivated Land	0.67	0.78	0.85	0.89	0.24	0
5	Grassland	0.39	0.61	0.74	0.8	0.05	0
7	Evergreen Forest	0.3	0.55	0.7	0.77	0.004	0
9	Scrub/Shrub	0.3	0.48	0.65	0.73	0.014	0
17	Bare Land	0.77	0.86	0.91	0.94	0.7	0
18	Water	0	0	0	0	1	1

3.1.1 Sub-Watershed Basin Determination

Watersheds are an essential unit for this hydrologic analysis, as they serve to link a plot of land with its stream and drainage network, and its point of discharge to the bay. Six sub-watershed areas were defined by the N-SPECT model in the advanced settings and are denoted A through F *(Figure 3.2 and Table 3.3)*. The watershed boundaries were confirmed by visual observation of USGS topography maps of the area. The areas of the sub-watershed basins ranged from 962 acres to 3518 acres. Runoff and sediment concentration values were obtained from the lowest grid cell in each sub-watershed just above the main stream. Sub-watershed 'A' had multiple small entry points to the main stream, so runoff and sediment concentration values were obtained by noting the difference in main stream volume between 'B' and the exit of 'A'.

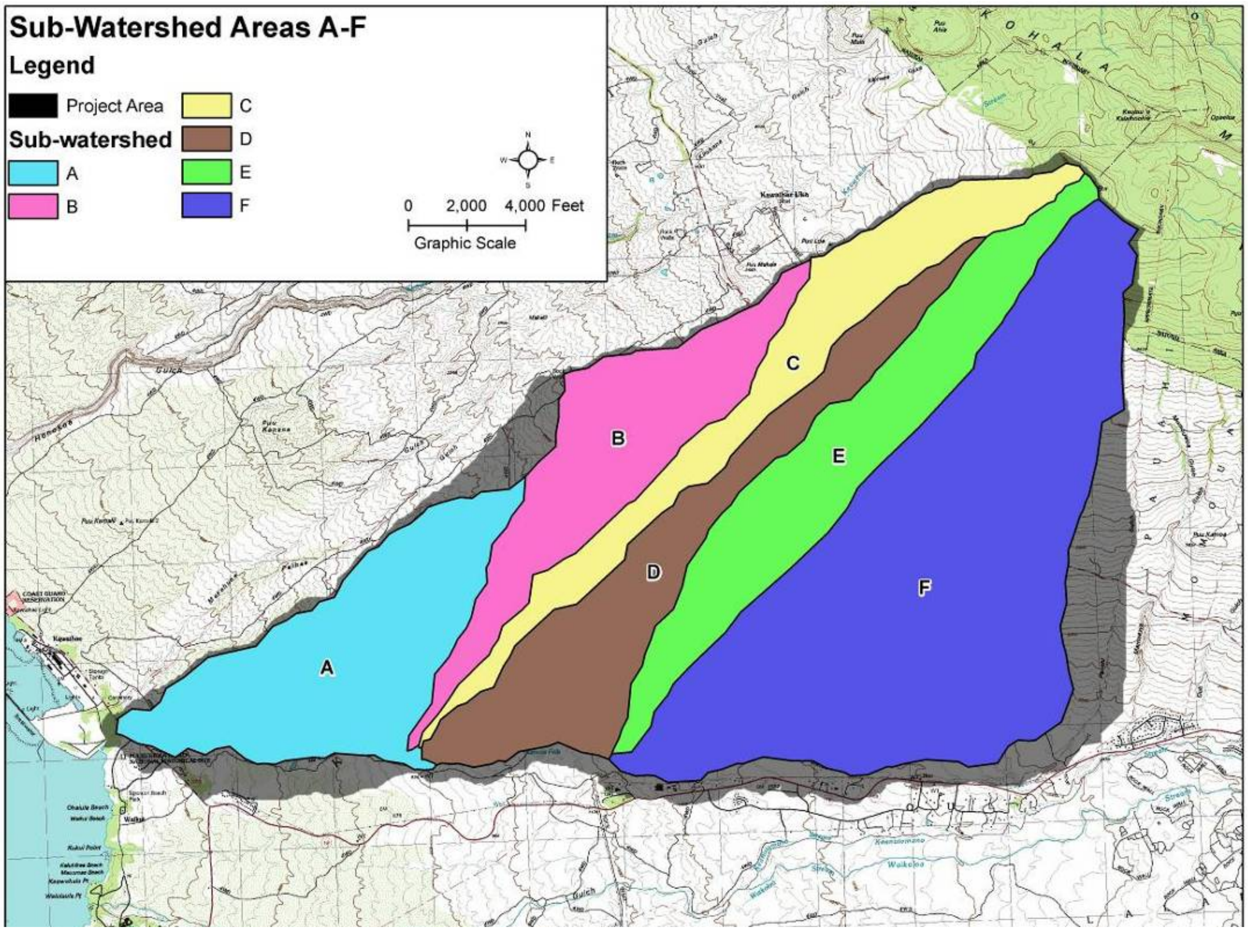


Figure 3.2 Sub-Watershed Areas A-F, defined for Pelekane Bay Watershed

Table 3.3 Watershed Areas

Watershed	Acres	Square Miles
A	1,346.59	2.10
B	1,046.09	1.63
C	960.16	1.50
D	1,161.99	1.81
E	1,197.30	1.87
F	3,510.19	5.48

3.1.2 Elevation and Topography

A digital elevation database was acquired from Digital Elevation Model (DEM) from Intermap Technologies Inc. The database is based upon synthetic aperture radar data with 1.5 meter accuracy. This data was processed down to the 30 X 30 meter grid size as required by the N-SPECT model and is displayed in *Figure 3.3* as a topographic shadowed model. Site topography, essentially the slope of each of the grid areas, is computed directly from the elevation model.

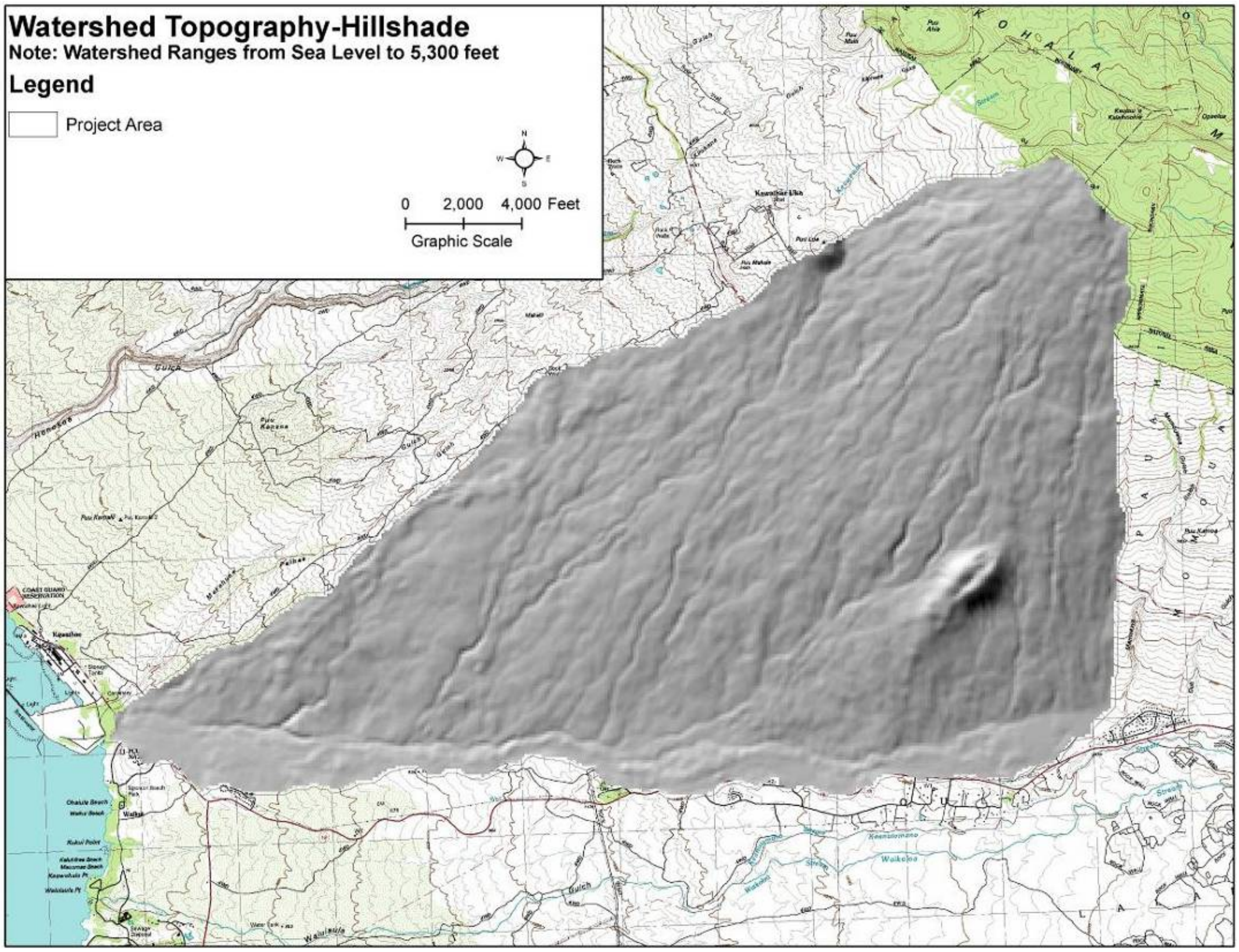


Figure 3.3 Digital Topography Model of Pelekane Bay Watershed. Intermap Technologies Dataset, 2007.

3.1.3 Land Cover

Land cover is an important variable in the control of both runoff and erosion. The type and density of vegetation cover is directly related to the ability of rainfall to be absorbed, erode sediments upon contact, resist erosion by sheet flow, and resist the formation of rills and gullies.

Land cover was obtained directly from the NOAA Coastal Change Analysis Program (C-CAP), clipped to the study area as shown in *Figure 3.4*. The land cover designations are verified by NOAA quality assurance national protocols, but are known to be at variance with true land cover specific to the Hawaiian Islands in a number of instances. A field visit to the site verified the general representative nature of the land cover data but specific grid-by-grid verification was not attempted.

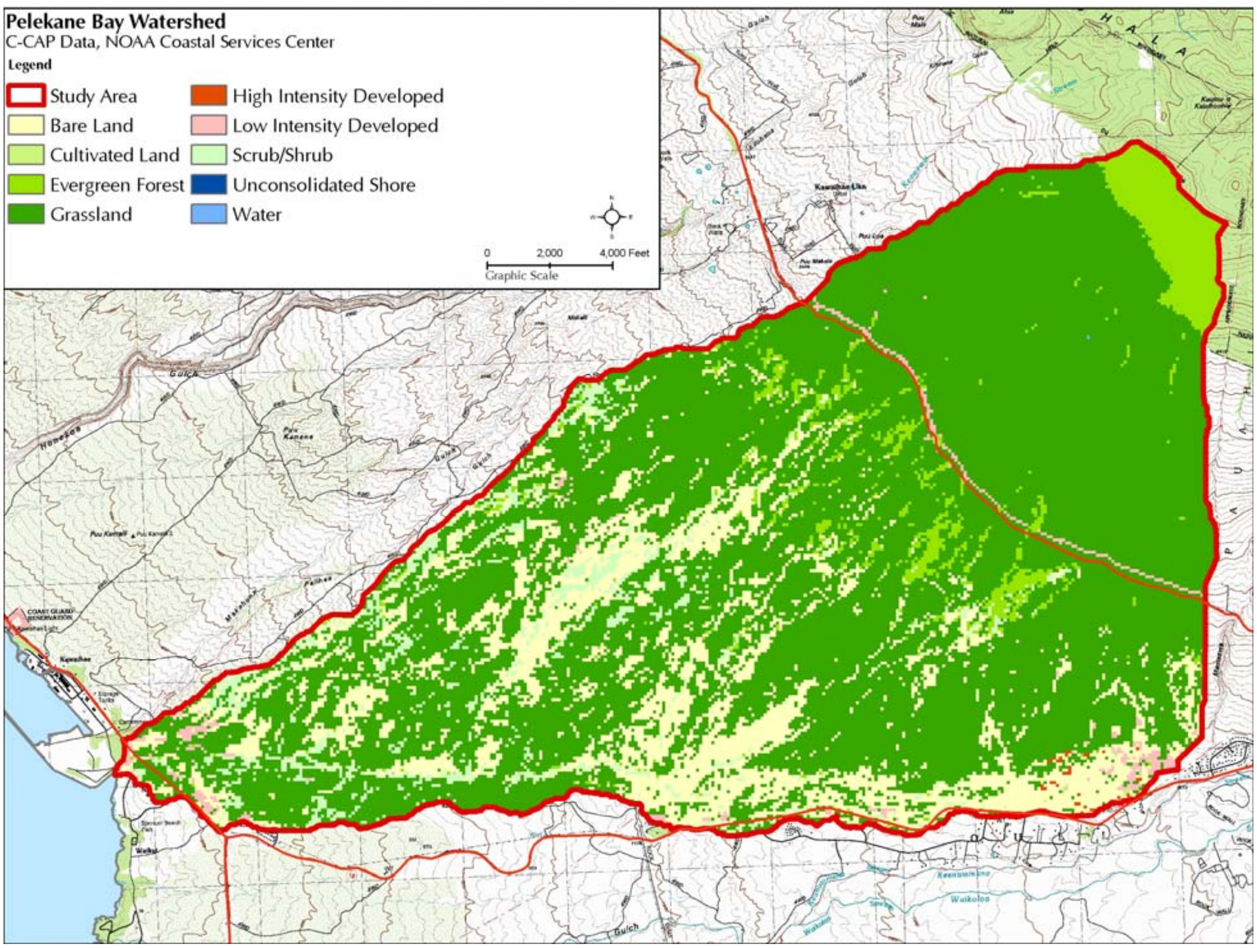


Figure 3.4 NOAA C-CAP Data Distribution of Land Cover, Pelekane Bay Watershed

3.1.4 Soil Type

Soil type impacts surface erodibility, infiltration rate, and the quantity of suspended load that will be carried by sheet flow and stream water. Soil type was determined from the National Resource Conservation Service (NRCS) soil report for the State of Hawai'i published in 2004. This data is available as a digital database from Soil Data Mart on the USDA national website (http://soildatamart.nrcs.usda.gov/) and is displayed graphically in *Figure 3.5* and defined in *Table 3.4*. Each Soil Code (Type) has a classification of erodibility factors and water absorption factors associated with the database.

The "depth class" is the normal depth of the soil; if the depth in the field is less, then the soil is most likely eroded, but soil depths vary and are based on many factors which are not always an indication of erosion (NRCS, 2007). The "Kf value" is the soil erodibility factor for the fine earth fraction or soil material less than 2.00 mm in diameter. The higher this number is, the more erodible the soil. Amorphous clays in the soils keep the Kf values in Hawai'i lower than on the U.S. Mainland. Sand, which is highly erodible, has a Kf value of 0.5 or 0.6. According to NRCS, dry volcanic soils tend to be hydrophobic. The dry volcanic soils located within Pelekane Bay Watershed were determined to be hydrophobic through anecdotal and direct field observations. Hydrophobic soils repel water, and the water beads up rather than infiltrating the soil. The N-SPECT model accounts for hydrophobic soils in the Kf-value of the soil definition, but does not have a factor for hydrophobic soils, which would require significant field testing to determine.

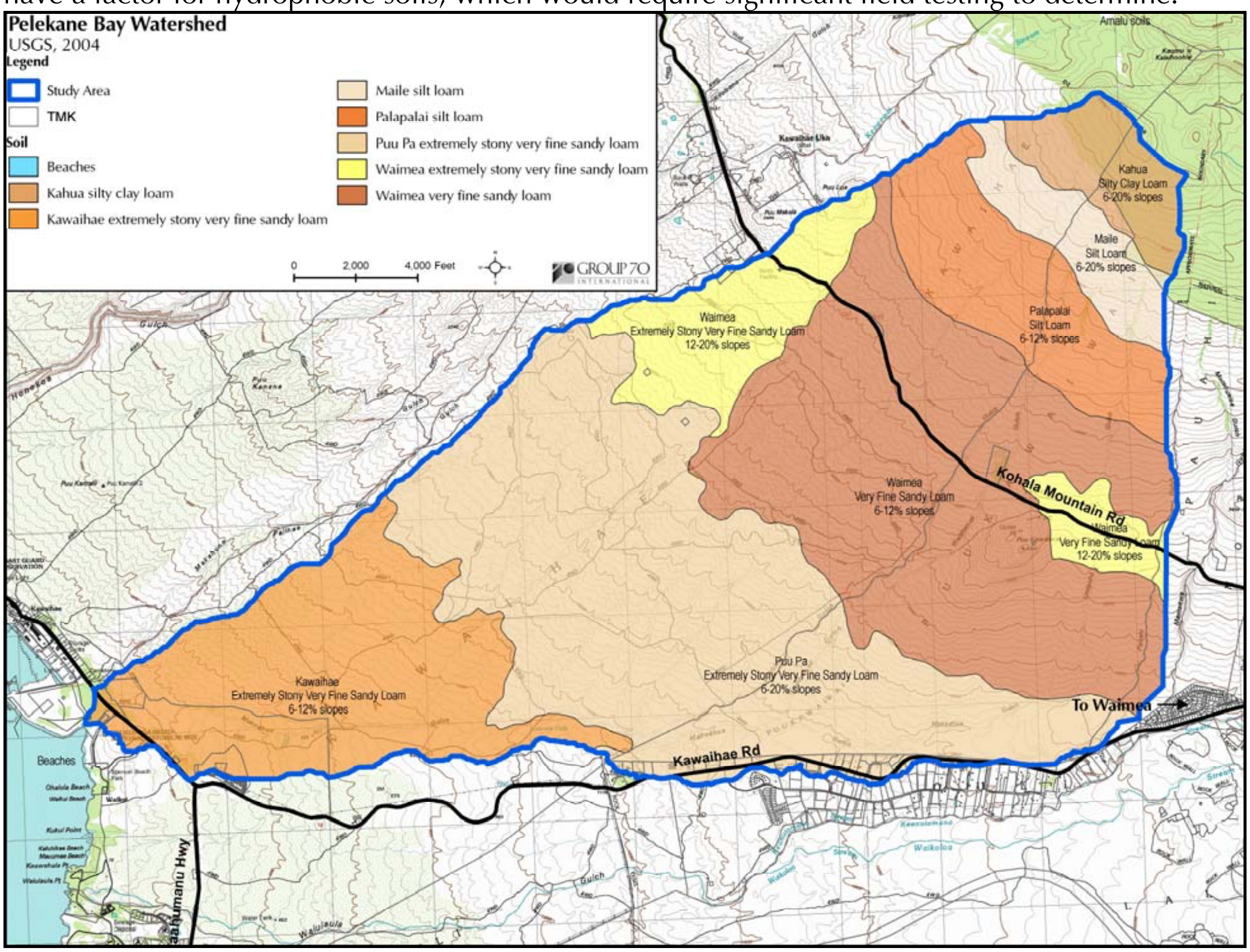


Figure 3.5 NRCS Soil Type 2007 Data, Pelekane Bay Watershed

Table 3.4 NRCS Soil Characteristics

Soil Type	Soil Name	Slope Range (%)	Drainage Class	Depth Class (inch)	Kf-value	Potential for Erosion	% of Watershed	Hydrophobic
FL	Fill land	Fill land	Well-drained	0-60	0.10	High	0%	yes
KCD	Kahua silty clay loam	6 to 20	Somewhat poorly drained	0-61	0.10	High	4%	no
KNC	Kawaihae extremely stony very fine sandy loam	6 to 12	Somewhat excessively drained	0-43	0.32	High	16%	yes
MLD	Maile silt loam	6 to 20	Well-drained	0-60	0.10	High	4%	yes
PLC	Palapalai silt loam	6 to 12	Well-drained	0-60	0.17	High	8%	yes
PVD	Puu Pa extremely stony very fine sandy loam	6 to 20	Well-drained	0-50	0.20	High	33%	yes
WMC	Waimea very fine sandy loam	6 to 12	Well-drained	0-52	0.17	High	28%	yes
WSD	Waimea extremely stony very fine sandy loam	12 to 20	Well-drained	0-52	0.17	High	8%	yes

3.1.5 Rainfall

Rainfall at the site was characterized by examination of data from four gauges: Kahua NWS, Kahua Ranch, Pelekane Upper, and Pelekane Lower. The National Weather Service's KASH1: Kahua (HI-96) Rainfall Gauge (Kahua NWS) is located approximately 4 miles north of the project watershed in an area with rainfall patterns similar to the upper Pelekane Bay Watershed. The Kahua NWS Gauge archives 15-minute interval data since 1995 on the internet Hydronet site (http://www.prh.noaa.gov/hnl/hydro/hydronet/hydronet-data.php). A separate rain gauge maintained by the Ranch, Kahua Ranch Gauge, has a daily rainfall database extending back to 1931. Two privately owned gauges within the Pelekane Bay Watershed also record data at 15-minute intervals and have been maintained by University of Hawai'i at Hilo researcher Dr. Jene Michaud, who has made records available from November 18, 2002 to March 13, 2005. The location and identification of Kahua NWS / Kahua Ranch and two private rain gauges in the area are shown in *Figure 3.6*. The locations used to represent "upper" and "lower" modeled rainfall in the watershed are also shown in this figure.

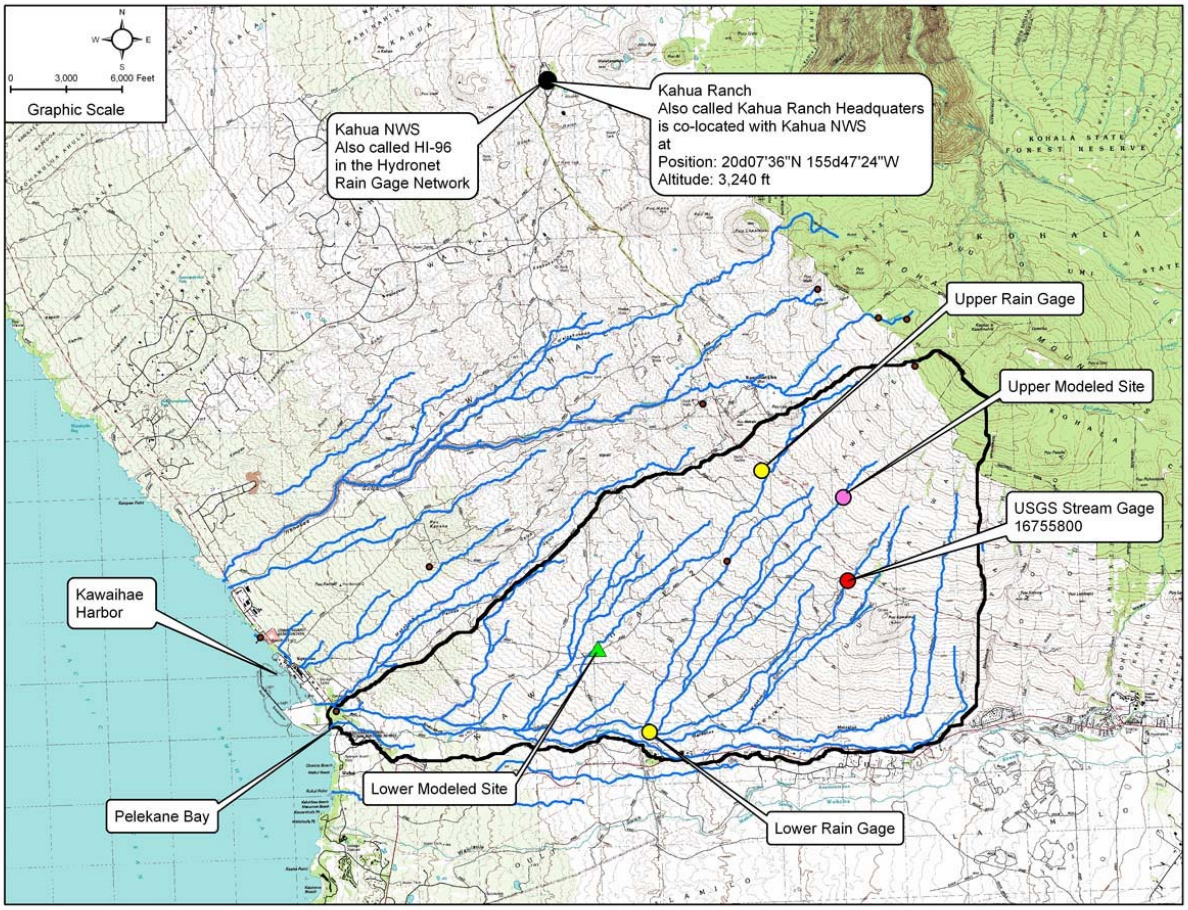


Figure 3.6 Location of Important Monitoring and Modeling Sites Relative to the Pelekane Bay Watershed

Data quality and temporal coverage vary between the four gauges. The Kahua Ranch Gauge has the longest recording record (since 1931) which was summarized to create the yearly and average annual rainfall graphs in *Figures 3.7 to 3.9.* However this data is only available as daily totals, which makes it unusable for depicting storm hyetograph. Note that the long term annual average rainfall from this data is only about 50.5-inches. This is significantly lower than the annual average of 70-inches per year given by the NWS rainfall atlas. The Kahua NWS Gauge does report record data at 15-minute intervals, but this record only goes back just over 12 years to July, 1994. Average annual rainfall reported from the Kahua NWS Gauge is only 34.2 inches. Data from the Kahua NWS Gauge was used to develop the hyetograph of the storms selected for modeling.

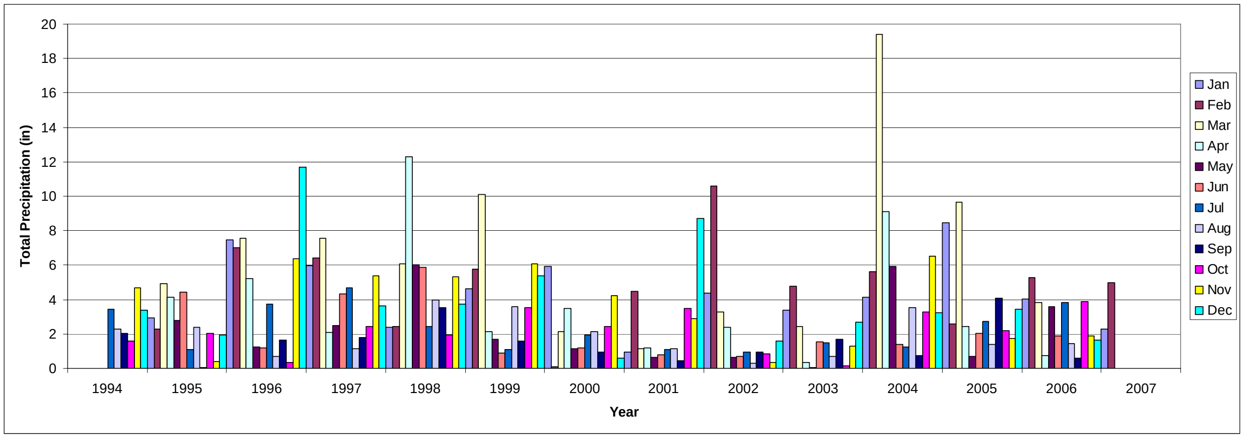


Figure 3.7 Monthly Precipitation Totals Recorded by Gauge HI-96 Annual

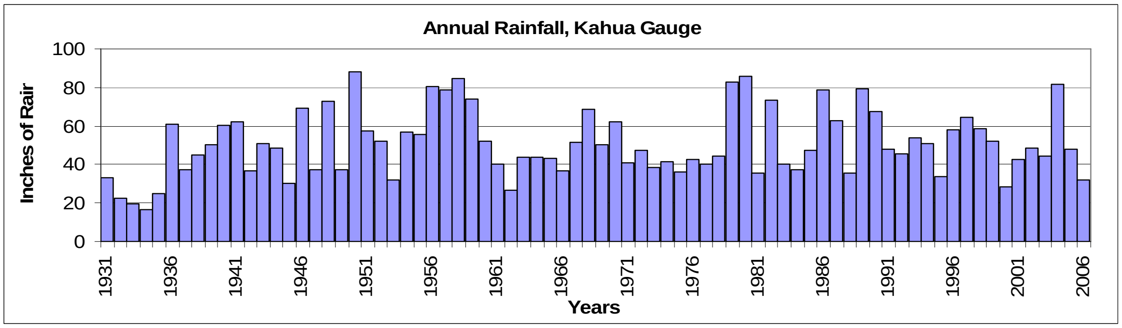


Figure 3.8 Annual Rainfall at the Kahua Ranch Gauge, 4.2 Miles North of Pelekane Bay Watershed

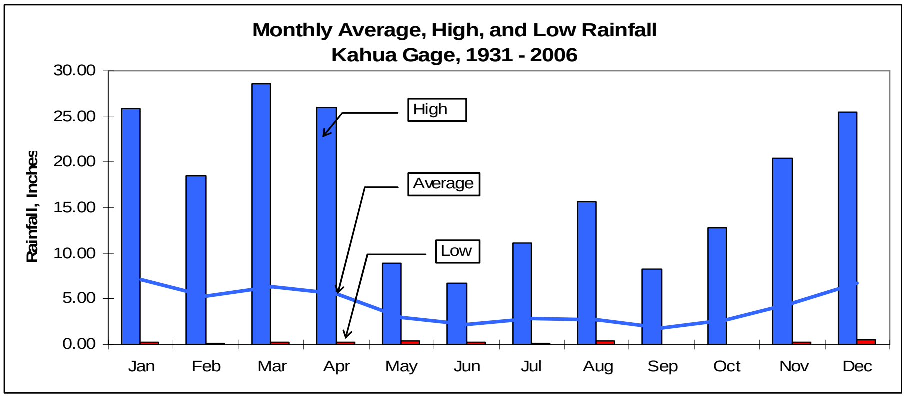


Figure 3.9 Monthly Average Rainfall over 75 Years at Kahua Ranch, Showing Large Variation in Range of Monthly Rainfall Amounts

3.1.5.1 Historical Storm Incidence

To select rainfall intensity, as required in the contract scope, with return frequencies of 10-year 1-hour, and 2-year, 24-hour storms requires analyses of the historical rainfall patterns of the watershed. This information was acquired from the three sources; 1) the Rainfall-Frequency Atlas of the Hawaiian Islands, 2) local rain gauges, and 3) a USGS stream peak-flow gauge on the project site.

Storm incidence was determined from "Rainfall-Frequency Atlas of the Hawaiian Islands (Technical Paper No. 43)." Portions of this atlas pertaining to the project site are displayed in *Figures 3.10 and 3.11.* Because there is such a large difference in rainfall between the upper and lower rainfall areas, two locations were selected, one in the upper and one in the lower watershed for determination of historical storm incidence. Data in *Table 3.5* and *Figure 3.10* were interpolated from the rainfall-frequency maps of *Figures 3.11* and *3.12*. Interpretation from these graphs and tables indicates that the 10-year 1-hour storm will drop 2-inches of rain in the upper watershed and 1.5-inches in the lower watershed. The 2-year, 24-hour storm will drop about 4.5 inches of rain in the upper watershed and 2.9 inches in the lower watershed.

Table 3.5 Tabular Representation of Storm Rainfall Frequency Information, Rainfall Frequency Atlas of the Hawaiian Islands, 1962

Upper Watershed

20º03'22'' N, 155º43'49'' W

Duration --> / Year Re-occurrence	30min	1 hr	2 hr	3 hr	6hr	12 hr	24 hr
1	0.9	1.25	1.5	1.75	2.1	2.7	3.2
2	1	1.5	1.8	2.1	2.8	3	4.5
5	1.4	1.8	2.2	2.7	3.6	4.5	5.6
10	1.5	2	2.9	3.2	4.5	4.8	7
25	1.75	2.3	3.2	3.5	5	6.5	8
50	2	2.5	3.4	4.1	6	7	9
100	2.3	2.9	3.9	4.5	7.5	8	11

Lower Watershed

20°02'16'' N, 155°46'36'' W

Duration --> / Year Re-occurrence	30min	1 hr	2 hr	3 hr	6hr	12 hr	24 hr
1	0.7	0.9	1.2	1.25	1.6	1.9	2.25
2	0.8	1	1.25	1.5	1.9	2.5	2.9
5	0.9	1.3	1.7	1.8	2.5	3	3.7
10	1.1	1.5	1.9	2.2	2.9	3.7	4.5
25	1.25	1.7	2.3	2.5	3.5	4.3	5.3
50	1.4	1.8	2.5	2.9	3.7	4.9	5.9
100	1.5	2.2	2.8	3.2	4.5	5.3	6.6

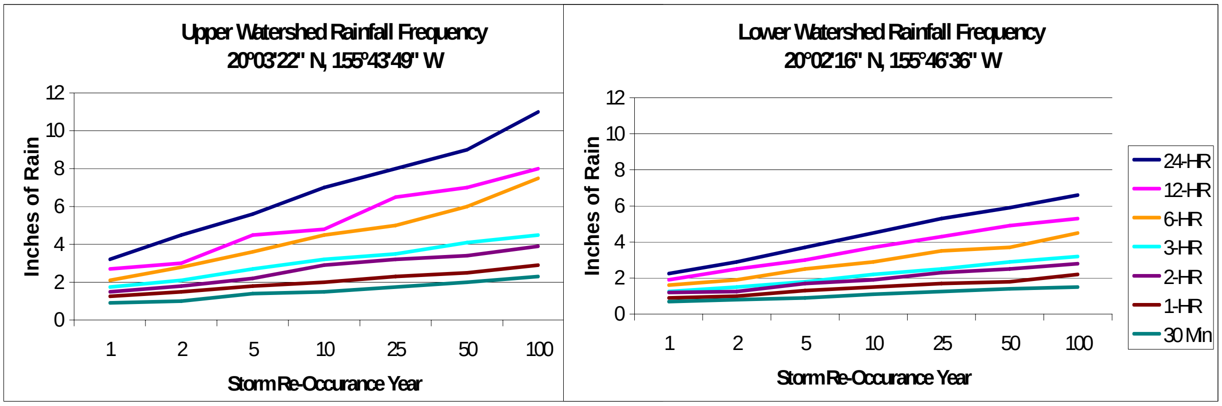
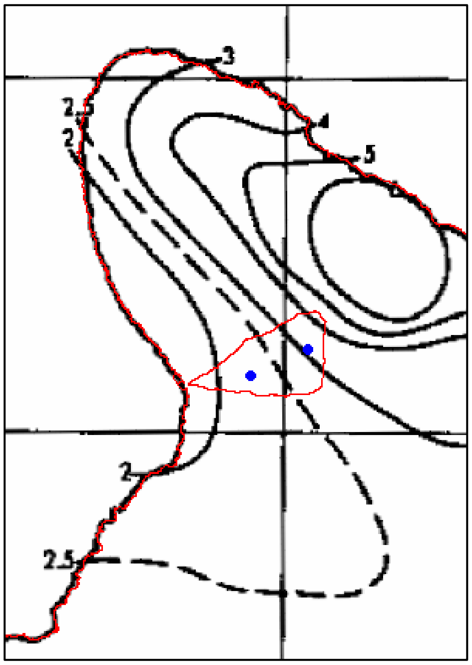
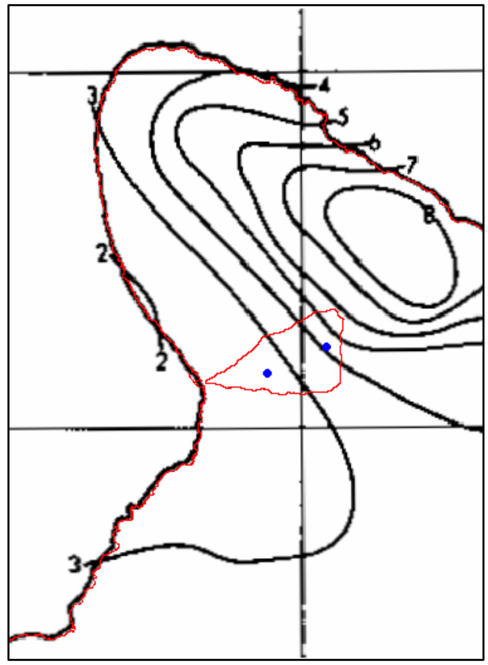


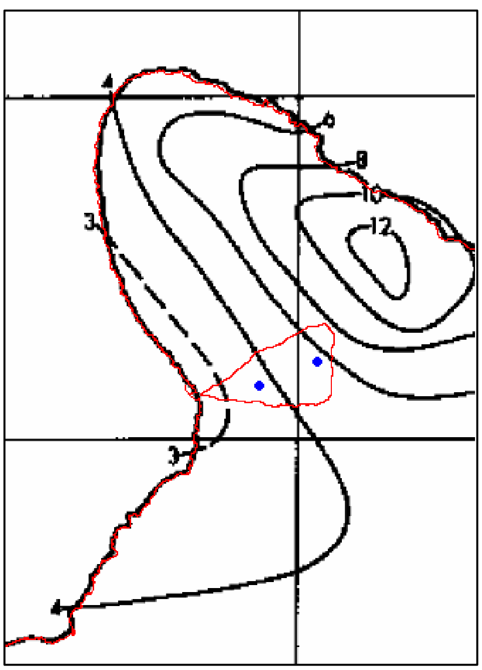
Figure 3.10 Graphical Representation of Storm Rainfall Frequency Information, Rainfall Frequency Atlas of the Hawaiian Islands,1962



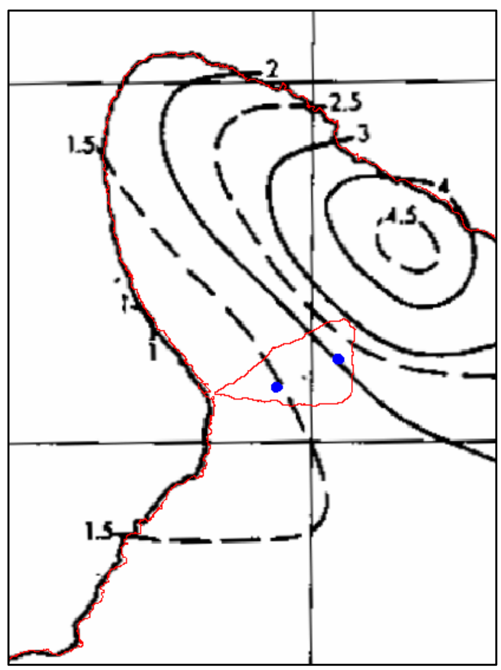
1-yr 24-hour



2-yr 24-hr

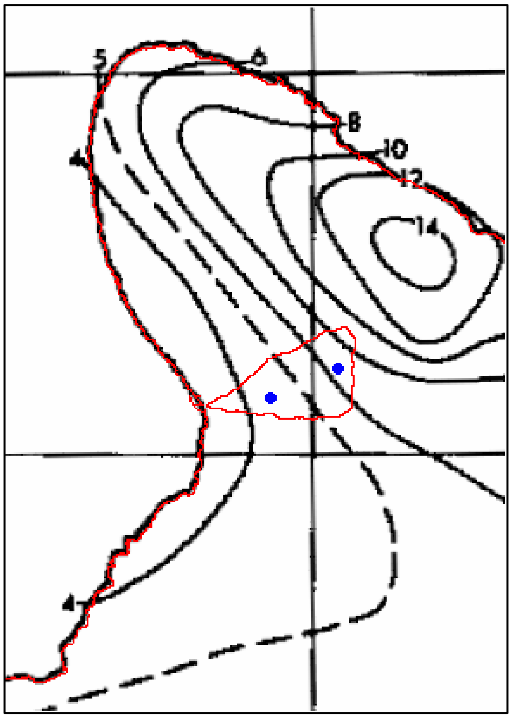


5-yr 24-hr

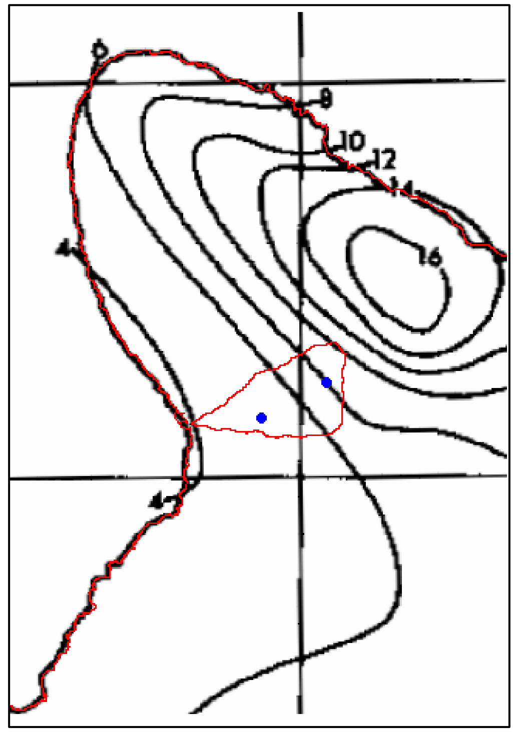


10-yr 1-hr

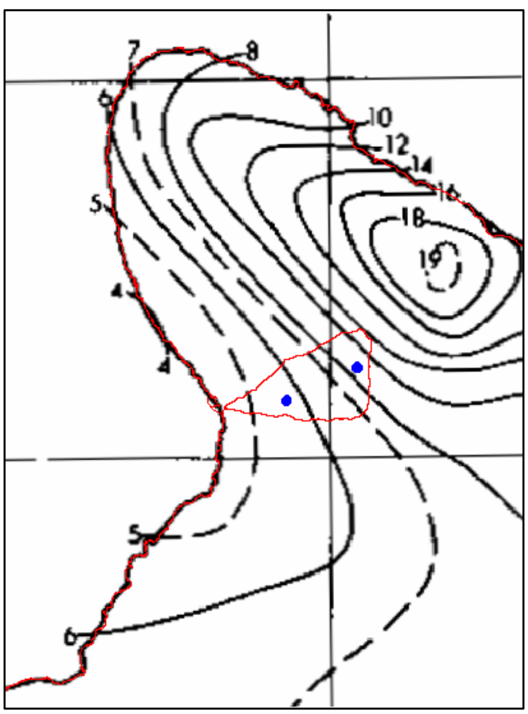
Figure 3.11 Rainfall Storm Frequency Maps with Project Area Outlined. Data Points Represent the Upper and Lower Locations for Extraction of Tabular Data.



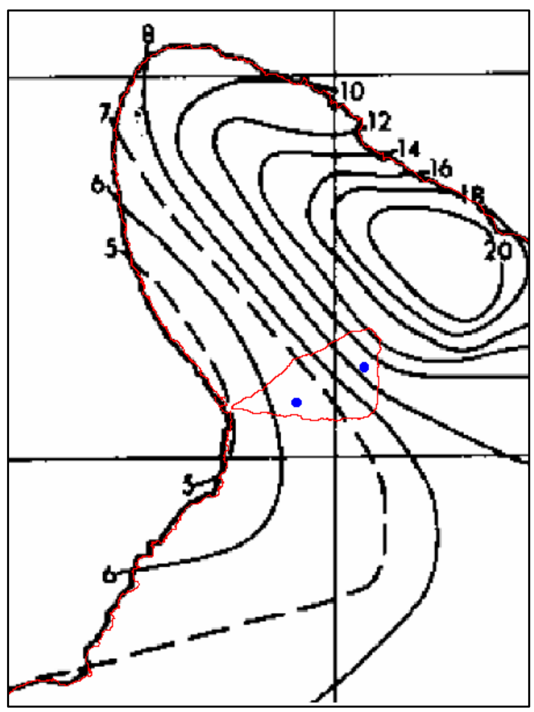
10-yr 24-hr



25-yr 24-hr



50-yr 24-hr



100-yr 24-hr

Figure 3.12 Rainfall Storm Frequency Maps with Project area Outlined. Data Points Represent the Upper and Lower Locations for Extraction of Tabular Data.

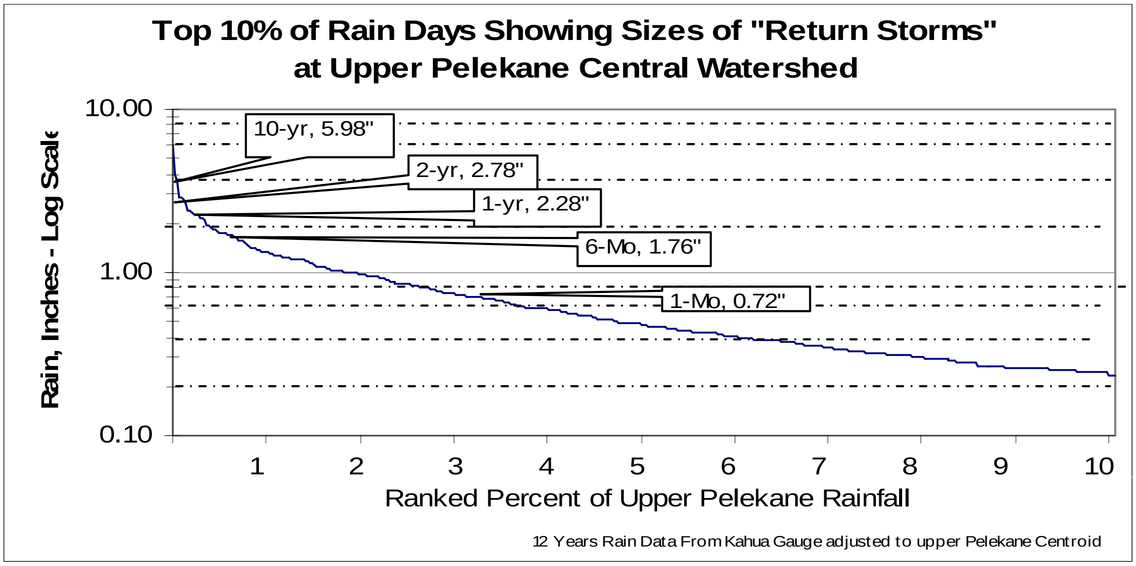


Figure 3.13 Plot Showing the Top 10% of Ranked Rainfall Days from 12 Years of Records

The relative position of various storm intensities are determined by rank order: i.e. the 1-year storm is the 12th ranked storm and the 1-month storm is the 36th ranked storm. The data has been adjusted from the Kahua Gauge to represent rainfall intensities in the upper Pelekane Bay Watershed.

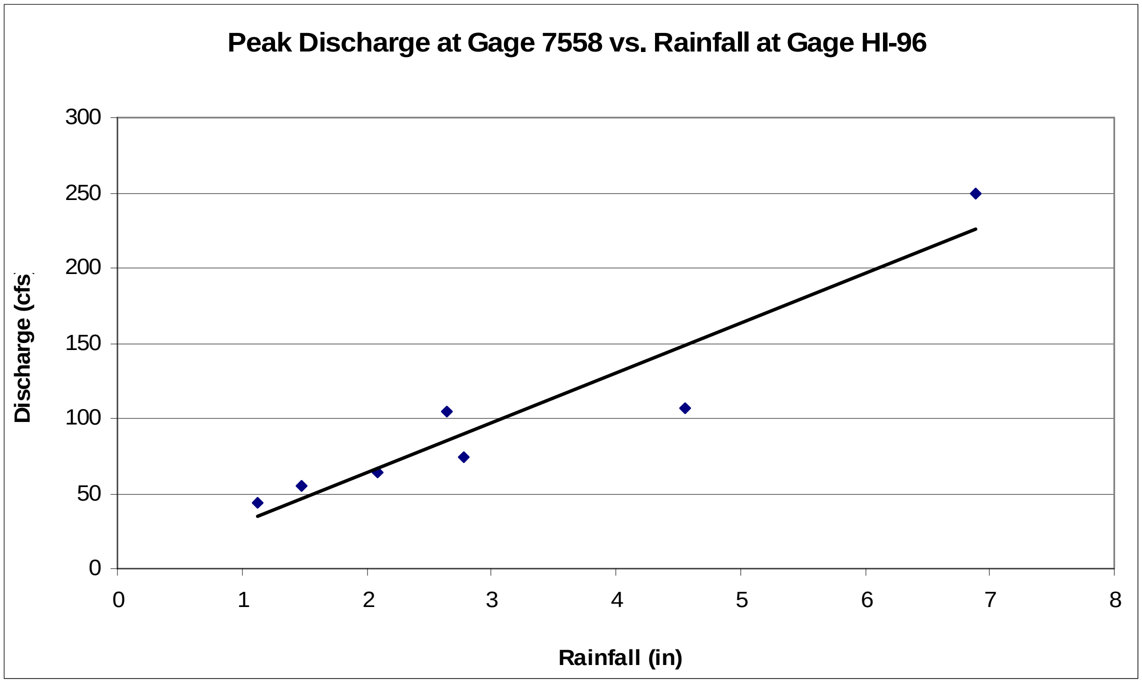
Storm incidence from the State-wide rainfall atlas was compared to storm return frequency data extracted from actual rainfall data obtained from the Kahua NWS Gauge and corrected to correspond to the "Upper" watershed location according to the PRISM average rainfall database. The top 440 rain days from the Kahua NWS Gauge are plotted from 12+ years (4,446 days) of rain data and are displayed in *Figure 3.13*. The 12 years of data is assumed to contain a single 10-year storm represented by the #1 ranked storm, two 5-year storms represented by the #2 ranked storms, six 2-year storms represented by the #6 ranked storms, and twelve 1-year storms represented by the #12 ranked storms. Note that magnitude of the return storms predicted from the rain gauge data is lower than that predicted from the Storm Frequency Atlas. This is to be expected as this data set is from a tipping bucket rain gauge that tabulates a much lower (34.2") annual rain fall total as compared to the 50.2-inch average from the Kahua Ranch Gauge during this same period of time, and the 70-inch per year annual rainfall given by the NWS rainfall atlas for this location. The differences between the annual averages of the Kahua Ranch and Kahua NWS gauges are not related to the time period of data collection. Evaluation of data from both gauges during the same period of time showed differences between the gauges. This difference persisted between wet and dry years; the two gauges yield data sets that are significantly different.

Note in *Figure 3.8,* the high year to year variation in rainfall from the Kahua Ranch Gauge, as well as the extremely high variance in monthly rainfall. During the 75 year history of the rain gauge, every month has had at least one occurrence of near-zero rainfall as well as rainfall that was two to four times higher than the monthly average. These infrequent occurrences of very heavy rainfall can greatly influence the long-term surface erosion of the watershed.

The rain gauges on the site have discontinuous records, and the Kahua Ranch and Kahua NWS Gauges do not appear to synchronize well with annualized NWS rain fall atlas. USGS stream

Gauge #16755800 is within the Pelekane Bay Watershed in Luahine Gulch near Waimea as shown in *Figure 3.6* and does have excellent data. Historical stream-flow data was analyzed in the region of the Pelekane Bay Watershed in order to determine the precipitation produced by a ten-year and two two-year historical storms. Assuming that extreme stream flow events correspond to extreme rainfall events, stream flow data was used to determine which storms represent the 10-year and 2-year storms. A frequency analysis was performed on 27 records of annual peak discharge at the stream gauge. The record of annual peak flows ranged from 1963 to 2005. The frequency analysis was performed using the USGS Peak FQ program. The resulting log-normal probability plot *(Figure 3.13)* showed that a peak discharge of about 100 cfs at the gauge has an annual exceedance probability of 50% (two-year). A peak discharge of about 215 cfs at the gauge has an annual exceedance probability of 10% (ten-year).

The stream gauge recorded a peak stream-flow of 104 cfs on January 31, 1996 and 107 cfs on March 24, 1997. Assuming that a two-year flow is produced at the gauge by a two-year rainfall, the precipitation on these dates can be considered two-year events. The stream gauge recorded a peak discharge of 250 cfs on March 14, 2004, which is larger than the expected ten-year flow, and is taken as a conservative estimate of a ten-year event. These dates were therefore chosen to represent the 10-year and 2-year storms. See *Figures 3.14* and *3.15*.



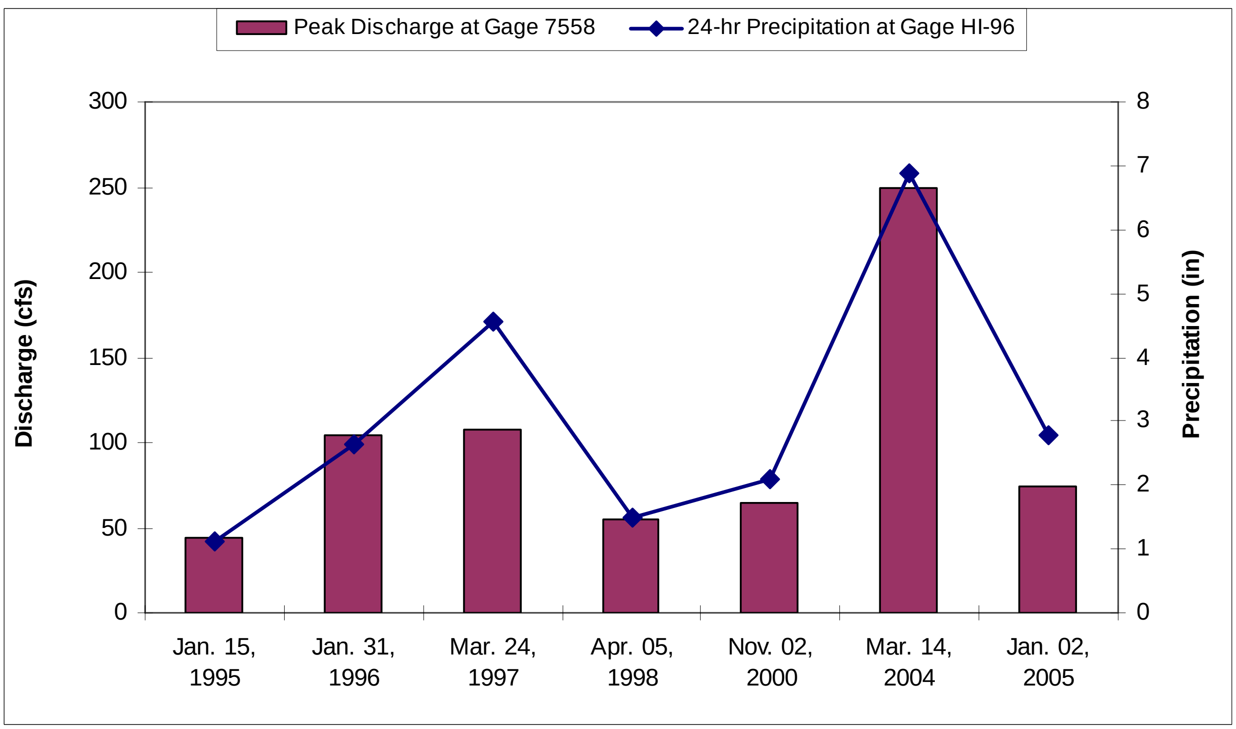


Figure 3.14 Rainfall and Ephemeral Stream Peak Flow Data from USGS Gauge 7558 Showing Poor Correlation between Rainfall at Gauge HI-96 and Peak Flow in the Upper Watershed

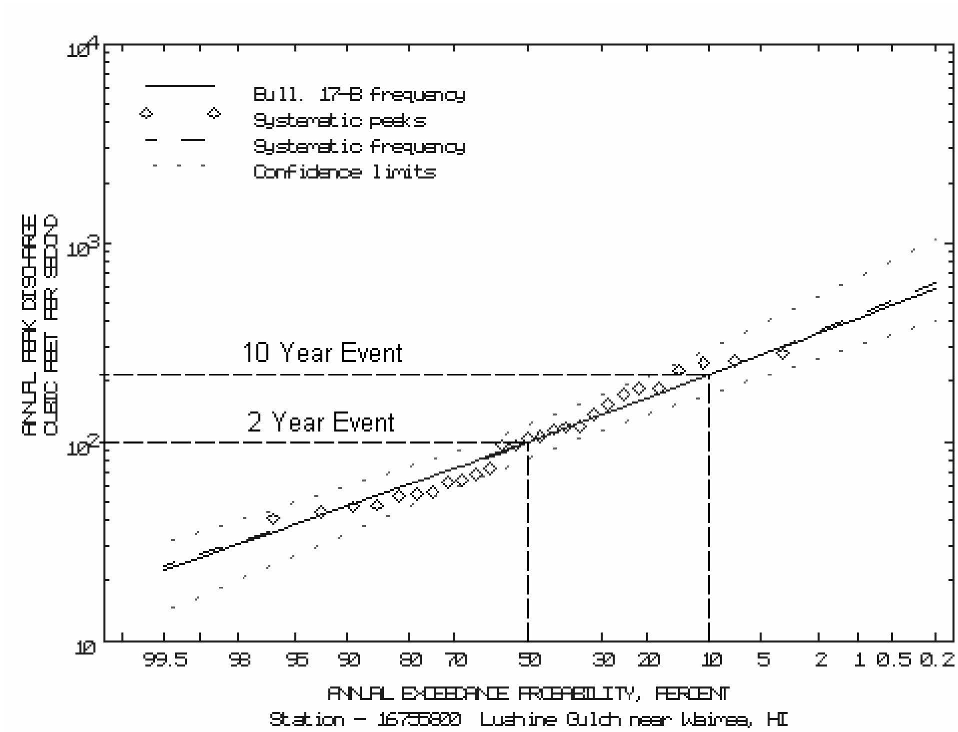


Figure 3.15 Analyses of Peak Flow Data from USGS Stream Gauge on Site was Used to Identify Storms Causing 2-year and 10-year Return Frequency Flow Events

3.1.5.2 Storms Selection for Modeling

Historic rainfall data was collected to capture the storms on the three dates specified in the Return Storm analyses above. Following preliminary analyses of the three storms, significant doubt was expressed as to the probable accuracy of the Annual Average results. To overcome this potential shortfall, two additional storms were selected and modeled that had magnitudes different from the initial storms (total of six). This distribution of storm sizes allowed the development of a regression of rainfall against sediment load from which an independent estimate of Annual Average sediment yield was obtained. This provides an alternative method to predict average annual sediment loads.

Data from the Kahua NWS Rain Gauge was used to determine the temporal distribution and the total precipitation of the six historic events. Fifteen minute interval rain gauge readings spanning a 72 hour period centered on the expected date of the storm was obtained from this rainfall gauge. The rainfall records from the six storms are shown in *Figure 3.16*.

- **Storm 1**: March 9, 2003 was a brief but intense "Kona storm" that approached the island from the south and, in contrast to other storms, deposited more rainfall at lower elevations than at upper elevations. The storm deposited 1.42 inches of rain, with 1.26 inches in one hour.
- **Storm 2**: A 10-year, 1-hour storm was extracted from the peak of the 10-year 24-hour storm of March 14, 2004. The 15 minute data showed that the peak 1-hour precipitation for this storm was 1.37 inches.

- **Storm 3**: The February 28, 2004 event was a 2-year, 24-hour storm with a total rainfall of 4.21 inches. This was the only storm with the classic bell shape intensity curve.
- **Storm 4**: The March 24, 1997 2-year, 24-hour event produced 1.75 inches over 24 hours, but consisted of two smaller events.
- **Storm 5** The January 31, 1996 2-year, 24-hour storm produced a total of 2.58 inches of rain during two separate periods of rainfall intensity.
- **Storm 6** The 10-year 24-hour storm on March 14, 2004 produced a total of 8.13 inches at the Kahua NWS Gauge. This intense storm included 3 separate peaks with continuous rain throughout the 24 hour period and caused significant flooding on many Big-Island streams *(Figure 3.15)*.

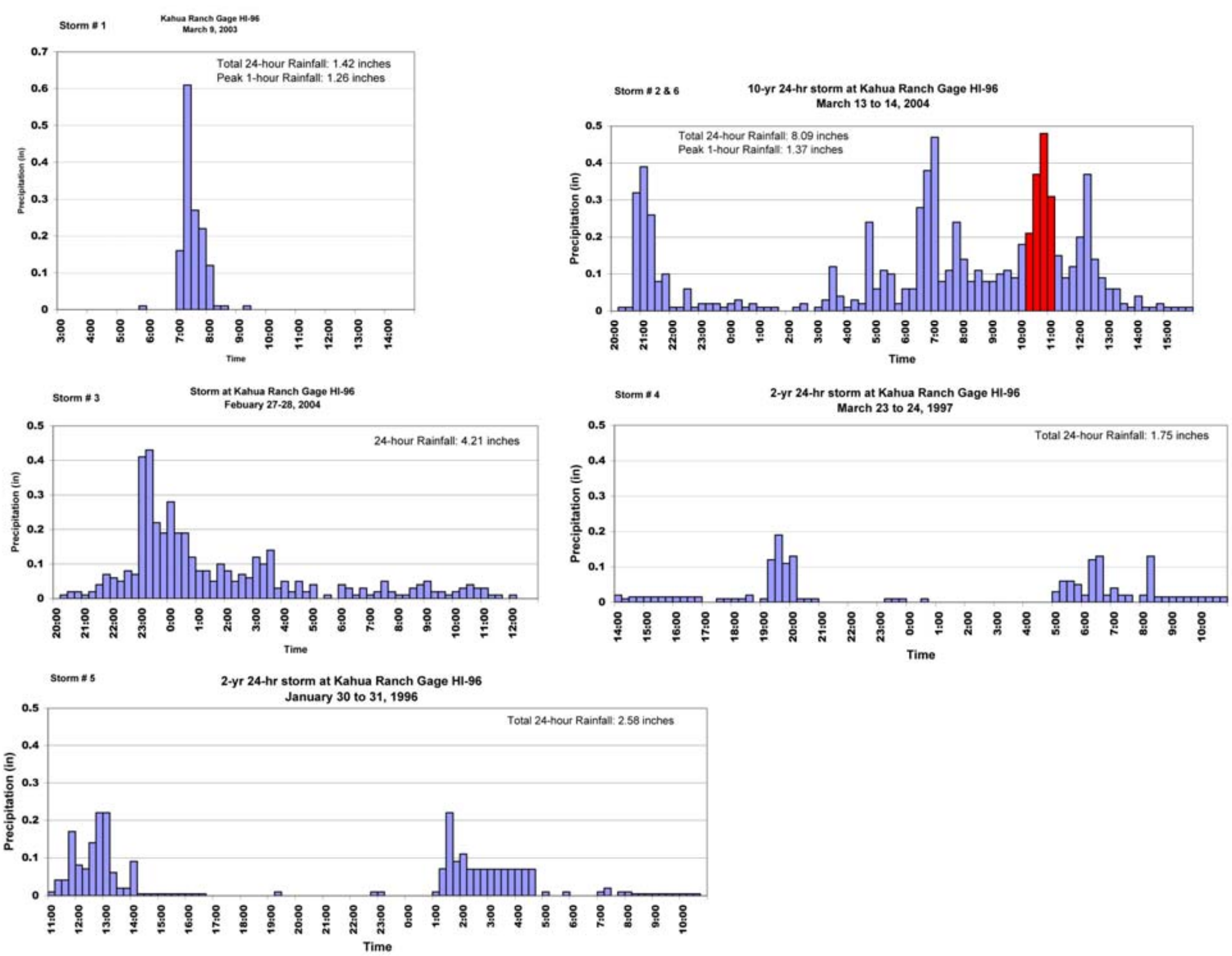


Figure 3.16 Rainfall Hyetograph for the Six Modeled Storms. Note that the 10-Year 1-Hour Storm is Extracted from the Height of the 10-Year 24-Hour Storm. Time and Rainfall Scales on all Charts Are Equal to Allow Direct Visual Comparison between Storms

3.1.5.3 Rainfall Distribution

Climatic distribution of rainfall plays a critical role in the character of vegetation across a watershed. The distribution of rainfall across the landscape during a storm event determines which portions of a watershed will produce the most runoff and thereby be subjected to the greatest erosive forces.

The N-SPECT model does not use true rainfall hyetograph information because there is no 'time-step' function in the model. Each rainfall event is inputted only as a total rainfall quantity per grid.

Due to the 4.2 mile distance between the Kahua NWS Gauge and the watershed, the precipitation recorded at the gauge will not be the same as the precipitation falling in the watershed. In addition, the precipitation within the watershed will not be constant throughout the entire area. Precipitation in this watershed is expected to increase with increasing elevation.

To understand the probable variation of storm rainfall over the site, average climatic rainfall values for the site were obtained from Parameter-elevation Regressions on Independent Slopes Model (PRISM), developed by the Spatial Climate Analysis Service at Oregon State University (http://www.ncgc.nrcs.usda.gov/products/datasets/climate/data/ and http://prism.oregonstate.edu/). Half-mile square grids were created to represent the rainfall totals occurring during the three storm events. The PRISM Group makes use of 30 years of data to develop spatially varied grids of monthly precipitation totals. The spatial variance of the rainfall pattern changes for each month, so the grid corresponding to the month of the storm in consideration was used (i.e. March monthly precipitation grid used for March 14, 2004 storm). The values in each square of the grids were then adjusted to reflect the historic precipitation occurring at the rain gauge. For instance, if 2.58 inches of rain fell at Kahua NWS on January 31, 1996, the value of the cell containing Kahua NWS was changed from the quantity given in the PRISM model to 2.58 inches. The values of all other cells were then changed by the same percentage. In this way, a rainfall grid that spatially distributed the historic rainfall over the entire watershed was created for each of the three storm events.

The assumption was made that rainfall from actual storms follows this long term rainfall distribution documented in the PRISM database. Experience of knowledgeable persons on site indicates that this is a valid assumption, except for rare "Kona" storms that approach the island from the south. The Kona storm (#1) occurred during a period when both upper and lower rain gauges were active in the watershed. The model rainfall was distributed to match actual rainfall amounts at these two gauges.

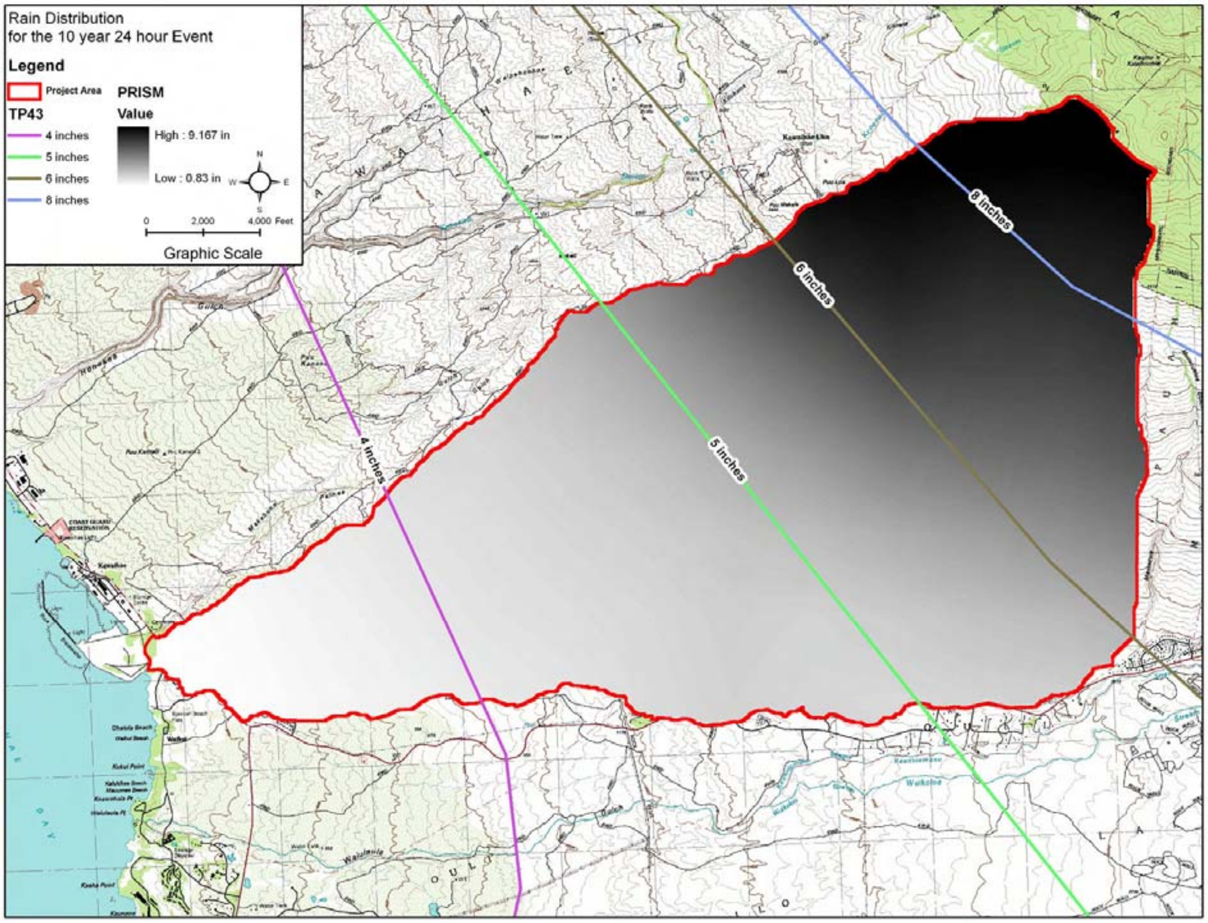


Figure 3.17 Distribution of Rainfall across the Watershed for the 10-Year 24-Hour Event

Verification of Rainfall Grids

The accuracy of the rainfall grids in depicting the precipitation in the watershed was determined by comparing the grid rainfall amounts to the actual record of the private rain gauges in upper and lower watershed locations. If the method used to develop the grids is accurate in representing reality, then we would expect the 10-year 1-hour grid to reproduce the same precipitation as the gauges recorded during the peak hour of the storm assuming same distribution as recorded storm.

Table 3.6 Comparison between Measured and Modeled Rainfall at Two Locations in the Watershed Measured in Inches.

Storm		Pelekane Rain Gauge - *Upper*	Pelekane Rain -Gauge *Lower*	Modeled Rain Upper	Modeled Rain Lower
1	Kona storm	1.41	1.83	1.41	1.83
2	10-yr 1-hour rain	1.04	0.29	1.06	0.32
3	2-yr 24 hr rain	4.41	5.22	3.14	0.97
4	2- yr 24 hr rain	1.36	0.41	1.36	0.43
5	2- yr 24 hr rain	1.75	0.80	1.75	0.85
6	10-yr 24 hr rain	4.97	2.37	6.30	1.92

It was concluded that, with the exception of storm #3, the difference between the actual measurements and the rainfall grid was small enough to consider the grid a good approximation of a typical rainfall distribution for normal rainfall events.

Kona storms approach the island from the south and do not typically follow the normal rainfall distribution. A single Kona storm (#1) was modeled that occurred on March 9, 2003. Rainfall distribution for this storm was opposite to that normally observed, with higher rainfall in the lower watershed area. Fortunately this event occurred during a period when both the upper and lower rain gauges on site were operational. The rainfall distribution was modeled to match the on-site data at these two locations.

3.1.6 Runoff

Runoff is a function of soil moisture prior to rainfall, the porosity of the soil, slope, vegetation cover, and the duration and intensity of the rainfall. Runoff initially occurs as thin surface flows (sheet flow) which coalesce as small rivulets of ever increasing size until they become concentrated runoff flows that empty into ephemeral streams. Sediments eroded and carried by sheet flows typically are fine enough to be carried to the base of the stream system without deposit in the stream. Ephemeral, intermittent, and permanent streams have developed stream beds that resist erosion during low to medium storm runoff events. Unless a storm exceeds a 1-year to 2-year event, there is not a significant amount of erosion and channel forming within the stream channel (Riley, 1998). In storms larger than a 1-year or 2-year event, surface flows are capable of coalescing to form rills and gullies with highly significant sediment production (Riley, 1998). These larger storms also produce enough energy within the streams to erode banks and modify stream alignment with significant additions to the stream sediment budget. A graphical interpretation of runoff over the Pelekane Bay Watershed is shown by *Figure 3.18*.

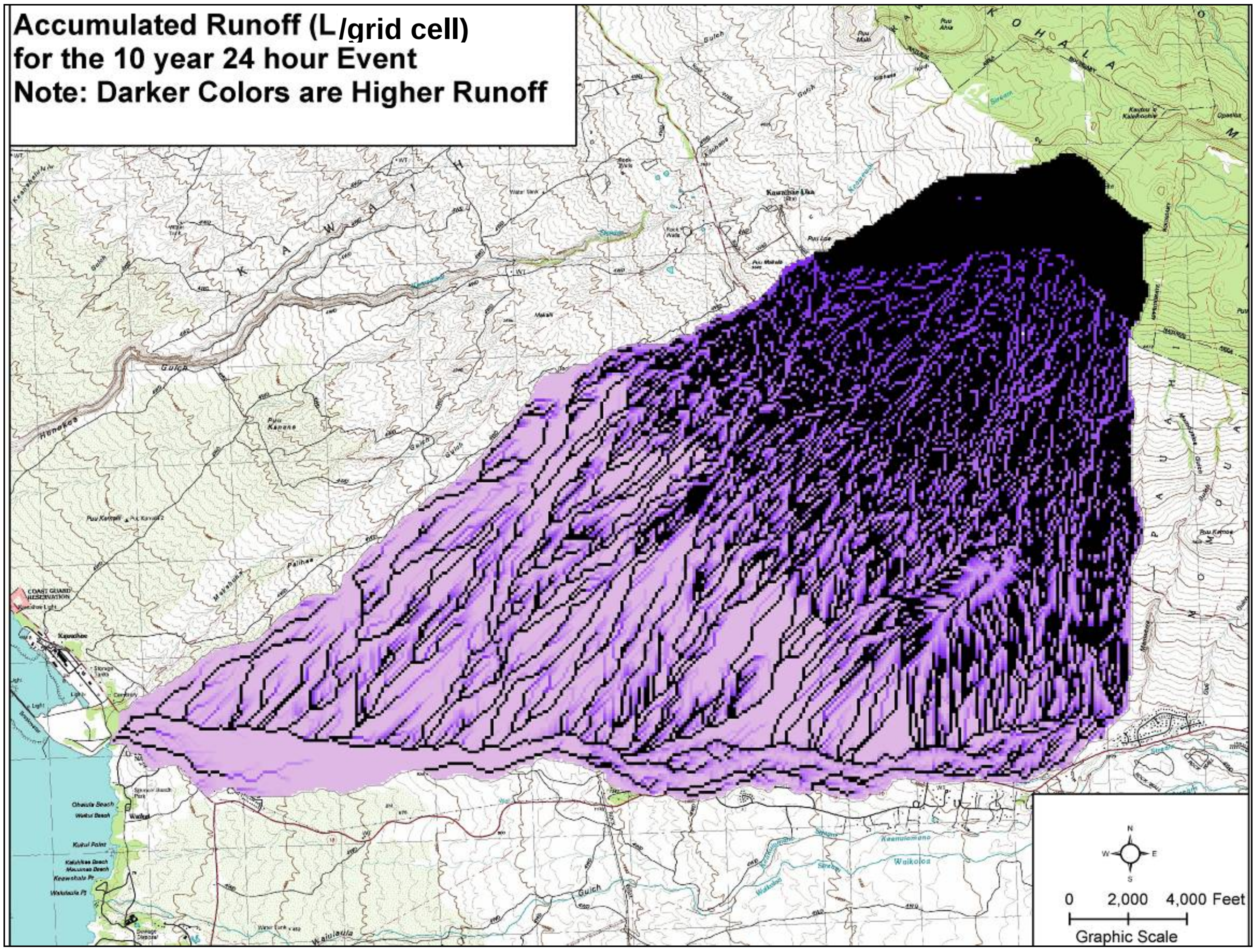


Figure 3.18 Graphical Interpretation of Runoff over Pelekane Bay Watershed

In the model each grid may receive runoff from adjacent grids with higher elevation. The curve number for the selected storm combined with the infiltration and absorption factors from soil type, slope, and vegetation combine to produce runoff that is directed to the next adjacent cell with the lowest elevation. In the runoff graphic *(Figure 3.18)* the color gradients represent only the lowest variations in runoff in surface flows, with all higher flows (essentially ephemeral streams) indicated as dark purple. In this largest of the storm events we modeled, sheet flow appears to have been dominant in the upper watershed where rainfall varied from about 4-inches to over 9-inches.

3.1.7 MUSLE Sediment Concentration

Given the quantity and location of runoff as well as the soil type, slope, and vegetation cover, the model uses the Universal Soil Loss Equation to calculate the amount of sediment eroded and carried by storm flows *(Figure 3.19)*. The model tracks sediment concentrations and volume of water as it is transferred (flows) and accumulated from each grid (down slope) to the next adjacent grid with the lowest elevation. The output from N-SPECT is MUSLE Sediment Concentration (kg/L).

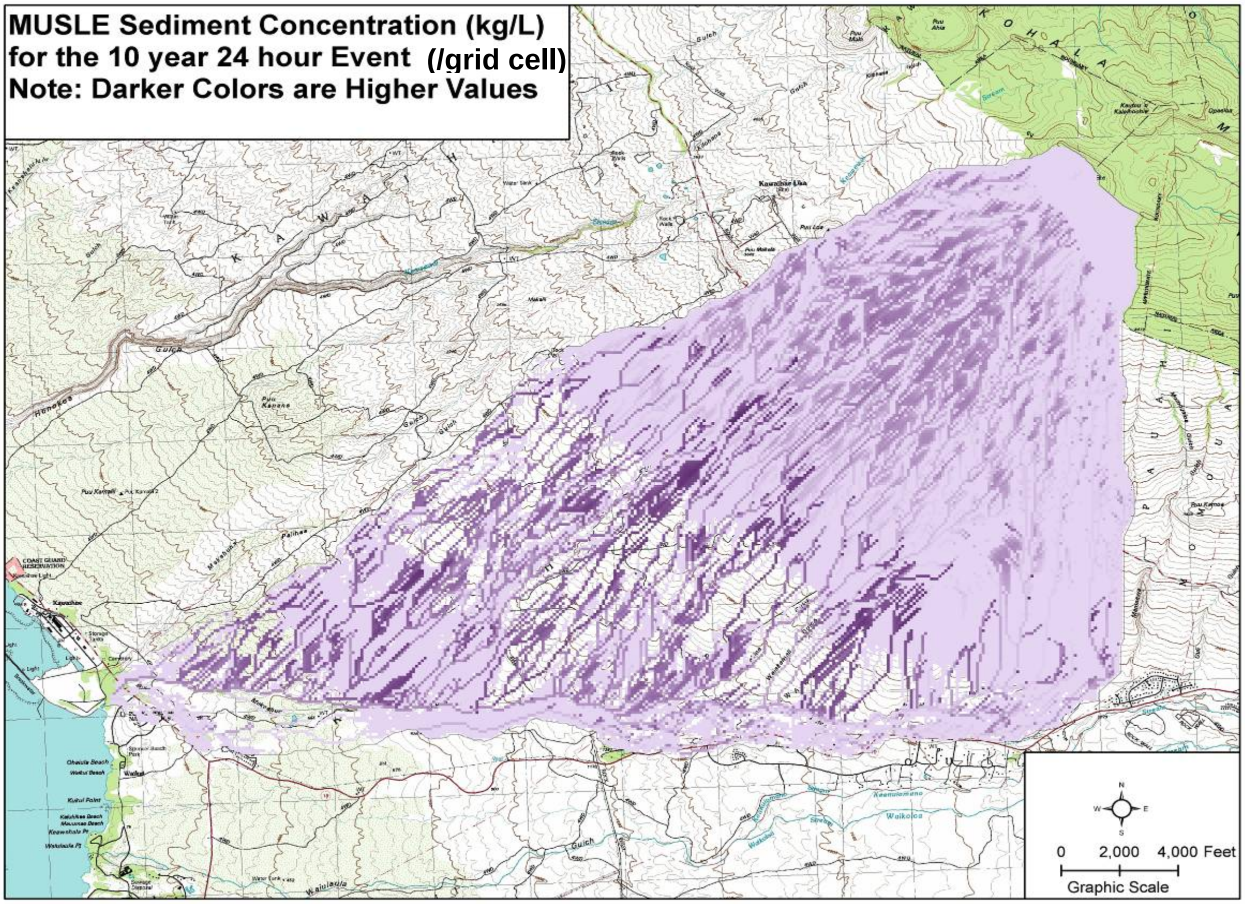


Figure 3.19 Sediment Concentration in the 10-Year, 24-Hour Event, Darker Areas Depict Areas where Erosion Leads to Higher Concentration of Sediment in Runoff

3.1.8 MUSLE Sediment Mass: Sediment Loads

Total sediment mass, or erosion, in the model is a simple product of runoff volume and sediment concentration to yield total mass. The model does not account for sediment re-deposition. Given the general geological form of the watershed, and the limited valley or low-slope areas, re-deposition of sediments does not appear to be a major factor in this watershed. Similar to the graphic for 'Runoff' the color gradation in *Figure 3.20* shows differences in the lowest sediment loads to show where erosion is taking place. Erosion quantities per grid, above some minimal amount, essentially represent sediments being transferred through a cell in a stream and are designated as black.

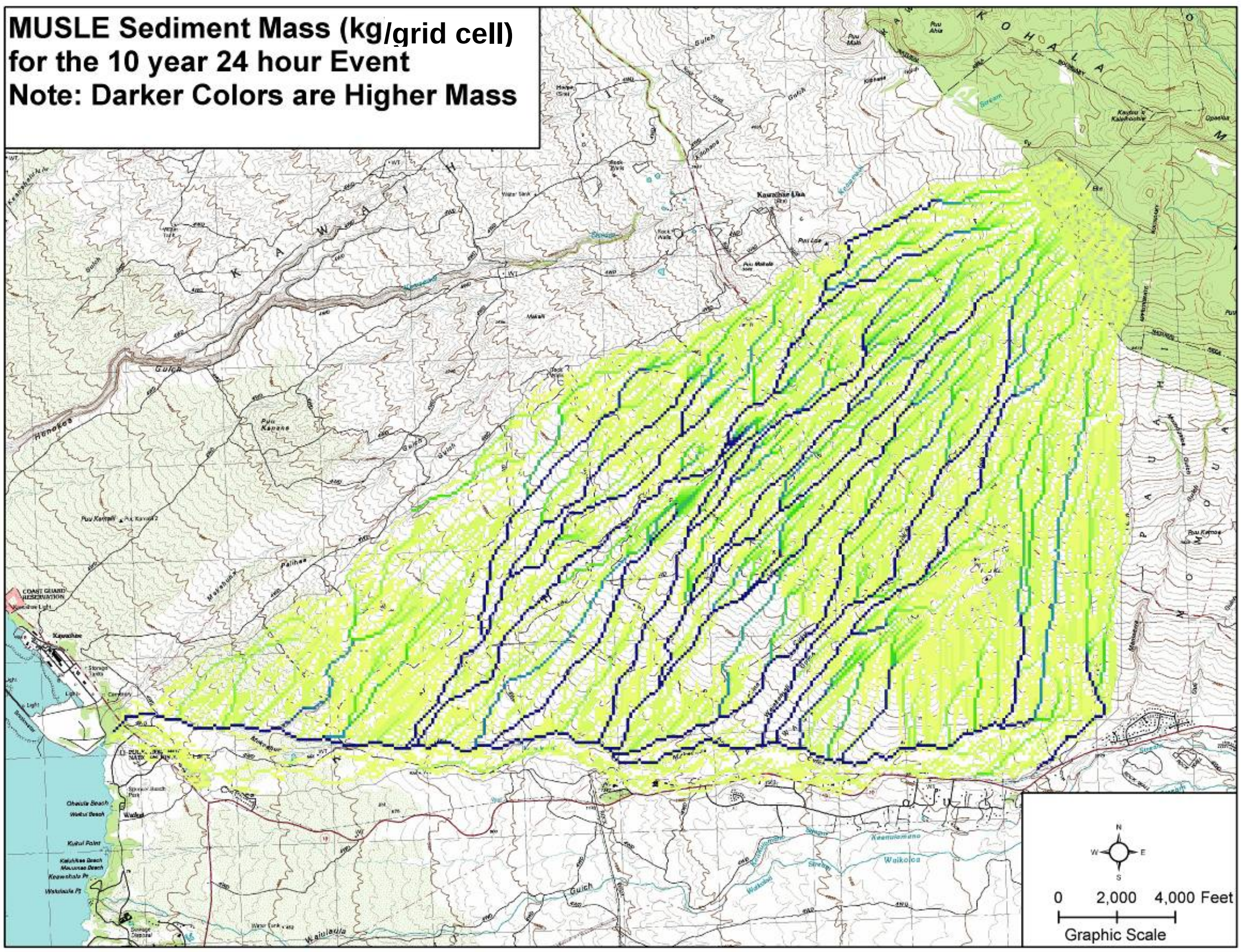


Figure 3.20 Mass of Sediment Calculated as the Volume of Water Times the Concentration of Sediments. Quantities in Cells at the Bottom of Each Sub-Watershed are Extracted to Tables and Represent Sediment Loss from Each Basin

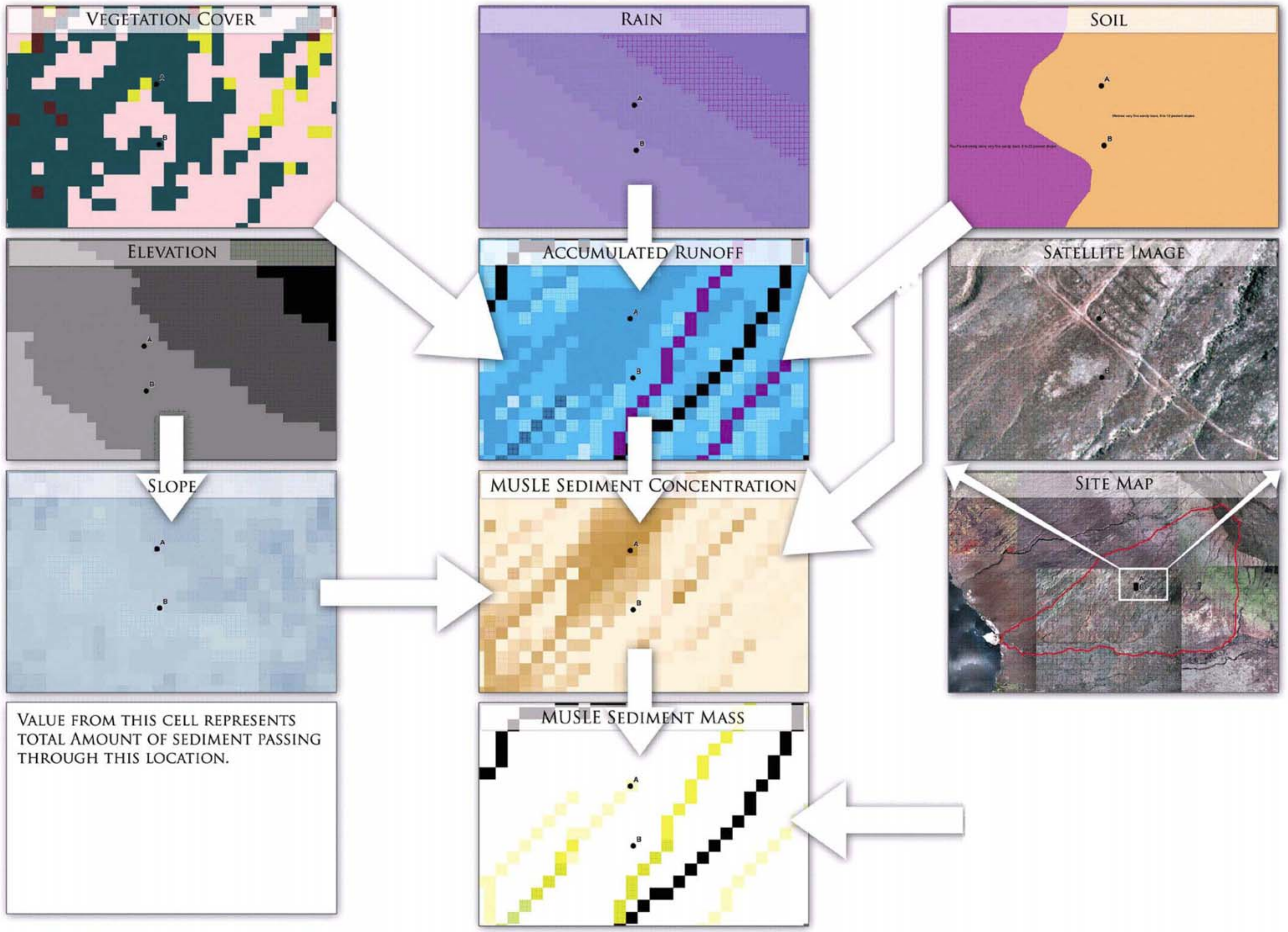


Figure 3.21 Graphic Representation of N-SPECT Model Operation Showing How Data Combined from Terrain, Rainfall, Soil Type and Vegetation Cover to Yield Runoff, Sediment Concentration and Total Mass of Sediment Eroded. Aerial Inset Shows Area of Enlargement. Dots A & B are Sample Points and are Representative of Scale.

3.2 MODEL INDEPENDENT CALCULATION OF WATERSHED SEDIMENT LOADS

Once the values of slope, curve number, cover, and soil type are set in each cell of the model across the watershed, rainfall quantity and distribution become the only true variables between storms. By running the model with different size storms and comparing the rainfall input to the model output (runoff volume and sediment mass) one is able to develop watershed specific regressions of rainfall versus sediment eroded.

4.0 MODEL RESULTS

4.0 MODEL RESULTS

4.1 N-SPECT MODEL RESULTS

A table showing the complete results of the six storm and one annual model runs is shown in the Appendix B. The total modeled sediment delivery mass by storm is shown graphically in *Figure 4.1*. A summary of the data from the entire watershed over all six storms is shown in *Table 4.1*, and by sub-watershed basin in *Table 4.2*.

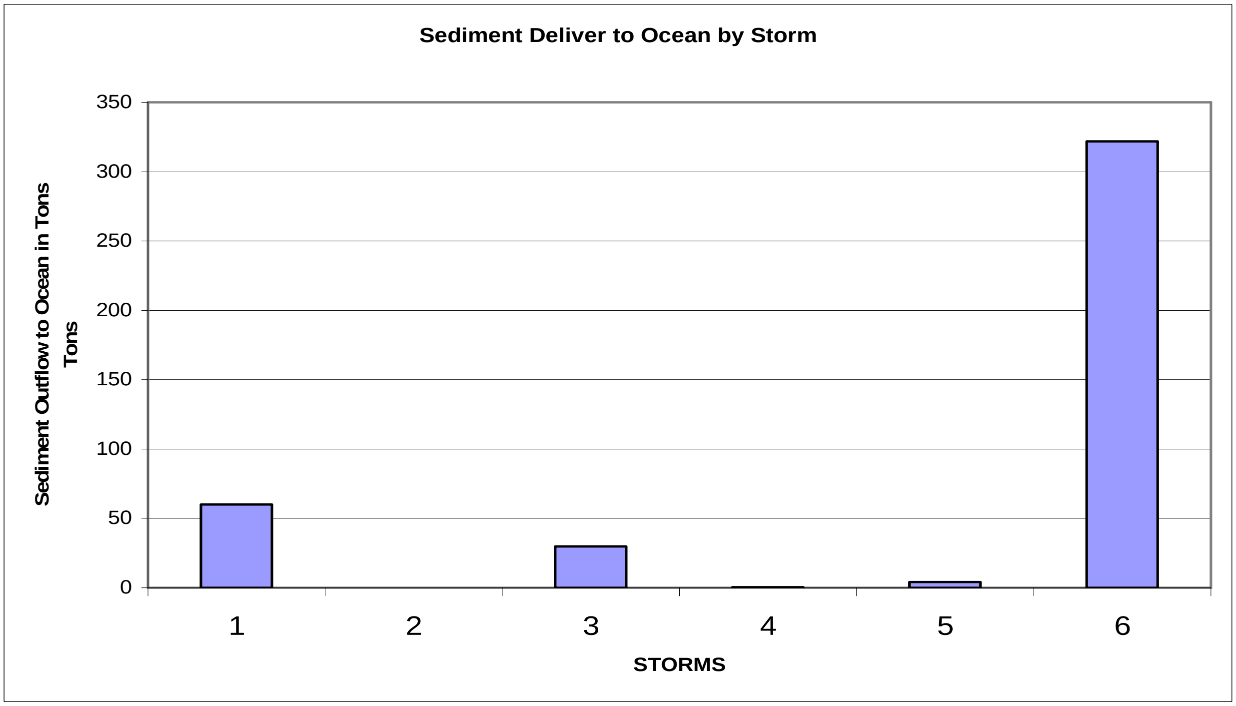


Figure 4.1 The Six Storms Modeled Resulted in Strikingly Different Quantities of Sediment Eroded to the Ocean at Pelekane Bay.

Table 4.1 Summary Results for Whole Watershed by Storm

Storm		Modeled Rainfall (inches)			Rain Vol m³	Accumulated Runoff m³	Percent Runoff	Sediment Conc. (mg/L)	Erosion	
		Upper	Lower	Average					Tons	Tons / acre
1	3/9/03 Event	1.41	1.84	1.64	1,559,000	86,000	5.5%	700	59.9	0.0065
2	10-year, 1-hour Storm, 2004	1.07	0.34	0.67	641,000	4,400	0.7%	21	0.1	0.0000
3	2/28/04 Event	3.14	0.97	2.08	1,972,000	267,000	13.5%	112	29.8	0.0032
4	2y-year 24-hour Storm, 1997	1.36	0.43	0.86	819,000	13,300	1.6%	37	0.5	0.0001
5	2- Year 24 Hour, 1996	1.75	0.85	1.26	1,198,000	41,000	3.4%	102	4.2	0.0005
6	10-year, 24-hour Storm, 2004	6.30	1.99	3.99	3,788,000	1,119,000	29.5%	288	321.8	0.0348

The average rainfall in the modeled storms varied from 0.67-inch to 3.99 inches and displays an exponential capability of larger storms to cause more erosion. In the largest storm with 3.99 average inches of rainfall approximately 322 tons of sediment was delivered to Pelekane Bay, but at half this average rainfall amount (2.06 –inch, Storm 3) less than 1/10th the sediment load (30 tons) was delivered. Storm 5, with 1.26 inch average rain, delivered only about 4 tons of sediment to the Bay. This is in sharp contrast, however, with the Kona storm (Storm 1, average rain 1.64-inch) which deposited the majority of the rainfall in the lower watershed and resulted in almost 60 tons of sediment yield. It is apparent that rainfall quantities in the lower watershed have a greater impact on sedimentation than rainfall in the upper watershed.

Examination of the erosion concentration graphics shows concentrations of high erosion rates (high sediment concentrations) in the central and lower watershed *(Figure 4.2 and Appendix A)*. These areas appear to be of moderate to steep slope with sparse or no vegetation cover. The erosion patterns in the watershed quickly coalesce into numerous parallel small gullies.

Analyzing more storms of greater variance than required by the contract allowed the construction of a regression relationship between rainfall and runoff / sediment production. The results of regression analyses of the six events, rainfall against runoff and rainfall against sediment production, are shown in *Figure 4.3*. Calculation of these regressions is only made possible due to the unique method N-SPECT uses to calculate all runoff and sediment load variables in terms of rainfall. This results in what is essentially one summation (one term for each modeled square area) with only a single variable – rainfall. In this model the only reason that two different storm events with equal intensity (i.e. both 1.5-inch storms) will yield different runoff quantities, is the distribution of the runoff across the watershed.

There was a direct exponential relationship between stream flow and sediment quantity eroded to the ocean *(Figure 4.3, g)*:

$$M = (7Q/100{,}000)^{1{,}4738} \qquad (R^2 = 0.94) \qquad (1)$$

where M is mass in metric tons of sediment eroded to the ocean during the storm and Q is the total runoff of water to the ocean in cubic meters during the storm.

A load of 10 tons of sediment to the ocean would result from a flow of 69,000 cubic meters of stream flow with an average sediment concentration of 145mg/L.

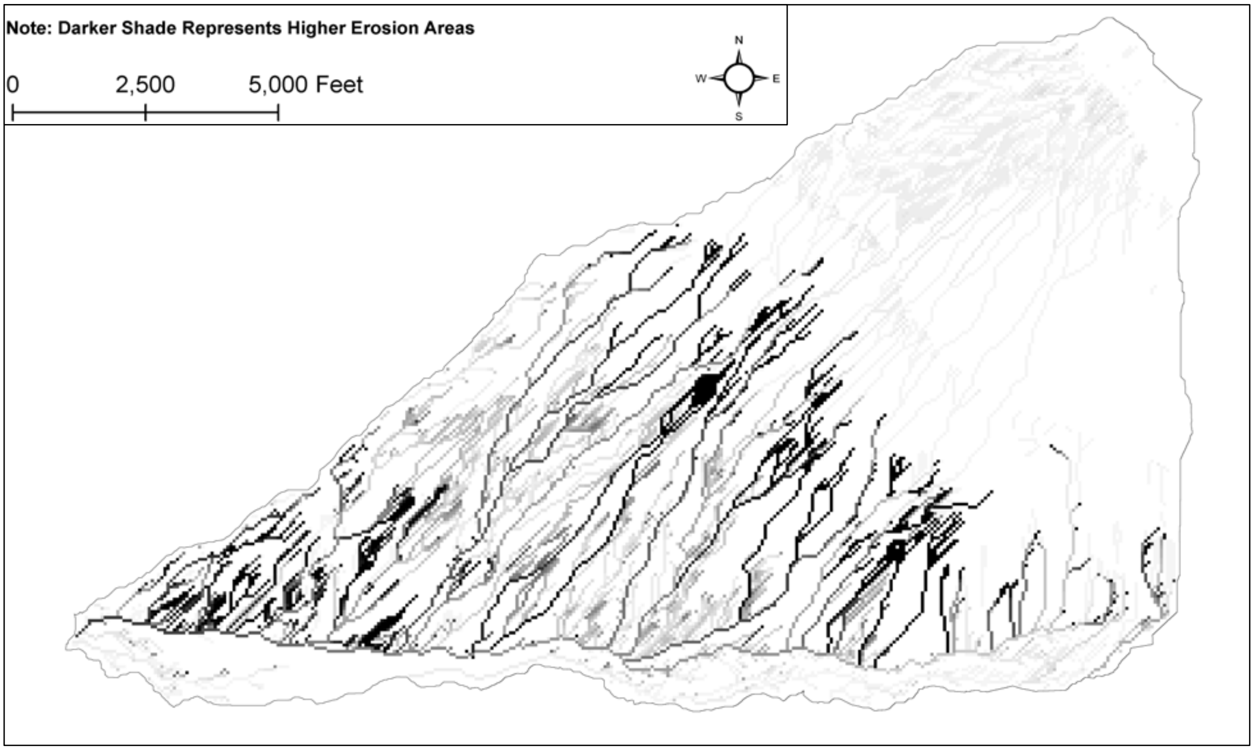
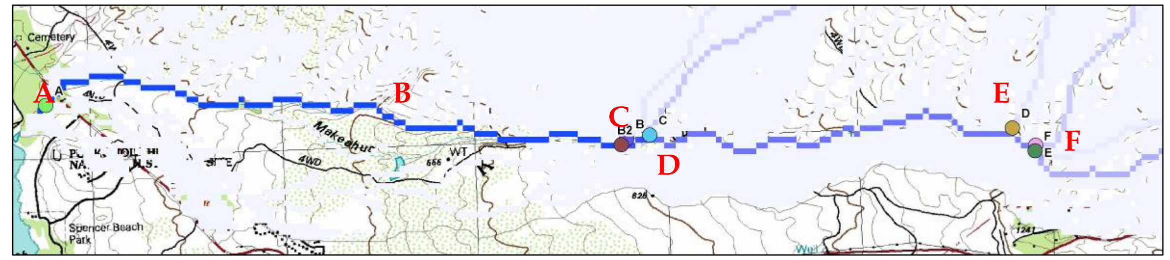


Figure 4.2 Graphic Representation of High Erosion Areas within Pelekane Bay Watershed Compiled from Five Storm Events



Annual Average – Total Rainfall 16.4" Upper, 5.5" Lower Watershed over 30 Days/Year

	Watershed	A	B	C	D	E	F
Water Flow, 1,000 m^3	4691	50	293	1173	385	955	1784
Sediment Transport, Tons	15,329	2604	1804	1500	1005	2483	4274

1. "Kona" Storm 3/09/03
Rainfall: 1.41" Upper, 1.84"Lower 5.5% Runoff

	Watershed	A	B	C	D	E	F
Water Flow, 1,000 m^3	85	30.3	8.7	6.5	3.4	6.3	21.8
Sediment Transport, Metric Tons	60	39	3	2	1	2	8

2. 10-Year 1-Hr Storm 3/14/04
Rainfall: 1.07" Upper, 0.34" Lower 0.7% Runoff

	Watershed	A	B	C	D	E	F
Water Flow, 1,000 m^3	4.4	0.0	0.2	1.5	0.3	0.9	1.4
Sediment Transport, Metric Tons	0.09	0.00	0.02	0.03	0.02	0.01	0.01

3. Storm 2/28/04
Total Rainfall: 3.1" Upper 0.97" Lower 13 % Runoff

	Watershed	A	B	C	D	E	F
Water Flow, 1,000 m^3	266.5	2.1	16.7	66.9	21.7	55.1	101.5
Sediment Transport, Metric Tons	29.8	1.2	3.5	7.1	4.1	5.7	7.2

4. 2-Year 24 Hr Storm Date
Total Rainfall: 1.36" Upper 0.43" Lower, 1.6% Runoff

	Watershed	A	B	C	D	E	F
Water Flow, 1,000 m^3	13.3	0.0	0.5	4.6	0.9	2.8	4.3
Sediment Transport, Metric Tons	0.05	0.00	0.01	0.01	0.01	0.01	0.00

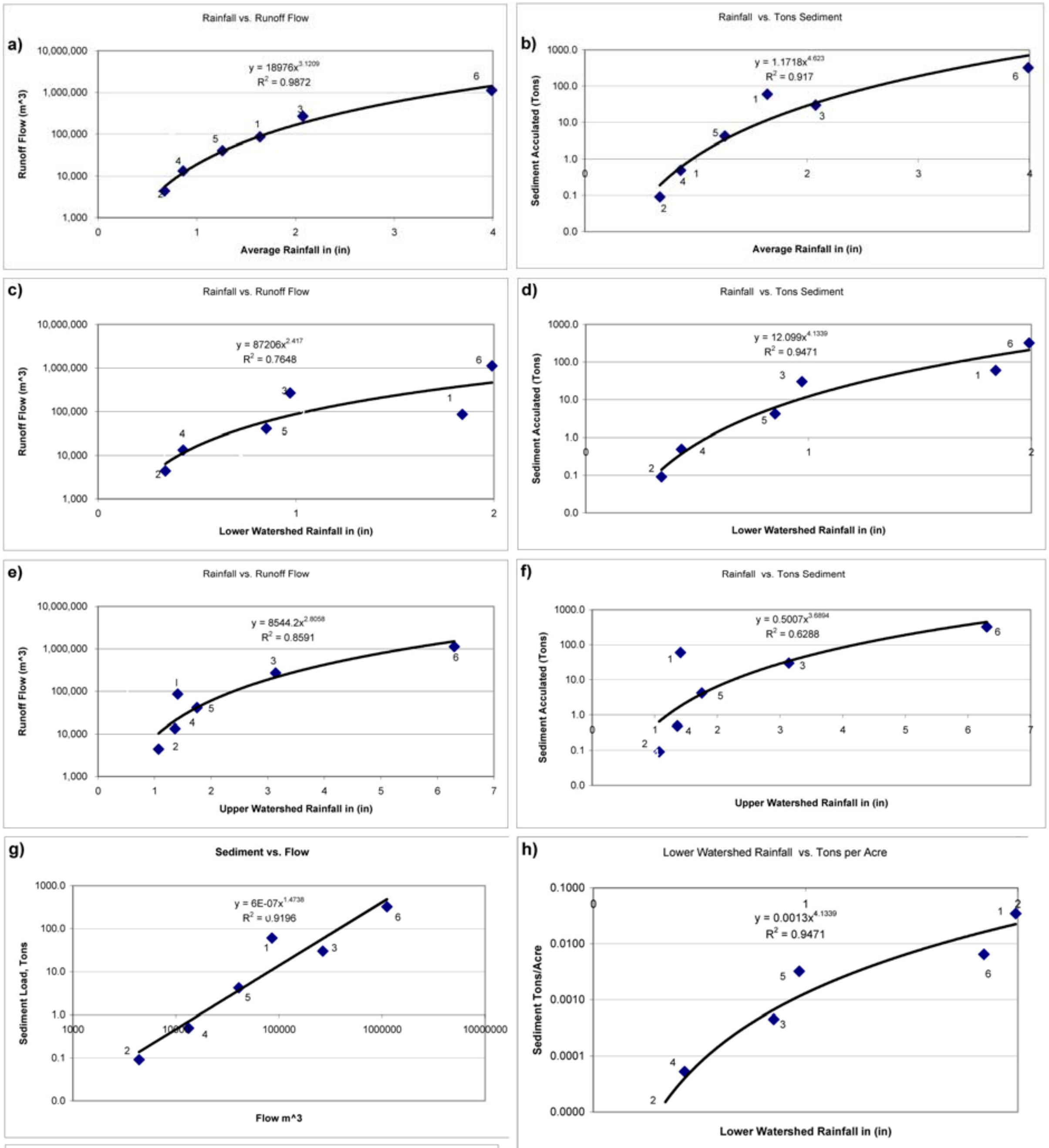
5. 2-Year 24 Hr Storm 3/23/96
Total Rainfall: 1.75" Upper 0.85" Lower 3.4% Runoff

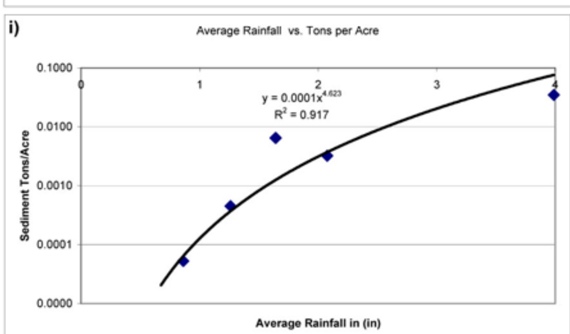
	Watershed	A	B	C	D	E	F
Water Flow, 1,000 m^3	40.8	1.2	3.5	12.1	3.5	8.0	11.2
Sediment Transport, Metric Tons	4.11	0.06	0.74	1.04	0.67	0.68	0.53

6. 10-Year 24 Hr Storm 3/14/04
Total Rainfall: 6.3" Upper 1.99" Lower 29.5% Runoff

	Watershed	A	B	C	D	E	F
Water Flow, 1,000 m^3	1118.6	12.9	83.4	242.5	90.4	223.5	453.2
Sediment Transport, Metric Tons	322	11	35	63	40	66	86

Table 4.2 Model Results





Storm	Year	Rainfall (inches)	
		Upper	Lower
1 3/9	'03	1.41	1.84
2 10y-1h	'04	1.07	0.34
3 2/28/04	'04	3.14	0.97
4 2y-24h	'97	1.36	0.43
5 2y-24h	'96	1.75	0.85
6 10y-24h	'04	6.3	1.99

Figure 4.3 Analyses of Total Flow and Sediment Load Exiting Stream Mouth as Calculated from Model Results from Six Storms in the Pelekane Bay Watershed

The best estimate for stream flow was obtained by comparison of flow to average rainfall across the whole watershed

$$Q = 18976\, r_{avg}^{3.1209} \qquad (R^2 = .98) \qquad (2)$$

where Q is total runoff to the ocean in cubic meters and
r_{avg} is inches of rainfall averaged across the watershed.

Stream flow of 69,000 m^3 would result from an average rainfall of 1.52 inches.

Direct substitution of equation *(2)* into equation *(1)* solves directly for mass eroded from average rainfall.

$$M = 1.519\, r_{avg}^{4.60} \qquad (3)$$

A rainfall of 1.52 inches would yield a mass of erosion equal to 10.4 tons.

The above equation (3) is close to the equation obtained by direct regression of average rainfall against erosion mass delivered *(Figure 5.3, b)*

$$M = 1.718\, r_{avg}^{4.623} \qquad (R^2 = .917) \quad (4)$$

A rainfall of 1.47 inches averaged across the whole watershed would produce an eroded mass of 10 tons to Pelekane Bay.

Note that the regression of rainfall averaged across only the lower watershed produces a better fit *(Figure 4.3, d)*, due to the greater sediment delivery potential of the lower watershed as seen in the Kona storm (#1).

$$M = 12.009\, r_{low}^{4.1339} \qquad (R^2 = .947) \qquad (5)$$

A rainfall in the <u>lower</u> watershed of only 0.96 inches would yield 10 tons of sediment to the ocean.

Direct model calculation of annual sediment load for the watershed yielded a result of 15,329 tons. This quantity appears to be unrealistically high. To attain this quantity of sediment yield both the percent runoff and the sediment concentration in the runoff would need to be unreasonably high [42-inch average rainfall over 37,400,400 square meters x 30% runoff = 1,196,962 m^3 @ 1,280 mg/L to yield 15,329 tons].

An independent estimate of the annual load was created using an "average" rainfall year totaling 22.5 inches over the lower watershed. We modeled against rainfall in the lower watershed because rainfall there had the best fit regression against eroded sediment delivered. This 22.5 inches of rain was distributed over storm intensities expected from long term (50-year) data records. The distribution of storms with return frequency of 1-year or greater was taken directly from the "Lower Watershed" and extracted from the United States Weather Bureau's, <u>Rainfall-Frequency Atlas of the Hawaiian Islands</u> (1962). Frequencies lower than one year were estimated by examination of the Kahua NWS Gauge and corrected for total rainfall according to the PRISM rainfall distribution. These calculations, summarized in *Table 4.3,* result in an average annual sediment load to Pelekane Bay of 4,222 tons, or 211,100 tons in 50 years. However, of the 4,222 ton average, 3,502 tons (83%) of sediment are the product of large storms with return periods greater than one year. This underscores the over-riding influence of large storms in the sediment budget of Pelekane Bay. Any measures aimed at reducing sediment loads to Pelekane Bay must be functional in very large storms. Erosion prevention measures should concentrate in the lower watershed area as these soils have the greatest potential for erosion during the large storm events.

Table 4.3 Annual and 50-year Total Sediment Load Calculations

Lower Watershed Rainfall Inches Rain (X)	Sediment Delivery Y = Tons per Storm	Annual Incidence of Storms Lower Pelekane Bay Watershed	Tons per Average Year	Rain per Year
0.01 to 0.25	0	145	0	7.00
0.25 to 0.49	0.21	15	3.1	5.63
0.5 to .74	1.73	2.5	4	1.56
0.75 to 0.99	6.97	1.4	10	1.23
1 to 2.24	90.03	1.1	99	1.79
2.25 to 2.89	603.76	1	604	2.25
2.9 to 3.69	1683.58	0.5	842	1.65
3.7 to 4.49	4129.87	0.2	826	0.82
4.5 to 5.29	8628.81	0.1	863	0.49
5.3 to 5.89	14985.94	0.04	599	0.22
5.9 or more	18594.08	0.02	372	0.12

4,222	Total Tons in Average Year
211,100	Total Tons in 50 Years
22.8	Average Annual Rainfall, Inches in Lower Watershed
720	Annual Load from Small Storms, Equal or Less than 1 Year Incidence
3,502	Annual Load from Large Storms Greater than 1 Year Incidence
83%	of Sediment Load Results from Large Storms with Return Periods > 1 Year

Y= Sediment Delivery to Ocean
X= Lower Watershed Rainfall
Y= 12.099 x^4.1339

4.2 N-SPECT MODEL SENSITIVITY ANALYSES

The reliability of data generated by a model is limited by the capacity of the algorithms to emulate natural processes, the correctness of the model parameters in emulating the physical characteristics of the site, and the accuracy of the storm data input. All of the parameters in the N-SPECT model are derived from curve numbers (CNs). The CNs used are derived exclusively from data generated in other watersheds (U.S. Mainland), and although they have been verified in Hawai'i, their application to the specific soil and vegetation types in Pelekane Bay Watershed have not been tested. It appears reasonable, therefore, to assess the sensitivity of the model output to controlled variation in the CNs used.

Simply stated CN is a relative measure of how much precipitation is expected to soak into the ground and how much is expected to runoff. A CN of 1.00 represents a totally impervious smooth surface where all of the rainfall runs off. A CN of 0.00 represents either a highly porous soil, or an open body of water, where all the rain that falls becomes absorbed and nothing runs off to lower portions of the watershed. To test the sensitivity of the model to changes in CN values, a single storm event was modeled with CN values varied by +10%, +0.01, -0.01, and -10%. For CNs above 0.83, a 10% increase was deemed too extreme (and could exceed 1.0!) and their values were increase by half the distance to 1.00.

Storm 3 (2/28/04) dropped an average of 2.08 inches of rainfall over the watershed, totaling 1,972,000 million cubic meters of water. This rainfall produced a total of 266,000 cubic meters of runoff (13.5%) and carried 29 tons of sediment. When the CN values were varied the results below were obtained.

Table 4.4 Sensitivity Analyses Results Based on Varied CN Values

CN	Rainfall m^3	Runoff m^3	Percent runoff	Tons Sediment
+ 10 %	1,972,086	408,798	20.7	82.8
+ 0.01	1,972,086	285,960	14.5	34.0
No Change	1,972,086	266,396	13.5	29.4
- 0.01	1,972,086	247,704	12.6	25.4
- 10%	1,972,086	160,516	8.1	7.8

The model, as expected, is sensitive to changes in the CN values. A 10% increase in all of the CN values will increase the calculated runoff by about half and the total sediment load by more than double. A decrease in CN values by 10% will cause an apparent decrease in both runoff and sediment load by about 40%. A change in CN number by +/- 0.01 will result in an increase or decrease in calculated runoff of about 7% and sediment load of 12-15%. There is some variance in these changes across the watershed, from one sub-watershed to the next, but the general trend of sensitivity to CN value change is consistent. Calculations for all of the parameters in all of the sub-watersheds and the CN values used in their calculation are presented in the attached spreadsheet.

In an attempt to further ground truth the model, flow data was downloaded from a USGS peak gauge located within the watershed. These gauges are measured only once per year. At each gauge the maximum flow height in the stream is ascertained (typically by noting the elevation of chalk washed off of a hanging tape measure protected by a pipe), and stream flow (cfs) is calculated knowing the slope and cross section of the stream at this point. The USGS peak flow gauge 16755800 is located at an elevation of 3,180 feet in sub-watershed F in Luahine Gulch with a drainage area of 0.32 square miles. Data from the gauge is shown in *Table 3.8* below.

Because the data is obtained only on an annual basis, and the date of the maximum flow is not recorded, it is difficult to ascertain the rainfall event that caused the maximum flow event. *Figure 3.14* shows the correlation between maximum flow and maximum annual 24-hour precipitation recorded at the nearby rain gauge HI-96. Because the peak gauge yields calculates data as instantaneous flow rate, and the N-SPECT model calculates total (accumulated) flow per storm event, there does not appear to be any effective method to use the peak flow data to ground truth the model.

Table 4.5 Data from Luahine Gulch USGS Gauge #16755800

Hawaii County, Hawaii
Hydrologic Unit Code 20010000
Latitude 20°02'54.0", Longitude 155°44'15.9" NAD83
Drainage area 0.32 square miles
Gage datum 3,180 feet above sea level HILOCAL

Output formats
Table
Graph
Tab-separated file
WATSTORE formatted file
Reselect output format

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1963	Jan. 16, 1963	3.83	174
1964	Jan. 27, 1964	2.83	115
1965	Mar. 03, 1965	2.29	53.0
1966	Aug. 24, 1966	2.87	96.0
1967	Jan. 11, 1967	5.03	254
1968	Apr. 20, 1968	4.09	186
1969	Dec. 13, 1968	3.17	119
1970	Jan. 06, 1970	2.86	96.0
1971	Jan. 19, 1971	3.69	155
1972	Aug. 31, 1972	2.22	48.0
1974	Jan. 07, 1974	3.16	118
1975	Mar. 01, 1975	2.51	69.0
1976	Jan. 16, 1976	2.21	47.0
1977	Apr. 20, 1977	2.34	56.0
1979	Jan. 14, 1979	3.41	136
1980	Jan. 09, 1980	4.69	230

Water Year	Date	Gage Height (feet)	Stream-flow (cfs)
1982	Feb. 11, 1982	4.09	185
1983	Dec. 18, 1982	2.12	41
1989	Apr. 07, 1989	5.33	277
1994	Mar. 25, 1994	2.44	63.0
1995	Jan. 15, 1995	2.17	44.0
1996	Jan. 31, 1996	2.99	104
1997	Mar. 24, 1997	3.03	107
1998	Apr. 05, 1998	2.31	55.0
1999	Mar. 21, 1999	2.34	56
2000	Dec. 03, 1999	2.21	47
2001	Nov. 02, 2000	2.45	64.0
2002	Feb. 26, 2002	2.71	83
2003	Jan. 20, 2003	2.52	70
2004	Mar. 14, 2004	4.96	250
2005	Jan. 02, 2005	2.57	74.0
2006	Dec. 08, 2005	2.09	39

5.0 BATHYMETRY AND SEDIMENT CHARACTERIZATION

5.0 BATHYMETRY AND SEDIMENT CHARACTERIZATION

5.1 BATHYMETRY SURVEY

To understand the impact of watershed erosion on the bay, the study analyzed sediments deposited in the bay and performed a near shore bathymetry survey and compared this information to similar data obtained prior to construction of the harbor. The difference in bathymetry gives an estimate of the quantity of sediment that has accumulated in the bay as a result of stream sediment deposition during the ensuing 50 years since harbor construction.

Anecdotal information indicates that Pelekane Bay has undergone significant sedimentation during the past 50 year since the construction of the adjacent harbor. While the runoff model can predict the amount of sediment eroded from the watershed, it can not predict how much of that sediment remains in the bay. Existing bathymetry (5-foot contours) was obtained from the USACE SHOALS LIDAR bathymetry dataset (USACE, 2000) (*Figure 5.1*). Although this data proved unreliable in the shallow bay (likely due to high turbidity) it does give a qualitative view of sedimentation patterns. To quantify the long term impact of sedimentation in Pelekane Bay the present bathymetry of the bay was measured and compared to pre-harbor bathymetry.

A bathymetric survey was conducted using a total station survey transit from a single location at the center of the beach. Horizontal measurements were made to existing physical landmarks, and to the shoreline surrounding the bay to create temporary benchmarks. Vertical control to the temporary benchmarks was established by serial measurements of physical sea level at known times and tying the measurements to tide measurements at the NOAA Tide Gauge (#1617433) located in the adjacent Kawaihae Harbor. Using this method, the vertical accuracy can be estimated as +/- 0.5 ft. Three transect lines were measured through the left, center, and right side of the bay with stations approximately every 100 feet to a depth of seven feet about 800 feet off shore where firm substrate was encountered.

Results of the present bathymetry were compared to a bathymetry chart developed prior to harbor construction (Corps, 1954) and showing the planned location of the breakwater along the north side of Pelekane Bay. Two bathymetry lines from this initial survey extended into what is now Pelekane Bay, and we were able to reconstruct bathymetry lines from this data *(Figure 5.2 (a))*. A depth of deposition chart was created by noting the difference between the pre-harbor and present bathymetry charts, and a total volume of this deposition was calculated (*Figure 5.2(b) & (c)*).

5.2 SEDIMENT CHARACTERIZATION

Based upon a pre-survey site visit it was assumed that the bulk of the sediment within the bay would be sufficiently soft to allow coring using a hand auger core. This proved to be incorrect with the hand operated core unable to penetrate more than about a half foot into the benthic substrate. Although coring of sediments proved to be an ineffective method of measuring new sediment depths, the surface sediments obtained were subjected to size fraction and calcium carbonate content analyses. Sediment samples were obtained from the stream mouth (which was open to the sea at the time of the sample), beach dune, beach toe, a series of substrate samples out to a depth of 4-feet, and from the adjacent Samuel Spencer Beach Park as a control.

5.3 RESULTS

To quantify the amount of material deposited, charts prepared for the construction of Kawaihae Harbor in 1955 were compared with bathymetry data obtained in the present study. The results of this survey are shown in *Figure 5.2 (b)*. By subtracting the present survey elevations from the historical elevations, we developed a chart showing the depth of accumulated sediments within the bay *(Figure 5.2 (c))*. The total quantity of accumulated sediments within the surveyed area of Pelekane Bay is approximately 1,264,000 cubic feet, or 46,800 cubic yards, with an estimated weight (@ 1.33 tons / cy) of 62,300 tons. This is less than 1/10th of the sediment load predicted by the N-SPECT annual model (766,450 tons) but only about 1/3 the volume predicted by the independent "average year" runoff calculations. A density of only 67.6 lg/ft^3 is very light and will tend to float away in sea water (density 64 lb/ft^3). In the field was a high percentage of basalt gravel & sand with little of the lighter fine sediments was found. Presumably, these less dense sediments have been washed away by waves and currents. Presenting a range of densities (and therefore deposition estimates) will not change the findings and are not likely justified by the imprecision of the model and bathymetric measurement results.

The extent of the sediment plume can be determined qualitatively by examination of high detail LIDAR bathymetry images created from USACE SHOALS bathymetry dataset (USACE, 2000). *Figure 5.3* shows a shaded relief and false color/depth chart of the general area in which details of the harbor and coral reefs can easily be seen. *Figure 5.4* presents a more detailed close-up of Pelekane Bay. Note that the LIDAR data does not extend to the inner shoreline of the bay – most likely because LIDAR is not able to penetrate highly turbid waters. The area of accumulated sediment can be seen as the relatively smooth benthic surface as compared to the irregular surface of the adjacent coral reef. Note also the pre-historic sand channel / drowned stream bed through the reef. These channels through the reef are thought to be the remnant of stream beds when the sea level was lower and often are the dominant route for freshwater and sediment flow from the land to the ocean.

Size fraction and calcium carbonate analyses of beach and benthic sediments show that the dark sand on Pelekane Beach and within the bay is primarily of land based origin *(Figure 5.5)*. Sand on the beach (#'s 1 & 2) has a higher percent of small grain sizes due to sorting by the very calm wave environment. Sand in the stream (# 8) contains 11.5 % of the fine silt category, whereas the fine silt content of the benthic substrate is low near shore and gradually increases out to a depth of 4 feet. Conversely the near shore sediments have a higher content of coarse sand and gravel. This shows that as the stream empties into the bay, the heavier sediments drop out of suspension first with lighter sediments being transferred to deeper areas, washed up to form the beach, or carried out to sea.

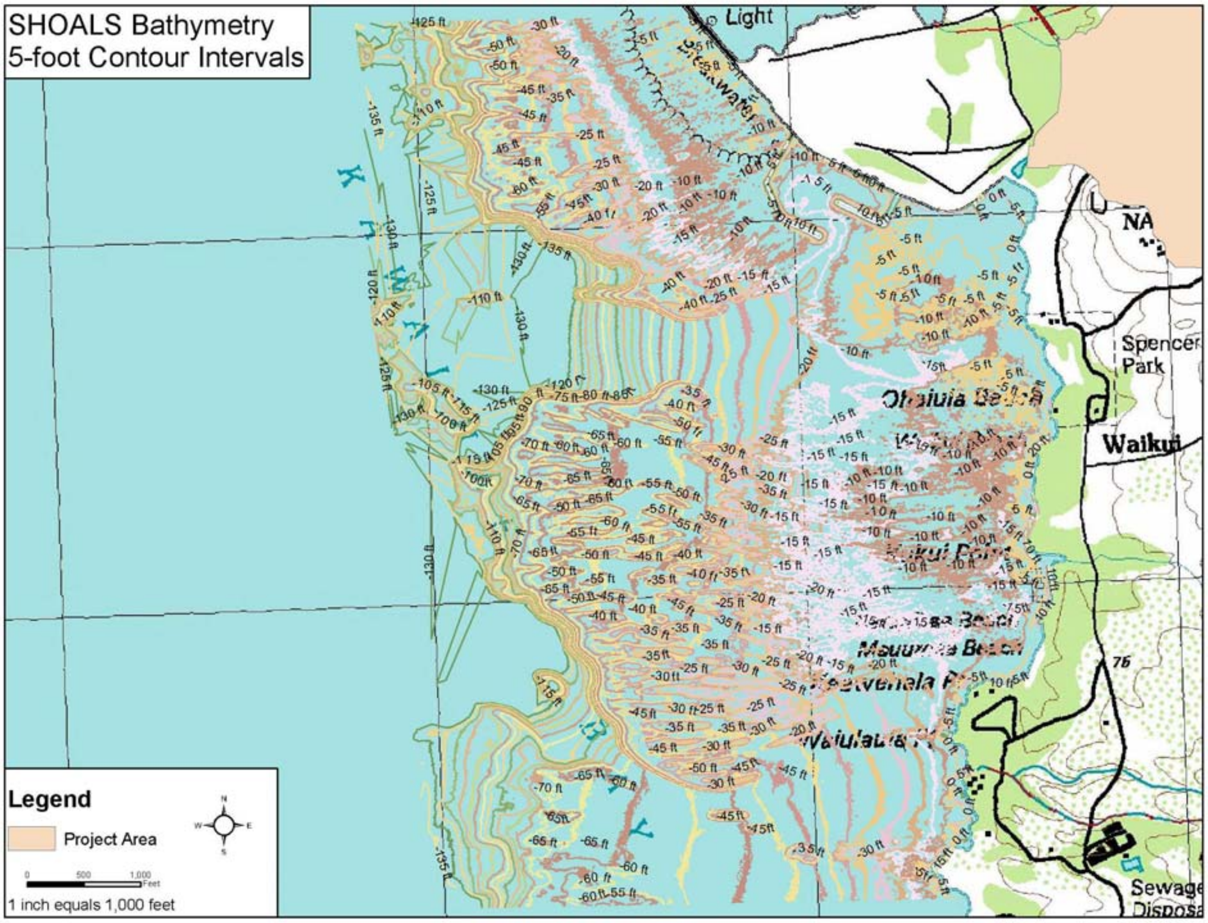


Figure 5.1 SHOALS Bathymetry, 5-foot Contour Intervals, USACE, 2000

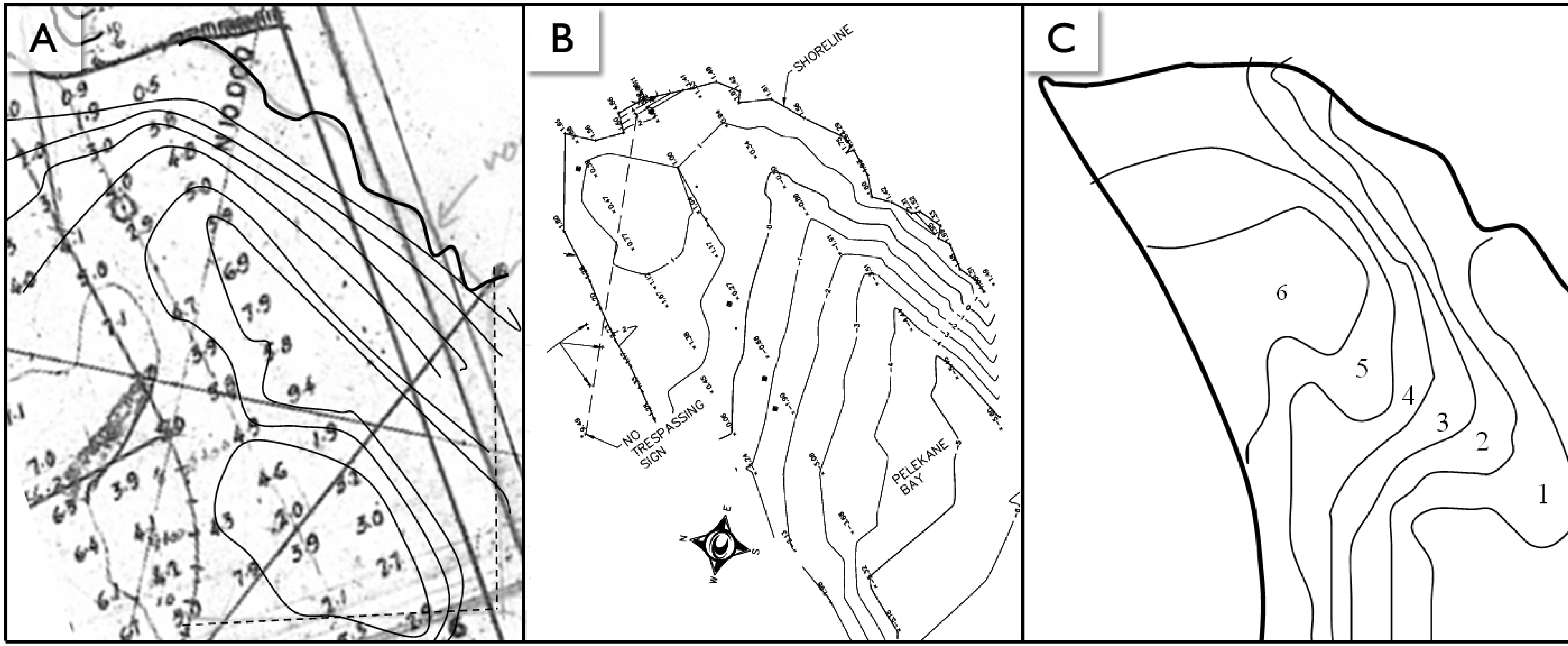


Figure 5.2 **Pre-Harbor Bathymetry (a) From 1955 Harbor Design Chart, Bathymetry 1953 by Nat Whiten to MLLW. Existing Bathymetry (b) by Oceanit 2006 Adjusted to MLLW According to Harbor NOAA Tide Gauge. Figure (c) Displays Difference between Charts (a) and (b) in Feet and Shows Areas and Depths to which Sediments have accumulated since Harbor Construction. Total Volume of Accumulated Sediment is approximately 46,800 Cubic Yards, or 1,264,000 Cubic Feet.**

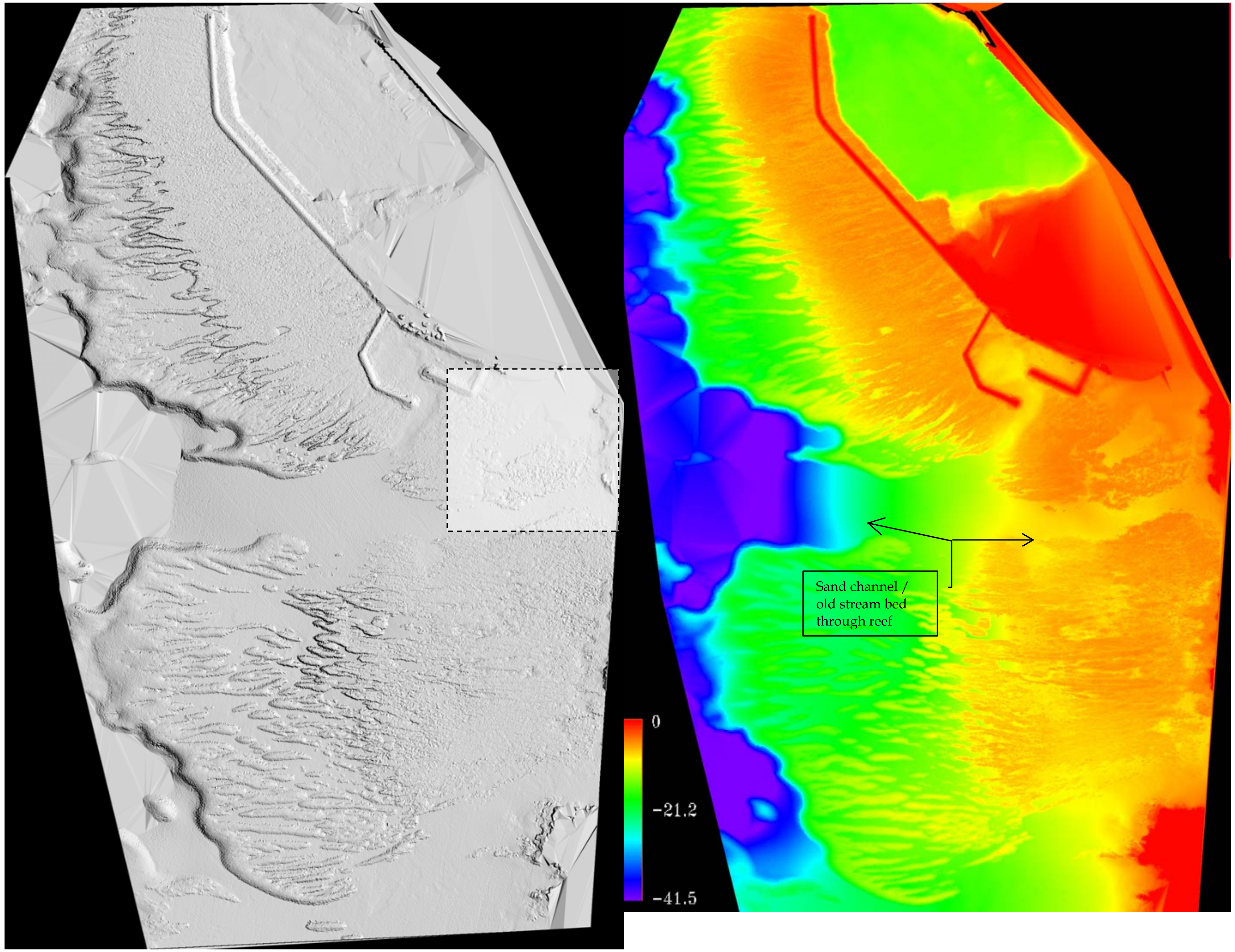


Figure 5.3 LIDAR Bathymetry Images of Kawaihae Harbor and Pelekane Bay from USACE SHOALS Database Showing Area Expanded for Figure 5.4.

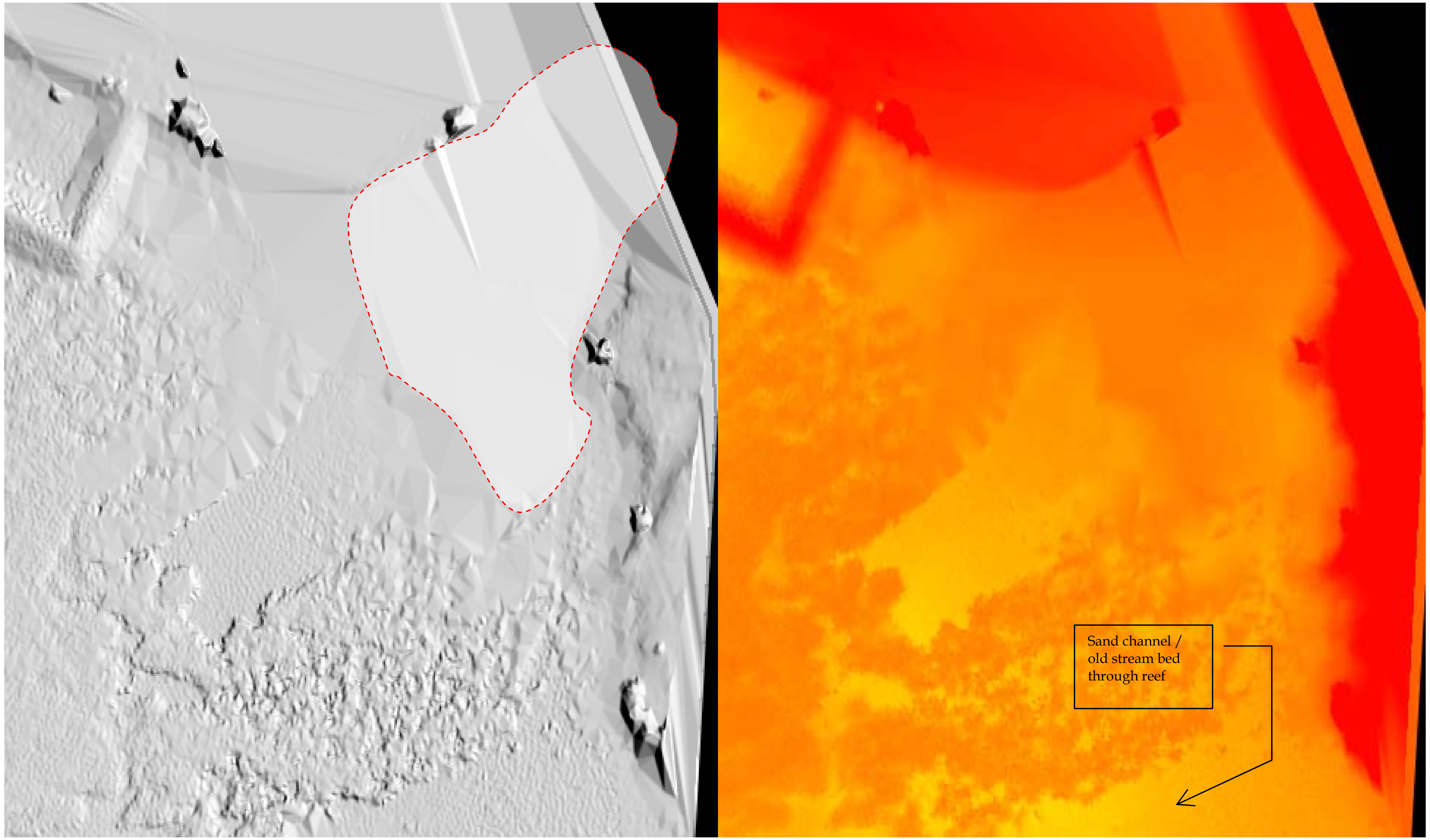
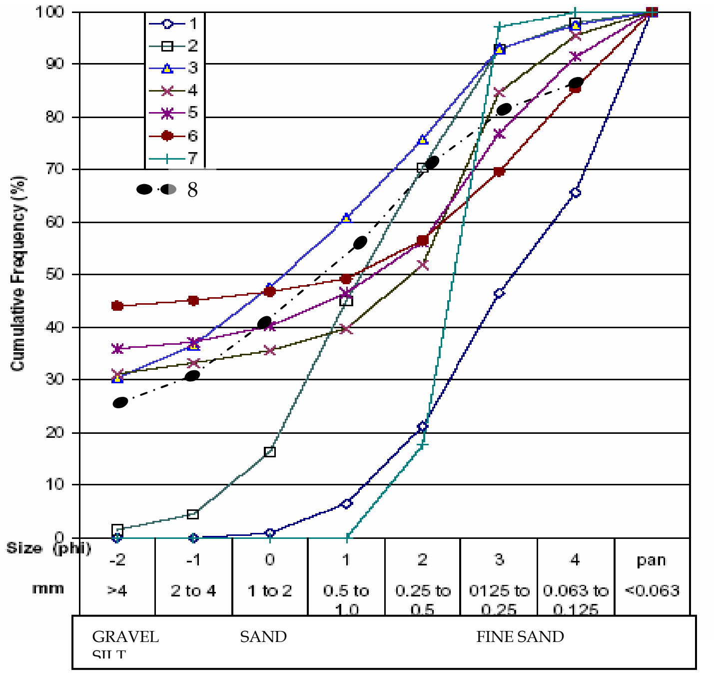


Figure 5.4 Expanded Views of LIDAR Bathymetry Images of Pelekane Bay from USACE SHOALS Database. Inscribed Area of Smooth Bathymetry shows Sediments Accumulating over Natural Rough Surface of Coral Reef. The Smooth Geometric Shapes are Anomalies Due to the Inability of the LIDAR to Penetrate Turbid Water in the Very Nearshore Areas of the Bay.



Sample	% CaCO3
1	36
2	54
3	40
4	44
5	25
6	19
7	86
8	23

Figure 5.5 Size Frequency and Calcium Carbonate Analyses of Sediment Samples. 1 – Sand Dune Top, 2 – Beach Water Level, 3 – Depth 1ft, 4 – Depth 2ft, 5 – Depth 3ft, 6 – Depth 4ft, 7 – Adjacent Coral Sand Beach, 8 – Stream Bed.

6.0 CRITICAL WATERSHED ISSUES AND RECOMMENDATIONS

6.0 CRITICAL WATERSHED ISSUES AND RECOMMENDATIONS

Critical watershed issues are resource conditions, human activities and recognized problem conditions. In addition, further study requirements and mitigation project definition for improving the Pelekane Bay Watershed are recommended. These serve as a basis for recommended actions to be implemented to improve the health of the watershed and create a framework for watershed restoration.

6.1 STAKEHOLDERS AND AGENCY COORDINATION

Watershed discussion involves a wide variety of land and people issues along with the interrelationship between these issues. As part of this investigation, meetings and coordination with stakeholders associated with the Pelekane Bay Watershed were conducted. The investigation included coordination with Federal, State and County agencies, and direct communication with landowners, organizations and individuals with interests in the watershed *(Table 6.1)*.

Mauna Kea Soil and Water Conservation District (MKSWCD)
Queen Emma Land Company, land owner
Parker Ranch, lessee
USDA's Natural Resources Conservation Service (NRCS)
U.S. Geological Survey (USGS)
U.S. Army Corps of Engineers (Corps)
National Oceanic Atmospheric Administration (NOAA)
University of Hawaiʻi, Cooperative Extension Service (CES)
University of Hawaiʻi, Water Resources Center
Hawaiʻi Coral Reef Assessment and Monitoring Program (CRAMP)
University of Hawaiʻi at Hilo
State of Hawaiʻi, Department of Land and Natural Resources (DLNR)
State of Hawaiʻi, Department of Health (DOH)
State of Hawaiʻi, Department of Hawaiian Home Lands
County of Hawaiʻi, Planning Department
National Park Services (NPS), Puʻukoholā Heiau National Historic Site
Kohala Mountain Watershed Partnership
Waimea Community Association

Table 6.1 Agencies Consulted for the Pelekane Bay Watershed Sediment Runoff Analysis

6.2 CRITICAL WATERSHED ISSUES

As a part of this study critical watershed issues are recognized to emphasize further study requirements, mitigation project definition, and management recommendations for improving the Pelekane Bay Watershed. The MKSWCD's Pelekane Bay Watershed Management Plan institutes a comprehensive watershed management program, which identifies problem conditions and provides recommendations, including monitoring activities, to implement watershed restoration and protection efforts (MKSWCD, 2005). Through the investigation of existing plans and conditions within the Pelekane Bay Watershed a number of critical watershed issues have been identified:

- Impaired Water Quality
- Grazing and Feral Goat Management
- Fire Management and Prevention
- Restoration of Ground Cover
- Sedimentation in Pelekane Bay

6.2.1 Impaired Water Quality

Soil erosion from the watershed has impaired the water quality of Pelekane Bay. Pelekane Bay is on DOH's 2004 Section 303(d) List of Impaired Waters. The Pelekane Bay Watershed was also identified by DOH in the Hawai'i Unified Watershed Assessment Plan as a Category I watershed, one of the State's watersheds in most urgent need of restoration (DOH, 2004). According to DOH, turbidity levels at Pelekane Bay have been recorded at almost 18 times the allowable water quality standard (26.5 vs. 1.5), not in compliance with State water quality standards (DOH, 2004).

Annually, storm waters from the watershed carry sediment loads into Pelekane Bay. Today, two to three meters of sediment covers much of Pelekane Bay, which has suffocated reef areas, damaged the spawning ground for certain marine life species, and covered archeological sites. Construction of Kawaihae Harbor in 1962, together with a recent expansion of a light-draft harbor in 2004, has impeded the circulation and littoral processes in this embayment resulting in the accumulation of silt.

6.2.2 Grazing and Feral Goat Management

Grazing management is important in maintaining vegetation cover, which consequently impacts erosion and sediment yield (EPA, 2003). In 2001, NRCS established general guidelines for judging proper grazing use on grass pasture as part of its Standards and Specifications for Prescribed Grazing (MKSWCD, 2005) *(Table 6.2)*. Use of these guidelines maintains ground cover and prevents destruction to vegetation (*Figure 6.1)*.

Since 1997, Parker Ranch has been following grazing management guidelines. Generally, there have been between 550-600 breeding cows on the 7480+ acres grazing through 6 paddocks. The grazing management guidelines encourage increasing the areas of the watershed accessible to cattle, rotational grazing and reduction of paddock sizes with additional fencing and water holes. As part of the *Pelekane Bay Watershed Management Project*, MKSWCD funded increased potential for rotational grazing by developing greater infrastructure in the watershed in the form of additional water resources and fencing to reduce paddock size and increase the areas of the watershed accessible to cattle (MKSWCD, 2005). A monitoring program to assess proper grazing and grass heights has also been established.

Table 6.2 General Guidelines for Judging Proper Grazing Use on Grass Pasture (NRCS, 2001)

Pelekane Bay Watershed Key Grass Species	Minimum Height to Begin Grazing (inches)	Minimum Height to Remove Livestock (inches)	Recovery Period (days)
Giant bermudagrass	4-6	2	18-40
Buffelgrass	8	3	30-60
Californiagrass	6	2-4	18-40
Dallisgrass	8	3	30-60
Green panicgrass	12	4	45-60
Guineagrass	12	4-5	45-60
Kikuyugrass	3-9	1-2	18-40
Limpograss	6	3	30-60
Napiengrass	12-18	5-7	45-60
Orchardgrass	8	3	30-60
Pangolagrass	4-6	3	30-60

Figure 6.1 Grazing Activities within Pelekane Bay Watershed

Recently, the proliferation of feral goats has become a critical issue in the watershed. According to the Pelekane Bay Watershed Management Plan, the goat population has increased to numbers in the thousands (MKSWCD, 2005). These animals have a tremendous impact on ground cover in the lower watershed *(Figure 6.2)*.

According to DLNR, harmful activity includes:

- Destroying native habitat through trampling, eating, and rooting;
- Creating soil disturbance, accelerating degradation, erosion, landslides and sedimentation;
- Spreading the seeds of invasive species; and
- Direct predation on native species such as tree ferns (*Cibotium* spp.), other succulent stemmed plants, and invertebrate species.

The Parker Ranch Hunting Club offers tourists the opportunity to hunt wild goats in this area. Without hunting pressure the population will likely increase. A feral goat control program needs to be devised to control the population (MKSWCD, 2005).

Figure 6.2 Degraded and Exposed Soils in Pelekane Bay Watershed

6.2.3 Fire Management and Prevention

Critical issues significant to fire prevention in the watershed are grazing management, to reduce the amount of vegetation or fuel modification, and changing vegetation type to a less flammable species. In addition, fountain grass *(Pennisetum setaceum)* is a dominant species in the watershed, which is highly flammable, and by replacing it with a more manageable species the threat of fires could be minimized (MKSWCD, 2005).

6.2.4 Restoration of Ground Cover

Revegetation of erosion-prone areas is recognized as a high priority for the watershed, in addition to implementation of the Native Species Revegetation Plan for the Pelekane Bay Watershed (MKSWCD, 2001 (B)). Grazing management is also important to effective ground cover restoration.

6.2.5 Sedimentation in Pelekane Bay

Poor land management practices in the watershed have increased soil erosion, and the detrimental effects of human activities, such as deforestation, wildfires and overgrazing, have left only barren soils that are vulnerable to the effects of intense rainfall. According to Hawaiʻi's Coastal Nonpoint Pollution Control Program Management Plan, a sediment retention structure has been recommended "to catch" and settle sediments before depositing into Pelekane Bay (CZM, 1996). Measures have also been recommended to address the sediment infill of Pelekane Bay, such as dredging the bay and creating a channel or canal through the coral flats to restore some of the circulation and natural flushing of the bay (Tissot, 1998).

In 2003, as part of the MKSWCD's *Pelekane Bay Watershed Management Project*, students from the University of Hawaiʻi at Hilo and Hawaiʻi Preparatory Academy constructed a sediment check dam to measure and estimate sediment runoff in the watershed (MKSWCD, 2005). Measurements were taken periodically through a volunteer monitoring program *(Table 6.3).* According to Dr. Michaud, the depth of soil trapped behind the check dam represents about an 18-acre sub-watershed (Michaud, 2005). The sediment check dam provides a preliminary model of monitoring sediment runoff in the watershed.

Table 6.3 Check Dam Amounts of Recovered Sediment, Pelekane Bay Watershed (Modified, Michaud, 2005)

Date of Excavation	Volume of Sediment (measured, m^3)	Volume of Sediment (estimated, m^3)*	Sediment Yield (tons per acre) **
16-Feb-04	0.183		24
8-Jul-05		0.215	29
24-May-05		0.162	22

* Measured weight divided by density of sub-sample.
** Contributing area behind dam is 18 acres or .07 km^2.

6.3 RECOMMENDATIONS

Federal, State and local agencies, landowners and organizations are striving to implement mitigation techniques to control sediment runoff into Pelekane Bay. The primary issue identified is to reduce soil erosion and runoff in the watershed. The following are recommendations or "management measures," which encourage reduction of soil erosion and runoff in the watershed and can be applied for future protection and management of the watershed. In addition, the recommendations emphasize the MKSWCD's Pelekane Bay Watershed Management Plan (MKSWCD, 2005).

6.3.1 Continued promotion of partnerships

Partnerships among landowners, government agencies and other stakeholders are currently the accepted means for addressing the complex and interrelated issues of watershed management. Partnerships are encouraged and work to promote watershed understanding and educational awareness. The roles of community groups and partnerships are key components in watershed restoration.

With the successful implementation of MKSWCD's *Pelekane Bay Watershed Management Project* many partnerships have developed. It is recommended to continue to promote participation and activities with involved landowner representatives, community stakeholders and public agencies to coordinate watershed planning and restoration for Pelekane Bay. Partnerships work as a forum for communication among all groups and agencies involved in watershed-related activities. Interested parties should continue to work together to formulate, execute and update the watershed management plan for the region; act as a clearing house regarding watershed issues; oversee and coordinate water quality programs, monitoring activities, promotion activities including educational programs, and act as an advisory board and intermediary between the public and various relevant agencies concerning watershed activities.

6.3.2 Reduce sediment deposits into Pelekane Bay from upland watershed areas

To minimize the delivery of sediment from the contributing area to surface waters management measures should be implemented. Application of management measures would ultimately reduce the mass load of sediment reaching a waterbody and improve water quality. The following management practices are recommended to reduce soil erosion in the Pelekane Bay Watershed. These management practices are also described in detail in the NRCS National Handbook of Conservation Practices or Field Office Technical Guide.

Conservation Cover: **Establishing and maintaining perennial vegetative cover to protect soil and water resources on land retired from agricultural production.** Restoration of ground cover is recognized as high priority for erosion-prone areas and will assist with stabilization and reduction of soil erosion.

Critical Area Planting: **Planting vegetation, such as trees, shrubs, vines, grasses, or legumes, on highly erodible or critically eroding areas.** This practice will assist in the stabilization of highly erodible or critically eroding areas.

Diversion: **A channel constructed across the slope with a supporting ridge on the lower side.** This practice will assist in the stabilization of a watershed, resulting in the reduction of sheet and rill erosion by reducing the length of slope. Sediment may be reduced by the elimination of ephemeral and large gullies. This may reduce the amount of sediment delivered to the surface waters.

Filter Strip: **A strip or area of vegetation for removing sediment, organic matter, and other pollutants from runoff and wastewater.** Filter strips for sediment and related pollutants meeting minimum requirements may trap the coarser grained sediment. They may not filter out soluble or suspended fine-grained materials.

Grassed Waterway: **A natural or constructed channel that is shaped or graded to required dimensions and established in suitable vegetation for the stable conveyance of runoff.** This practice may reduce the erosion in a concentrated flow area, such as in a gully or in ephemeral gullies. This may result in the reduction of sediment and substances delivered to receiving waters. Vegetation may act as a filter in removing some of the sediment delivered to the waterway, although this is not the primary function of a grassed waterway.

Sediment Basins: **Basins constructed to collect and store debris or sediment.** Sediment basins will remove sediment, sediment associated materials and other debris from the water which is passed on downstream.

6.3.3 Increase ground cover density and quality in the watershed

Restore damaged ground cover and areas of bare soil in the watershed. Planting vegetation, such as trees, shrubs, or grasses on highly erodible or critically eroding areas is highly recommended to reduce soil erosion and sediment delivery to Pelekane Bay. Further research on native species for erosion control potential is encouraged. Implementation of the Native Species Revegetation Plan for the Pelekane Bay Watershed (MKSWCD, 2001 (B)) should be continued and encouraged.

6.3.4 Implement feral goat management and continue to monitor grazing management

Over-grazing and feral goats damage vegetation cover in the watershed, which leads to erosion and thus increases sediment loads in drainage-ways of the Pelekane Bay Watershed. Encourage land users who graze livestock in the watershed to continue to implement grazing management plans, with technical assistance from NRCS and incorporating Standards and Specifications for Prescribed Grazing, to help maintain healthy groundcover, including installation of additional fencing and water to further subdivide the watershed (MKSWCD, 2005).

According to the Pelekane Bay Watershed Management Plan, a feral goat management program is recommended to assess techniques for eliminating feral goats in the watershed and evaluate their feasibility (MKSWCD, 2005). Recommendations for feral goat control include:

- Assess techniques for eliminating feral goats in the watershed and evaluate their feasibility.
- Establish an animal population and damage monitoring system.
- Initiate goat eradication program(hunting, trapping, etc).

6.3.5 Minimize the number of fires within and adjacent to the watershed

Minimization of fires within the watershed depends upon implementation of management goals and guidelines outlined by the Pelekane Bay Watershed Management Plan (MKSWCD, 2005) and

Fire Management Plan for the Pelekane Bay Watershed (MKSWCD, 2001 (A)). Additional recommendations include implementation of an assets management plan to maintain water resources, access points, roads/trails maintenance and repair, and equipment available in the watershed for fire suppression.

6.3.6 Restoration of Pelekane Bay

Recommendations for restoration of Pelekane Bay have included the following (Tissot 1998):

- Reduction in the amount of terrestrial sediment runoff.
- Removal of accumulated sediments, requiring careful dredging of the sediment in the middle of Pelekane Bay.
- Coral transplantation.

6.3.7 Implement monitoring programs to measure the success and effectiveness of watershed restoration and protection activities.

Monitoring Objectives Include:

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

Monitoring Activities:

Erosion Monitoring: To monitor soil loss and obtain data on the amount of sediment erosion and transport.

Recommendations for Erosion Monitoring:

i. Continue downloading rainfall data from rain gauges in the watershed, in order to further the study on the relationship between rainfall, runoff events, and sedimentation events in Pelekane Bay.
ii. As land management practices and other management activities are implemented in the watershed, construct check dams below each site to measure changes in soil loss from the area before, during and following management measure implementation.

Vegetative Cover Monitoring: To determine percent and composition of groundcover in the watershed.

Recommendations for Vegetative Cover Monitoring:

i. Implement vegetation cover monitoring on an annual or semi-annual basis.
ii. Explore remote sensing as a tool for vegetative cover monitoring

Stubble Height Monitoring: To determine when cattle should be rotated out of paddocks, based on the minimum heights established under NRCS's Standards and Specifications for Prescribed Grazing, 528A, and as a monitoring tool to ensure that paddocks are not being over-grazed.

Recommendations for Stubble Height Monitoring:

i. Continue stubble height monitoring on a semi-annual basis.
ii. Maintain existing monitoring sites and identify additional monitoring sites, if necessary.

Water Quality Monitoring: To measure in-stream flow and turbidity useful in calculating soil loss and developing the watershed-specific rainfall-runoff correlation.

Recommendations for Water Quality Monitoring:

i. Continue water quality monitoring in Pelekane Bay and Watershed streams, such as Makeāhua.
ii. Continue to monitor automatic samplers in streams which drain the watershed, such as Makeāhua Stream.

<u>Implementation of Tracking:</u> Track BMP's to determine whether pollution controls have been implemented, operated and maintained adequately. Evaluations are an effective tracking method. As land management practices and other management activities are implemented, monitoring and tracking of changes in the watershed are key actions to determining whether pollution controls have been implemented, operated, and maintained adequately. Tracking can determine whether the management measures are effective and whether additional ones are needed.

7. DISCUSSION AND CONCLUSION

7.0 DISCUSSION AND CONCLUSION

7.1 DISCUSSION

This study focused on estimating the load of sediments produced in runoff by individual rain events and the delivery and physical impact of these sediments on the receiving waters of Pelekane Bay. The N-SPECT runoff and pollution tracking model demonstrated that larger storms, with return periods greater than one year, had a disproportionately large impact upon sediment erosion as compared to smaller storms. A rainfall of less than 0.5-inch over the whole watershed does not typically yield significant erosion, and a 1- inch rainfall is only likely to yield runoff and sedimentation if it is of high intensity and short duration with sediment erosion typically about 1-3 tons. Significant runoff and sedimentation (~10 tons) is to be expected from a 1.5-inch average rain, but a 2.5-inch rainfall is likely to generate 100 tons of sediment, and a 4-inch rainfall will generate in excess of 300 tons of sediment. Surface flows from all storms quickly concentrated into numerous independent parallel small rills and gullies as opposed to fewer established dry stream beds as would be more typical in a geologically mature watershed.

The quantity of rainfall in the lower less vegetated, more arid, portions of the watershed appears to be more directly correlated with erosion as compared to similar rainfall quantities in the upper watershed where vegetation cover is more dominant. One inch of rain in the lower watershed will generate sediments comparable to 1.5 inches over the whole watershed or 2.3 inches in the upper watershed. For this reason, storms that approach from the south (Kona) and concentrate rainfall over lower elevations have a disproportionate ability to cause erosion. Specific areas with high erosion capacity can be identified from the model generated GIS sediment load maps for each rainfall event.

Direct model results for annual sediment load (erosion) to Pelekane Bay were higher than judged to be reasonable (~15,000 tons average per year). Therefore, an alternate approach to estimate annual load was used. Annual rainfall records for the area were used to create an average rainfall year including fractional day percentages for storms with longer return periods. A sediment production regression was developed from model runs and applied to the "average" rainfall year to yield an annual average sediment load of 4,222 tons. Of this erosion quantity, 3,502 tons (83%) was the result of runoff from storms with greater than 1-year return periods, i.e. very large and relatively rare storms were responsible for the largest quantity of sediment erosion in the watershed. The total quantity of material eroded to Pelekane Bay in the past half century is estimated to be 50 times the annual load (4,222 tons) or approximately 211,100 tons.

The physical impact of this sediment load to Pelekane Bay was determined in Section 5 by comparing the depth of the area prior to construction of Kawaihae Harbor with a bathymetry survey conducted as part of this project. Analyses of the results show a deposition delta formed within the bay with a total volume of 46,800 cubic yards or approximately 64,000 tons (assuming an average density of about 1.4 tons per cubic yard). The deposited material within the bay has a low calcium carbonate content consistent with its land derivation and extends about 800 feet out from the historic shoreline. Compared to stream mouth sediments, the composition of coarser benthic sediments was lacking 10-15 percent of the finest size classifications. The finer graduation of sediments is a result of offshore erosion by nominal wave action and normal coastal currents. Of the estimated 211,100 tons eroded, this would leave approximately 185,000 tons to be initially deposited within the bay, or approximately 3-times the volume measured by bathymetry changes. However, just as large storm events are seen to be the major cause of land erosion, large ocean storms are likely responsible for major redistribution of benthic sediments.

In order to calibrate the model, the following assessments were conducted:

1. Comparisons of Luahine Gulch 0.3 sq mile sub basin peak flow data;
2. Runs of additional storm events using N-SPECT;
3. Bathymetry analysis studies for Pelekane Bay; and
4. Model Sensitivity Analyses

The instantaneous peak flow data available for the Luahine Gulch (USGS peak flow gage 7558) sub basin, located in the upper Pelekane Bay Watershed, was found to correlate well with peak 24-hour rainfall data from Gage HI-96. Data from Gage HI-96 was used to populate the N-SPECT model with appropriate rainfall quantities. However, there is no way to tie the instantaneous peak flow data from the USGS gage to the model output which is in cumulative total flow volume. Runs of additional storm events using N-SPECT were assessed and found to further verify the model results for the watershed. Additionally, the N-SPECT sediment delivery/yield N-SPECT output correlated with the results of the bathymetry analysis conducted for Pelekane Bay. Results of the sensitivity analyses show that the model is sensitive to variations in CN numbers. Curve numbers for the Pelekane Bay Watershed tend to be very low indicating a high tendency for rainfall to infiltrate to groundwater. All of these correlations were determined to validate the N-SPECT model results for the Pelekane Bay Watershed Analysis.

Additional outcomes established with this study include the following:

- Identifies areas prone to high and low amounts of runoff.
- Identifies drainage and flow networks not identified by USGS.
- Identifies preferred areas for restoration in the Pelekane Bay Watershed.
- Creates awareness for conservation of Hawaii's coral reef habitats.
- Application of N-SPECT, a GIS-based watershed conservation analysis tool.
- Provides base data for continued N-SPECT analysis, including land use change analysis and assessment of watershed management.
- Implementation of the Mauna Kea Soil and Water Conservation District's (MKSWCD), Sediment Management Plan for the Pelekane Bay Watershed Management Project (MKSWCD, 2001 (C)) and Pelekane Bay Watershed Management Plan (MKSWCD, 2005).

7.2 CONCLUSION

The application of the N-SPECT model for the Pelekane Bay Watershed provided a baseline of data that indicates where sediment originates and also provided an estimated volume of sediment being transported into the bay. Knowledge of the distribution of areas demonstrating erosion and sediment runoff will help resource managers and planners target areas within the watershed needing better management practices (*Figure 7.1*). In addition, the estimates are useful for examining relative patterns and conditions of the watershed.

The results may be interpreted in terms of land management strategies:

- Land management to prevent erosion should focus on the lower watershed area, particularly in specific areas noted with high sediment production on the erosion maps.
- Because of the young geological age of the land, and the make-up of the surface soils, erosion tends to occur along parallel rills and gullies (as opposed to quickly coalescing into dry stream beds with protective stone beds). Stopping the upward development of the rills and gullies would appear to be a good strategy; albeit one that requires a large number of small check dams.
- Because the large majority of erosion occurs in relatively infrequent by very large storms, any land management techniques applied should be constructed to accommodate very large flows.
- Deposition of sediments can be expected to continue within Pelekane Bay as the delta continues to build seaward until it reaches an equilibrium point where long shore currents transport light sediments away, and heavier sediments begin contributing to the pre-historic sand channel / stream bed through the reef to the deep ocean slopes of the island.
- It is not likely that lowering erosion rates in the watershed above the bay will be accompanied by a retreat of the shoreline back to its historical location.

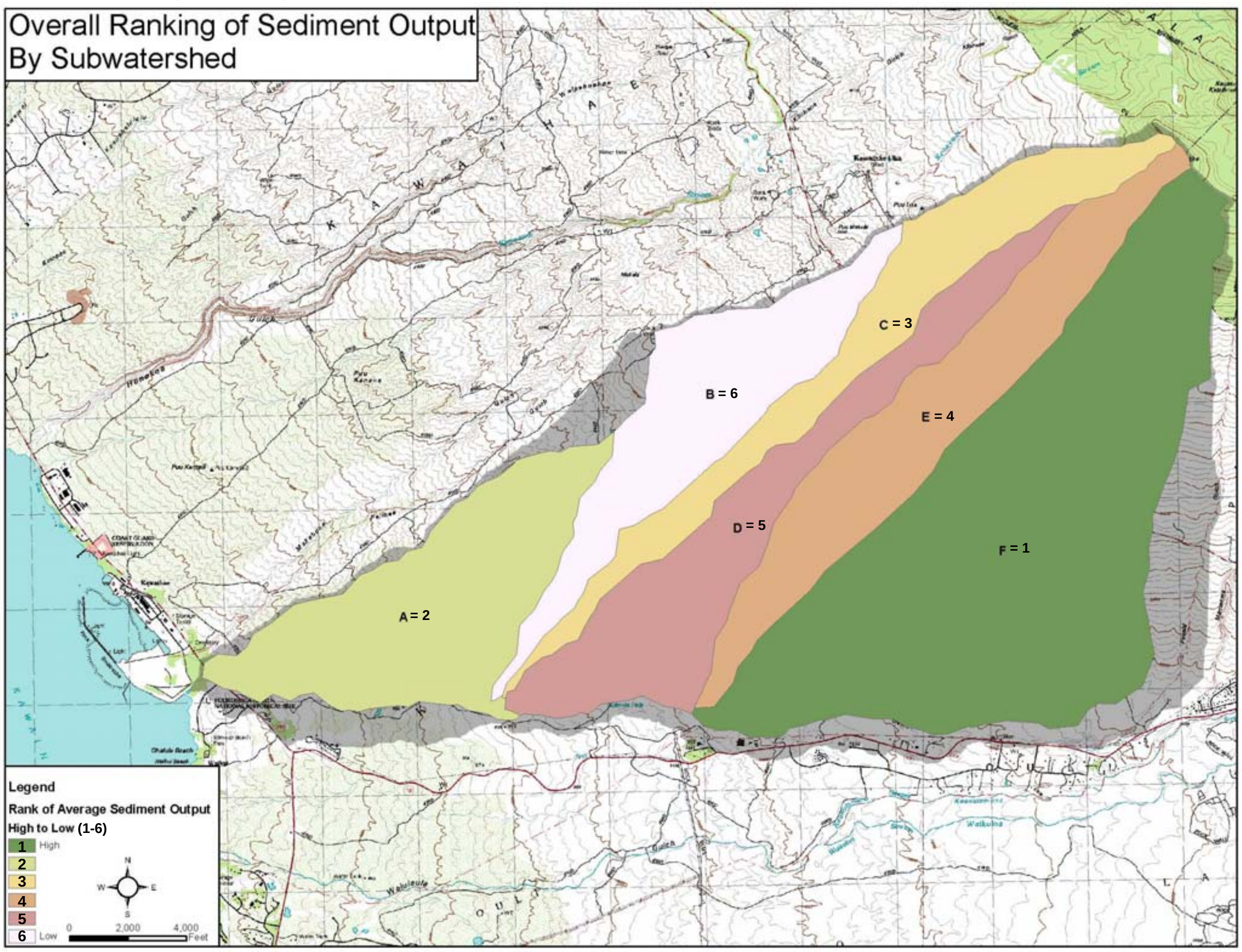


Figure 7.1 Overall Ranking of Sediment Output by Sub-Watershed, Pelekane Bay Watershed

The N-SPECT model is designed to be a tool for watershed managers. For Pelekane Bay Watershed, the N-SPECT model was able to accomplish the goals of the project by providing and identifying high erosion areas and the sediment yield. The results of the N-SPECT analyses are intended to be used as screening tools. The distribution and magnitude of the results should be treated as general indicators. Further use of N-SPECT for additional research and studies is recommended to help understand and predict the impacts of management decisions on water quality and ultimately the implications of different policy scenarios.

8.0 REFERENCES

8.0 REFERENCES

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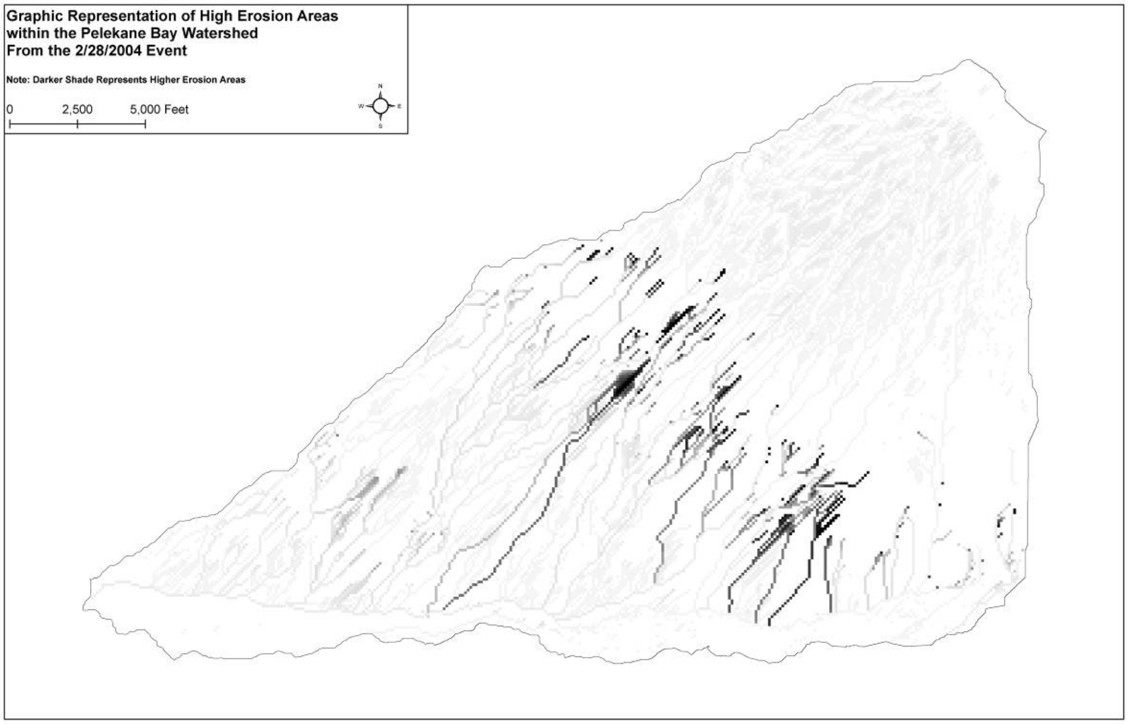
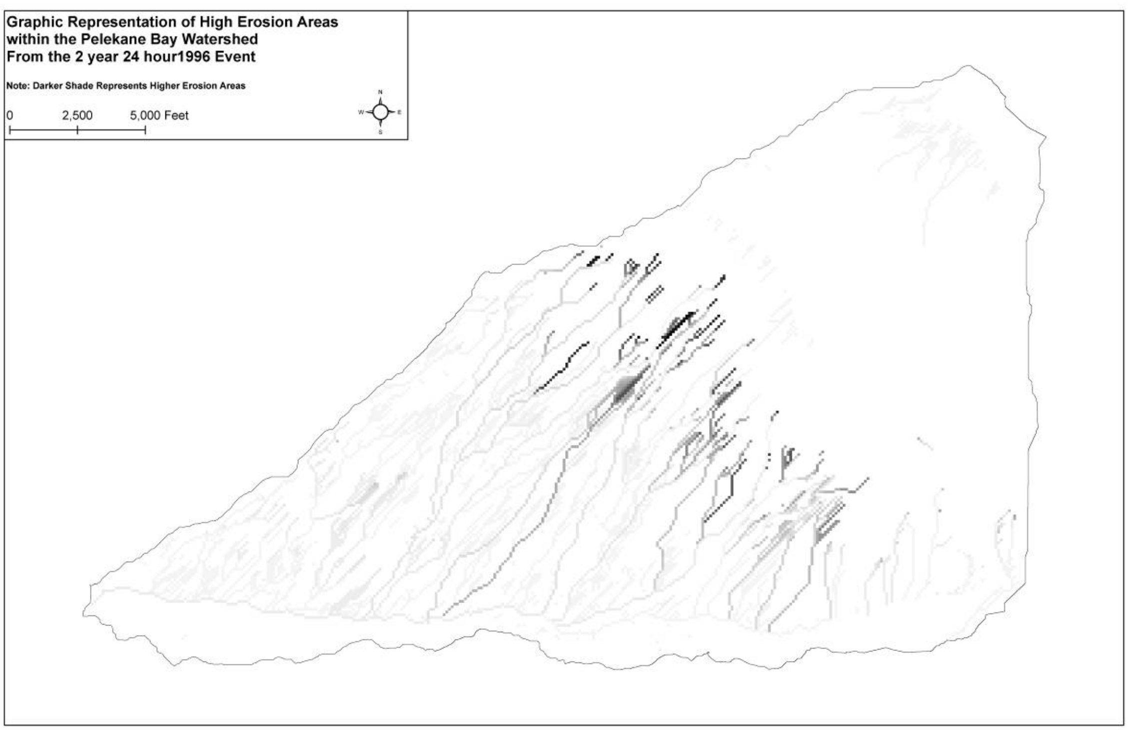
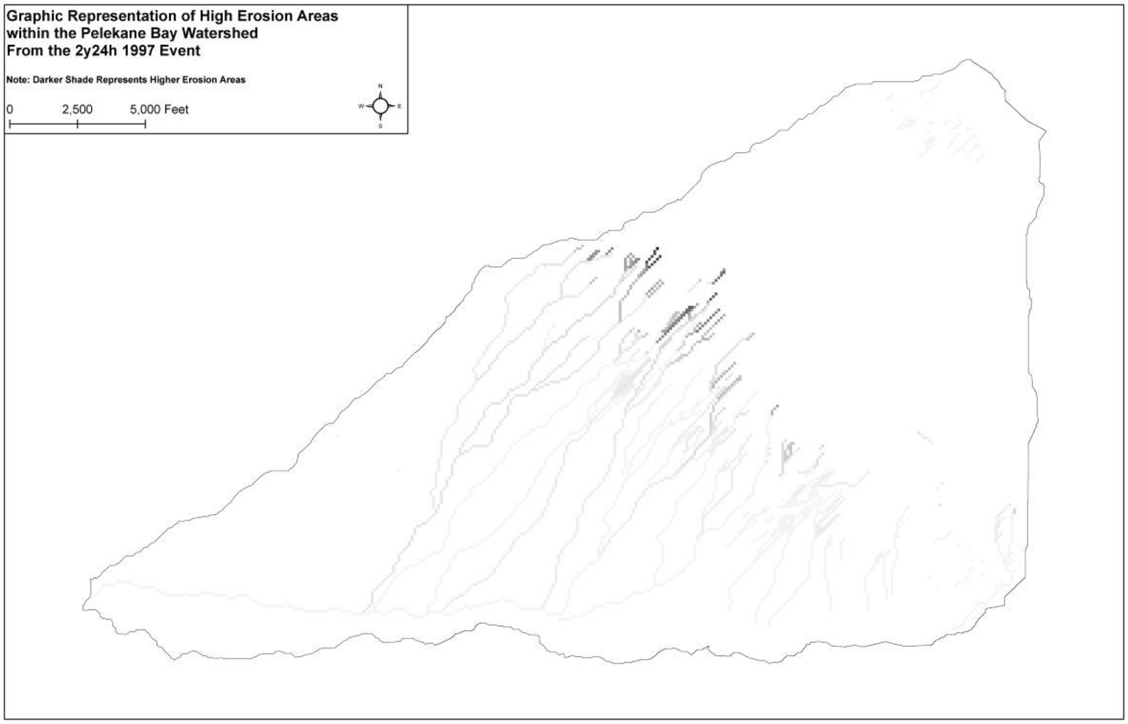
APPENDICES

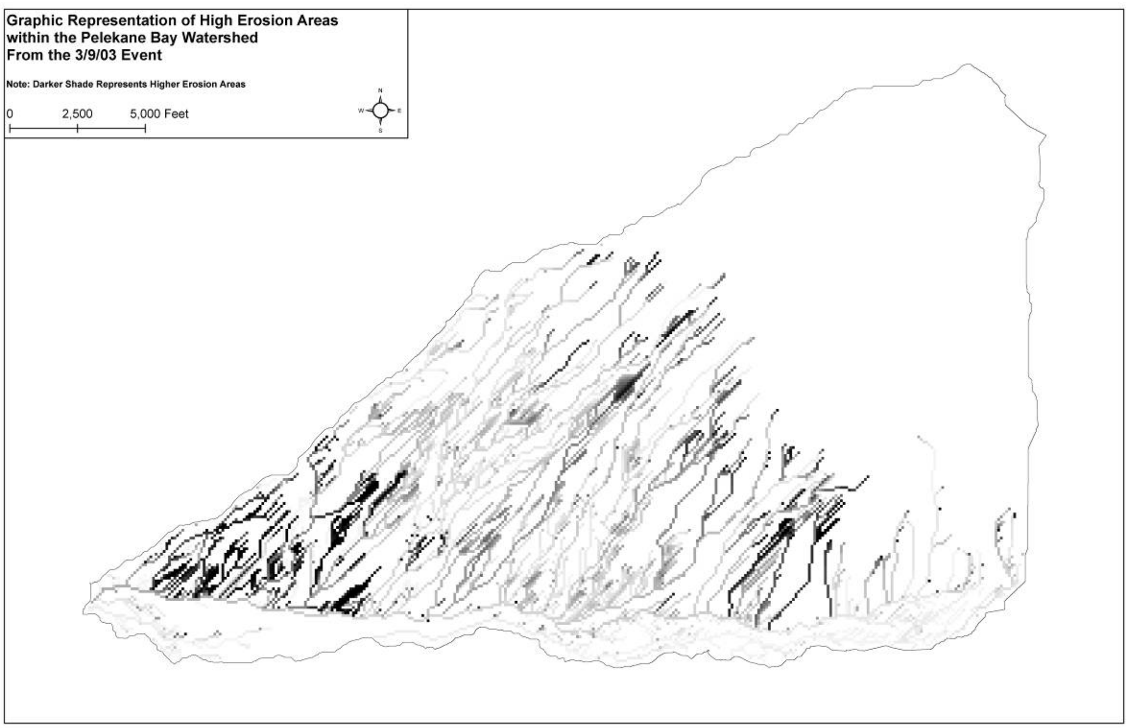
Appendix A. Graphical Distribution of High Erosion Areas by Storm

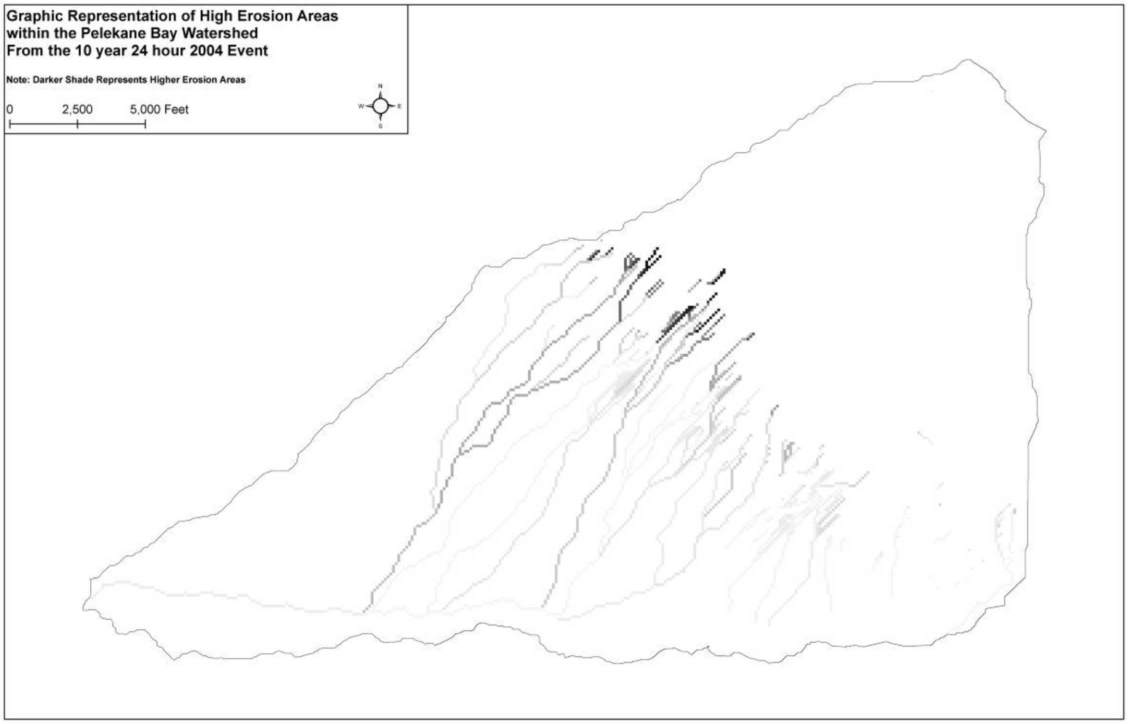
APPENDIX A: GRAPHICAL DISTRIBUTION OF HIGH EROSION AREAS BY STORM

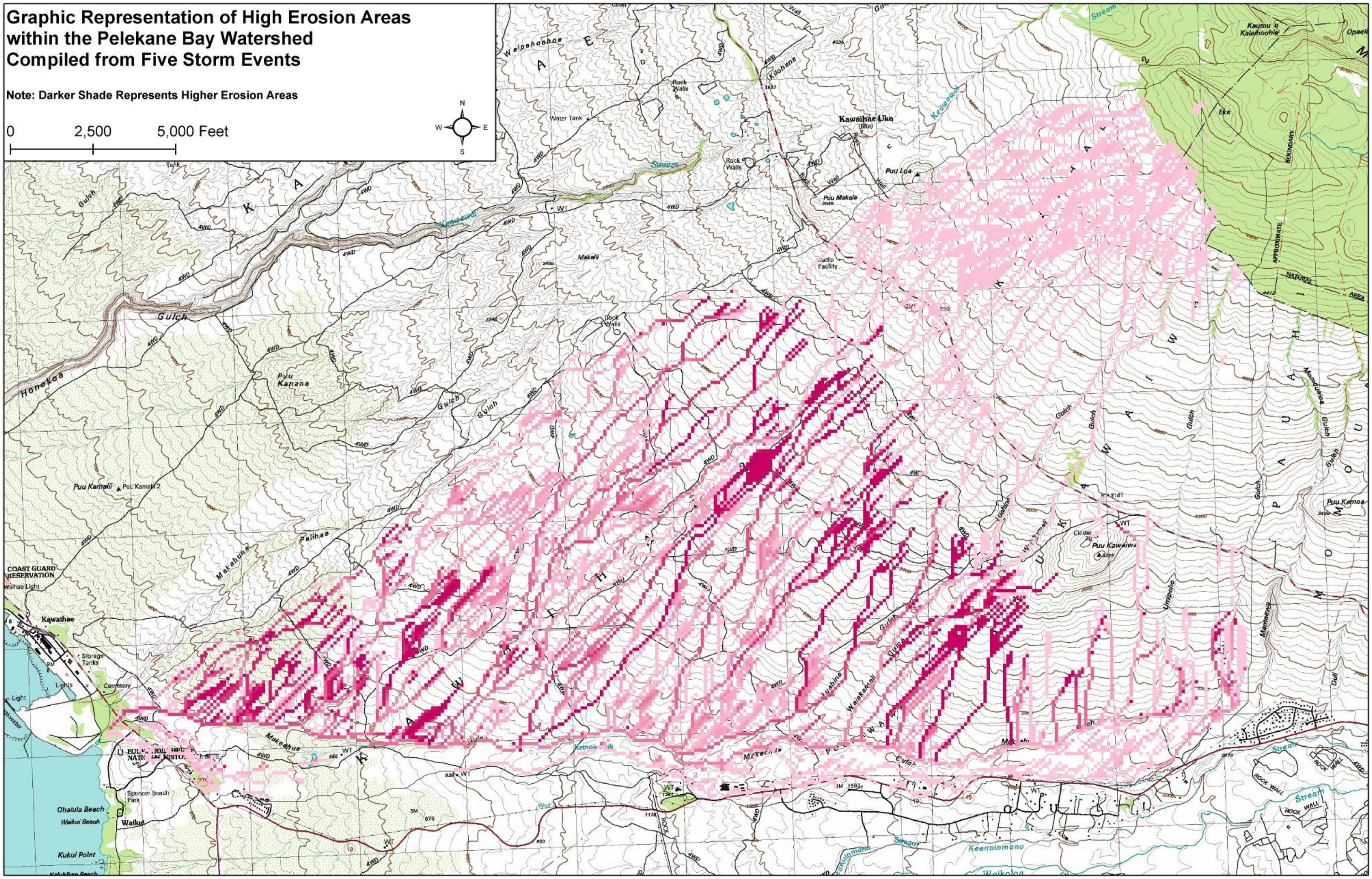





Graphic Representation of High Erosion Areas
within the Pelekane Bay Watershed
From the 2y24h 1997 Event
Note: Darker Shade Represents Higher Erosion Areas
0
2,500
5,000 Feet


Graphic Representation of High Erosion Areas
within the Pelekane Bay Watershed
From the 3/9/03 Event
Note: Darker Shade Represents Higher Erosion Areas
0
2,500
5,000 Feet


Graphic Representation of High Erosion Areas
within the Pelekane Bay Watershed
From the 10 year 24 hour 2004 Event
Note: Darker Shade Represents Higher Erosion Areas
0
2,500
5,000 Feet


Graphic Representation of High Erosion Areas
within the Pelekane Bay Watershed
Compiled from Five Storm Events
Note: Darker Shade Represents Higher Erosion Areas
0
2,500
5,000 Feet
N
E
S
W
Kawaihae Uka
Puu Loa
Puu Makela
Radio Facility
Makela
Rock Walls
Water Tank
Gulch
Honokoa
Puu Kanane
Puu Kamalii
Puu Kamalii 2
Makahuna
Palihae
COAST GUARD RESERVATION
Kawaihae
Storage Tanks
Cemetery
Makeahua
Spencer Beach Park
Ohaiula Beach
Waikui Beach
Kukui Point
Puu Kawaiwa
Cinder Pit
Umipoho
Mamaewa
Mamakuaiea
Puu Kamoa
Kaumu o Kaleihoohie
Eke
APPROXIMATE
NATURAL
AREA
BOUNDARY
Keanuiomano
Waikoloa
Stream
ROCK WALL

Appendix B. N-SPECT Model Results

APPENDIX B: N-SPECT MODEL RESULTS

Total Rain by Sub-Basin ANNUAL			Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment conc	Total Erosion	Erosion	Model Point			
Watershed	Ttl Precip, cm all grids	# grids in watershed	Acres	Inches	centimters	meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Ton / acre	Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A	103,591	6,066	1,349	6.72	17.08	0.171	5,459,400	932,320	50,042	5.4%	52032	2603.80	1.930	A	4,691,125,760	15,329,143	0.0032677
B	183,500	4,714	1,048	15.33	38.93	0.389	4,242,600	1,651,500	293,331	17.8%	6149	1803.59	1.721	B	293,331,456	1,803,587	0.0061486
C	271,449	4,328	962	24.69	62.72	0.627	3,895,200	2,443,043	1,173,178	48.0%	1278	1499.58	1.559	C	1,173,177,600	1,499,579	0.0012782
D	190,427	5,240	1,164	14.31	36.34	0.363	4,716,000	1,713,840	384,996	22.5%	2612	1005.45	0.863	D	384,996,160	1,005,445	0.0026116
E	296,153	5,401	1,200	21.59	54.83	0.548	4,860,900	2,665,373	955,110	35.8%	2600	2483.45	2.070	E	955,109,632	2,483,445	0.0026002
F	721,150	15,807	3,518	17.96	45.62	0.456	14,226,300	6,490,352	1,784,245	27.5%	2395	4274.08	1.215	F	1,784,245,248	4,274,085	0.0023953
All	1,766,270	41,556	9,242	16.73	42.50	0.425	37,400,400	15,896,427	4,691,126	29.5%	3268	15329.14	1.659	**B2**	**4,641,083,904**	**12,725,345**	**0.0027419**

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	65	21
Actual, inches -->	NA	NA

Storm 1 Total Rain by Sub-Basin 3/9/03		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment conc	Total Erosion	Erosion	Model Point			
Watershed	Ttl Precip, cm all grids	per sub Watershed	Acres	Inches	centimters	meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Ton / acre	Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A	30,434	6,066	1,349	1.98	5.02	0.050	5,459,400	273,904	30,340	11.1%	1294	39.26	0.029	A	85,589,192	59,896	0.0006998
B	19,630	4,714	1,048	1.64	4.16	0.042	4,242,600	176,672	8,697	4.9%	349	3.04	0.003	B	8,697,057	3,039	0.0003495
C	16,291	4,328	962	1.48	3.76	0.038	3,895,200	146,618	6,461	4.4%	344	2.22	0.002	C	6,460,919	2,222	0.0003440
D	22,615	5,240	1,164	1.70	4.32	0.043	4,716,000	203,533	3,411	1.7%	286	0.98	0.001	D	3,410,676	976	0.0002862
E	20,761	5,401	1,200	1.51	3.84	0.038	4,860,900	186,845	6,271	3.4%	374	2.34	0.002	E	6,270,942	2,344	0.0003738
F	63,483	15,807	3,518	1.58	4.02	0.040	14,226,300	571,343	21,867	3.8%	372	8.14	0.002	F	21,867,334	8,144	0.0003724
All	173,213	41,556	9,242	1.64	4.17	0.042	37,400,400	1,558,916	85,589	5.5%	700	59.90	0.006	**B2**	**55,248,964**	**20,638**	**0.0003735**

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	1.41	1.84
Actual, inches -->	1.41	1.83

Storm 2 Total Rain by Sub-Basin10y1hr_04		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment conc	Total Erosion	Erosion	Model Point			
Watershed	Ttl Precip, cm all grids	per sub Watershed	Acres	Inches	centimters	meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Ton / acre	Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A	3,768	6,066	1,349	0.24	0.62	0.006	5,459,400	33,913	1	0.0%	0	0.00	0.000	A	4,400,508	91	0.0000206
B	7,339	4,714	1,048	0.61	1.56	0.016	4,242,600	66,050	228	0.3%	109	0.02	0.000	B	227,666	25	0.0001094
C	11,157	4,328	962	1.01	2.58	0.026	3,895,200	100,415	1,528	1.5%	17	0.03	0.000	C	1,528,298	26	0.0000173
D	7,546	5,240	1,164	0.57	1.44	0.014	4,716,000	67,910	255	0.4%	79	0.02	0.000	D	254,816	20	0.0000793
E	12,132	5,401	1,200	0.88	2.25	0.022	4,860,900	109,188	920	0.8%	13	0.01	0.000	E	920,266	12	0.0000132
F	29,286	15,807	3,518	0.73	1.85	0.019	14,226,300	263,577	1,416	0.5%	4	0.01	0.000	F	1,416,187	5	0.0000038
All	71,228	41,556	9,242	0.67	1.71	0.017	37,400,400	641,054	4,401	0.7%	21	0.09	0.000	**B2**	**4,400,508**	**91**	**0.0000206**

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	1.07	0.34
Actual, inches -->	1.06	0.32

Storm 3 Total Rain by Sub-Basin 2/28/04		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment conc	Total Erosion	Erosion	Model Point			
Watershed	Ttl Precip, cm all grids	per sub Watershed	Acres	Inches	centimters	meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Ton / acre	Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A	11,587	6,066	1,349	0.75	1.91	0.019	5,459,400	104,286	2,064	2.0%	108	0.22	0.000	A	266,533,360.00	29,820.26	0.000112
B	22,631	4,714	1,048	1.89	4.80	0.048	4,242,600	203,676	16,697	8.2%	211	3.52	0.003	B	16,696,832.00	3,520.77	0.000211
C	34,388	4,328	962	3.13	7.95	0.079	3,895,200	309,495	66,928	21.6%	106	7.07	0.007	C	66,928,180.00	7,074.62	0.000106
D	23,177	5,240	1,164	1.74	4.42	0.044	4,716,000	208,595	21,755	10.4%	190	4.14	0.004	D	21,754,876.00	4,143.65	0.000190
E	37,305	5,401	1,200	2.72	6.91	0.069	4,860,900	335,744	55,077	16.4%	104	5.74	0.005	E	55,076,680.00	5,744.78	0.000104
F	90,032	15,807	3,518	2.24	5.70	0.057	14,226,300	810,290	101,457	12.5%	71	7.20	0.002	F	101,456,976.00	7,195.88	0.000071
All	219,121	41,556	9,242	2.08	5.27	0.052	37,400,400	1,972,086	266,533	13.5%	112	29.82	0.003	**B2**	**264,469,168.00**	**29,596.47**	**0.000112**

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	3.14	0.97
Actual, inches -->	NA	NA

Storm 4 Total Rain by Sub-Basin2y24h_97		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment conc	Total Erosion	Erosion	Model Point			
Watershed	Ttl Precip, cm all grids	per sub Watershed	Acres	Inches	centimters	meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Ton / acre	Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A	4,813	6,066	1,349	0.31	0.79	0.008	5,459,400	43,320	4	0.0%	3	0.00	0.000	A	13,281,589	489	0.000037
B	9,375	4,714	1,048	0.78	1.99	0.020	4,242,600	84,371	553	0.7%	207	0.11	0.000	B	552,701	114	0.000207
C	14,252	4,328	962	1.30	3.29	0.033	3,895,200	128,269	4,571	3.6%	33	0.15	0.000	C	4,571,143	149	0.000033
D	9,638	5,240	1,164	0.72	1.84	0.018	4,716,000	86,746	882	1.0%	112	0.10	0.000	D	881,560	99	0.000112
E	15,497	5,401	1,200	1.13	2.87	0.029	4,860,900	139,473	2,791	2.0%	26	0.07	0.000	E	2,791,154	74	0.000026
F	37,409	15,807	3,518	0.93	2.37	0.024	14,226,300	336,684	4,349	1.3%	9	0.04	0.000	F	4,348,897	41	0.000009
All	90,985	41,556	9,242	0.86	2.19	0.022	37,400,400	818,864	13,282	1.6%	37	0.49	0.000	**B2**	**13,277,554**	**489**	**0.000037**

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	1.36	0.43
Actual, inches -->	1.36	0.41

Storm 5 Total Rain by Sub-Basin2yr24hr_96		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment conc	Total Erosion	Erosion	Model Point			
Sub-watershed	Ttl Precip, cm all grids	per sub Watershed	Acres	Inches	centimters	meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Ton / acre	Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A	10,143	6,066	1,349	0.66	1.67	0.017	5,459,400	91,288	1,221	1.3%	51	0.06	0.000	A	40,849,044	4,177	0.000102
B	15,714	4,714	1,048	1.31	3.33	0.033	4,242,600	141,430	3,534	2.5%	209	0.74	0.001	B	3,534,404	739	0.000209
C	19,614	4,328	962	1.78	4.53	0.045	3,895,200	176,523	12,148	6.9%	86	1.04	0.001	C	12,148,345	1,039	0.000086
D	15,696	5,240	1,164	1.18	3.00	0.030	4,716,000	141,267	3,546	2.5%	188	0.67	0.001	D	3,545,535	667	0.000188
E	21,439	5,401	1,200	1.56	3.97	0.040	4,860,900	192,950	8,003	4.1%	85	0.68	0.001	E	8,002,863	682	0.000085
F	50,483	15,807	3,518	1.26	3.19	0.032	14,226,300	454,345	11,194	2.5%	47	0.53	0.000	F	11,194,020	530	0.000047
All	133,089	41,556	9,242	1.26	3.20	0.032	37,400,400	1,197,804	40,849	3.4%	102	4.18	0.000	**B2**	**39,628,136**	**4,115**	**0.000104**

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	1.75	0.85
Actual, inches -->	1.75	0.8

Storm 6 Total Rain by Sub-Basin 10Y24H		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment conc	Total Erosion	Erosion	Model Point			
Watershed	Ttl Precip, cm all grids	per sub Watershed	Acres	Inches	centimters	meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Ton / acre	Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A	22,325.77	6,066	1,349	1.45	3.68	0.037	5,459,400	200,932	12,894	6.4%	870	11.22	0.008	A	1,118,620,416	321,811	0.000288
B	43,512.09	4,714	1,048	3.63	9.23	0.092	4,242,600	391,609	83,446	21.3%	425	35.47	0.034	B	83,445,752	35,468	0.000425
C	65,902.02	4,328	962	5.99	15.23	0.152	3,895,200	593,118	242,486	40.9%	258	62.65	0.065	C	242,485,712	62,649	0.000258
D	44,612.43	5,240	1,164	3.35	8.51	0.085	4,716,000	401,512	90,405	22.5%	438	39.58	0.034	D	90,404,816	39,581	0.000438
E	71,642.24	5,401	1,200	5.22	13.26	0.133	4,860,900	644,780	223,352	34.6%	296	66.20	0.055	E	223,352,032	66,200	0.000296
F	172,886.42	15,807	3,518	4.31	10.94	0.109	14,226,300	1,555,978	453,218	29.1%	190	85.96	0.024	F	453,218,208	85,963	0.000190
All	420,880.97	41,556	9,242	3.99	10.13	0.101	37,400,400	3,787,929	1,118,620	29.5%	288	321.81	0.035	**B2**	**1,105,726,592**	**310,591**	**0.000281**

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	6.3	1.99
Actual, inches -->	6.27	1.91

Appendix C. N-SPECT Model Sensitivity Analyses Results

APPENDIX C: N-SPECT MODEL SENSITIVITY ANALYSES RESULTS

Plus 10% **Curve Number Adjusted**

Model Output with CN numbers Plus 10%

Plus 10% CNs

Storm 3 Total Rain by Sub-Basin 2/28/04		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment Conc	Total Erosion	Erosion
Watershed	Total Precip, cm (all grids)	per Sub Watershed	Acres	Inches	Centimeters	Meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Tons/Acre
A	11,587	6,066	1,349	0.75	1.91	0.019	5,459,400	104,286	6,830	6.5%	660	4.51	0.003
B	22,631	4,714	1,048	1.89	4.80	0.048	4,242,600	203,676	28,890	14.2%	342	9.87	0.009
C	34,388	4,328	962	3.13	7.95	0.079	3,895,200	309,495	93,805	30.3%	164	15.38	0.016
D	23,177	5,240	1,164	1.74	4.42	0.044	4,716,000	208,595	32,620	15.6%	321	10.47	0.009
E	37,305	5,401	1,200	2.72	6.91	0.069	4,860,900	335,744	81,569	24.3%	184	15.03	0.013
F	90,032	15,807	3,518	2.24	5.70	0.057	14,226,300	810,290	279,259	34.5%	75	20.91	0.006
All	219,121	41,556	9,242	2.08	5.27		37,400,400	1,972,086	408,798	20.7%	203	82.83	0.009

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	3.14	0.97
Actual, inches -->		

|------------------ MODEL OUTPUT HERE ---|

Model Point			
Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A_lower	408,797,792	82,826	0.000203
A_upper	401,968,032	78,318	0.000195
B	28,890,346	9,868	0.000342
C	93,804,808	15,383	0.000164
D_Branch	32,620,206	10,469	0.000321
D_Lower	279,259,392	53,060	0.000190
D_upper	240,614,448	35,938	0.000149
E	81,568,968	15,031	0.000184
F	159,037,920	20,907	0.000131
Gauge	37,658,848	1,864	0.000050

Plus 10%	CCAP	CCAP Landcover	CN+~10% CORRECTED FORMULA					
Plus 10%	2	High Intensity Developed	0.945	0.96	0.97	0.975	0	0
Plus 10%	3	Low Intensity Developed	0.671	0.825	0.913	0.935	0.03	0
Plus 10%	4	Cultivated Land	0.737	0.858	0.925	0.945	0.24	0
Plus 10%	5	Grassland	0.429	0.671	0.814	0.88	0.05	0
Plus 10%	7	Evergreen Forest	0.33	0.605	0.77	0.847	0.004	0
Plus 10%	9	Scrub/Shrub	0.33	0.528	0.715	0.803	0.014	0
Plus 10%	17	Bare Land	0.847	0.93	0.955	0.97	0.7	0
Plus 10%	18	Water	0	0	0	0	1	1

Plus 1% **Curve Number Adjusted**

Model Output with CN numbers Plus 10% — Plus 1% CNs

Storm 3 Total Rain by Sub-Basin 2/28/04		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment Conc	Total Erosion	Erosion
Watershed	Total Precip, cm (all grids)	per Sub Watershed	Acres	Inches	Centimeters	Meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Tons/Acre
A	11,587	6,066	1,349	0.75	1.91	0.019	5,459,400	104,286	2,495	2.4%	155	0.39	0.000
B	22,631	4,714	1,048	1.89	4.80	0.048	4,242,600	203,676	18,278	9.0%	226	4.13	0.004
C	34,388	4,328	962	3.13	7.95	0.079	3,895,200	309,495	70,703	22.8%	106	7.53	0.008
D	23,177	5,240	1,164	1.74	4.42	0.044	4,716,000	208,595	23,317	11.2%	218	5.08	0.004
E	37,305	5,401	1,200	2.72	6.91	0.069	4,860,900	335,744	58,855	17.5%	110	6.48	0.005
F	90,032	15,807	3,518	2.24	5.70	0.057	14,226,300	810,290	194,479	24.0%	42	8.19	0.002
All	219,121	41,556	9,242	2.08	5.27		37,400,400	1,972,086	285,960	14.5%	119	34.06	0.004

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	3.14	0.97
Actual, inches -->		

|------------------ MODEL OUTPUT HERE --|

Model Point			
Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A_lower	285,959,552	34,056	0.000119
A_upper	283,464,992	33,669	0.000119
B	18,277,546	4,134	0.000226
C	70,703,016	7,526	0.000106
D_Branch	23,316,802	5,084	0.000218
D_Lower	194,479,424	22,007	0.000113
D_upper	168,238,016	14,672	0.000087
E	58,854,884	6,480	0.000110
F	109,380,664	8,192	0.000075
Gauge	28,563,766	1,011	0.000035

Plus 1%	CCAP	CCAP Landcover	CN+~10% CORRECTED FORMULA					
Plus 1%	2	High Intensity Developed	0.9	0.93	0.95	0.96	0	0
Plus 1%	3	Low Intensity Developed	0.62	0.76	0.84	0.88	0.03	0
Plus 1%	4	Cultivated Land	0.68	0.79	0.86	0.9	0.24	0
Plus 1%	5	Grassland	0.4	0.62	0.75	0.81	0.05	0
Plus 1%	7	Evergreen Forest	0.31	0.56	0.71	0.78	0.004	0
Plus 1%	9	Scrub/Shrub	0.31	0.49	0.66	0.74	0.014	0
Plus 1%	17	Bare Land	0.78	0.87	0.92	0.95	0.7	0
Plus 1%	18	Water	0	0	0	0	1	1

Given **Curve Numbers as Given in N-SPECT Model**

Pelekane Bay Watershed. Summary of Runoff & Sedimentation Modeling
Normal Output Using Provided CN numbers

NORMAL CNs

Storm 3 Total Rain by Sub-Basin 2/28/04		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment Conc	Total Erosion	Erosion
Watershed	Total Precip, cm (all grids)	per Sub Watershed	Acres	Inches	Centimeters	Meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Tons/Acre
A	11,587	6,066	1,349	0.75	1.91	0.019	5,459,400	104,286	2,068	2.0%	114	0.24	0.000
B	22,631	4,714	1,048	1.89	4.80	0.048	4,242,600	203,676	16,687	8.2%	214	3.58	0.003
C	34,388	4,328	962	3.13	7.95	0.079	3,895,200	309,495	66,790	21.6%	100	6.67	0.007
D	23,177	5,240	1,164	1.74	4.42	0.044	4,716,000	208,595	21,747	10.4%	206	4.47	0.004
E	37,305	5,401	1,200	2.72	6.91	0.069	4,860,900	335,744	55,064	16.4%	102	5.62	0.005
F	90,032	15,807	3,518	2.24	5.70	0.057	14,226,300	810,290	180,847	22.3%	38	6.93	0.002
All	219,121	41,556	9,242	2.08	5.27		37,400,400	1,972,086	266,396	13.5%	110	29.43	0.003

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	3.14	0.97
Actual, inches -->		

|----------------- MODEL OUTPUT HERE ---|

Model Point			
Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A_lower	266,395,648	29,433	0.000110
A_upper	264,327,984	29,197	0.000110
B	16,687,404	3,579	0.000214
C	66,789,572	6,670	0.000100
D_Branch	21,747,132	4,474	0.000206
D_Lower	180,846,816	18,948	0.000105
D_upper	156,506,752	12,544	0.000080
E	55,064,080	5,616	0.000102
F	101,440,680	6,928	0.000068
Gauge	27,002,406	891	0.000033

Curve Numbers

ORIGINAL	CCAP	CCAP Landcover	Model Defined CNs					
ORIGINAL	2	High Intensity Developed	0.89	0.92	0.94	0.95	0	0
ORIGINAL	3	Low Intensity Developed	0.61	0.75	0.83	0.87	0.03	0
ORIGINAL	4	Cultivated Land	0.67	0.78	0.85	0.89	0.24	0
ORIGINAL	5	Grassland	0.39	0.61	0.74	0.8	0.05	0
ORIGINAL	7	Evergreen Forest	0.3	0.55	0.7	0.77	0.004	0
ORIGINAL	9	Scrub/Shrub	0.3	0.48	0.65	0.73	0.014	0
ORIGINAL	17	Bare Land	0.77	0.86	0.91	0.94	0.7	0
ORIGINAL	18	Water	0	0	0	0	1	1

Minus 1% Curve Number Adjusted

Model Output with CN numbers Plus 10%

Minus 1% CNs

Storm 3 Total Rain by Sub-Basin 2/28/04		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment Conc	Total Erosion	Erosion
Watershed	Total Precip, cm (all grids)	per sub Watershed	Acres	Inches	Centimeters	Meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Tons/Acre
A	11,587	6,066	1,349	0.75	1.91	0.019	5,459,400	104,286	1,695	1.6%	83	0.14	0.000
B	22,631	4,714	1,048	1.89	4.80	0.048	4,242,600	203,676	15,186	7.5%	209	3.18	0.003
C	34,388	4,328	962	3.13	7.95	0.079	3,895,200	309,495	62,990	20.4%	93	5.85	0.006
D	23,177	5,240	1,164	1.74	4.42	0.044	4,716,000	208,595	20,237	9.7%	197	3.98	0.003
E	37,305	5,401	1,200	2.72	6.91	0.069	4,860,900	335,744	51,415	15.3%	94	4.83	0.004
F	90,032	15,807	3,518	2.24	5.70	0.057	14,226,300	810,290	167,828	20.7%	34	5.77	0.002
All	219,121	41,556	9,242	2.08	5.27		37,400,400	1,972,086	247,704	12.6%	102	25.36	0.003

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	3.14	0.97
Actual, inches -->		

|----------------- MODEL OUTPUT HERE ---|

Model Point			
Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A_lower	247,703,504	25,363	0.000102
A_upper	246,008,224	25,222	0.000103
B	15,186,066	3,180	0.000209
C	62,990,368	5,848	0.000093
D_Branch	20,237,436	3,977	0.000197
D_Lower	167,828,336	16,194	0.000096
D_upper	145,300,176	10,604	0.000073
E	51,414,708	4,834	0.000094
F	93,883,864	5,770	0.000061
Gauge	25,482,818	781	0.000031

Minus 1%	CCAP	CCAP Landcover	CN+~10% CORRECTED FORMULA					
Minus 1%	2	High Intensity Developed	0.88	0.91	0.93	0.94	0	0
Minus 1%	3	Low Intensity Developed	0.6	0.74	0.82	0.86	0.03	0
Minus 1%	4	Cultivated Land	0.66	0.77	0.84	0.88	0.24	0
Minus 1%	5	Grassland	0.38	0.6	0.73	0.79	0.05	0
Minus 1%	7	Evergreen Forest	0.29	0.54	0.69	0.76	0.004	0
Minus 1%	9	Scrub/Shrub	0.29	0.47	0.64	0.72	0.014	0
Minus 1%	17	Bare Land	0.76	0.85	0.9	0.93	0.7	0
Minus 1%	18	Water	0	0	0	0	1	1

Minus 10% Curve Number Adjusted

Model Output with CN Minus 10%

Minus 10% CNs

Storm 3 Total Rain by Sub-Basin 2/28/04		# Grids	Area	Average Rain	Average Rain	Average Rain	Grid Area @	Rain Volume	Accumulated	Percent	Sediment Conc	Total Erosion	Erosion
Watershed	Total Precip, cm (all grids)	per Sub Watershed	Acres	Inches	Centimeters	Meters	900m^2/grid#	m^3	Runoff m^3	Runoff	mg/L	Tons	Tons/Acre
A	11,587	6,066	1,349	0.75	1.91	0.019	5,459,400	104,286	183	0.2%	19	0.00	0.000
B	22,631	4,714	1,048	1.89	4.80	0.048	4,242,600	203,676	8,403	4.1%	141	1.19	0.001
C	34,388	4,328	962	3.13	7.95	0.079	3,895,200	309,495	44,496	14.4%	49	2.19	0.002
D	23,177	5,240	1,164	1.74	4.42	0.044	4,716,000	208,595	13,181	6.3%	105	1.38	0.001
E	37,305	5,401	1,200	2.72	6.91	0.069	4,860,900	335,744	34,247	10.2%	43	1.47	0.001
F	90,032	15,807	3,518	2.24	5.70	0.057	14,226,300	810,290	107,434	13.3%	11	1.23	0.000
All	219,121	41,556	9,242	2.08	5.27		37,400,400	1,972,086	160,516	8.1%	48	7.78	0.001

	Upper Watershed	Lower Watershed
Rain Fall Modeled, inches -->	3.14	0.97
Actual, inches -->		

s |----------------- MODEL OUTPUT HERE ---|

Model Point			
Name	Accumulated Runoff (L)	MUSLE Sediment Mass (kg)	MUSLE Sediment Concentration (kg/L)
A_lower	160,516,064	7,780	0
A_upper	160,333,552	7,777	0
B	8,403,068	1,186	0
C	44,496,128	2,191	0
D_Branch	13,180,972	1,384	0
D_Lower	107,433,992	4,399	0
D_upper	93,440,640	2,696	0
E	34,247,148	1,467	0
F	59,193,432	1,230	0
Gauge	18,010,440	325	0

Minus 10%	CCAP	CCAP Landcover	CN - 10% ORIGINAL					
Minus 10%	2	High Intensity Developed	0.801	0.828	0.846	0.855	0	0
Minus 10%	3	Low Intensity Developed	0.549	0.675	0.747	0.783	0.03	0
Minus 10%	4	Cultivated Land	0.603	0.702	0.765	0.801	0.24	0
Minus 10%	5	Grassland	0.351	0.549	0.666	0.72	0.05	0
Minus 10%	7	Evergreen Forest	0.27	0.495	0.63	0.693	0.004	0
Minus 10%	9	Scrub/Shrub	0.27	0.432	0.585	0.657	0.014	0
Minus 10%	17	Bare Land	0.693	0.774	0.819	0.846	0.7	0
Minus 10%	18	Water	0	0	0	0	1	1