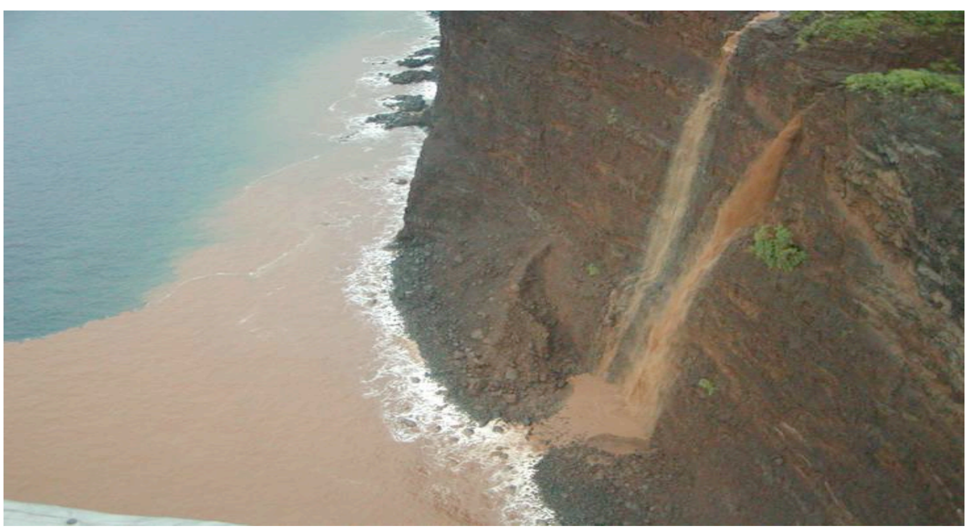
Turbidity on the Shallow Reef off Kaulana and Hakioawa Watersheds on the North Coast of Kahoʻolawe, Hawaiʻi

Measurements of Turbidity and Ancillary Data on Winds, Waves, Precipitation, and Stream flow Discharge, November 2005 to June 2008

Open-File Report 2010-1037



Surface runoff and subsequent turbidity in marine waters off of Kahoʻolawe. Photo courtesy of KIRC.

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Turbidity on the Shallow Reef off Kaulana and Hakioawa Watersheds, North Coast of Kaho‘olawe, Hawai‘i

Measurements of Turbidity and Ancillary Data on Winds, Waves, Precipitation, and Stream flow Discharge, November 2005 to June 2008

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Introduction

The island of Kaho‘olawe has particular cultural and religious significance for native Hawaiians. Once known as Kanaloa, the island was a center for native Hawaiian navigation. In the mid-20th century, the island was used as a bombing range by the U.S. Navy, and that practice, along with the foraging by feral goats, led to a near-complete decimation of vegetation. The loss of ground cover led to greatly increased erosion and run-off of sediment-laden water onto the island's adjacent coral reefs. Litigation in 1990 ended the U.S. Navy's use of the island as a bombing range, and in 1994 the island was transferred to the Kaho‘olawe Island Reserve Commission (KIRC), *http://kahoolawe.hawaii.gov/*. As a result of the litigation, the U.S. Navy began a 10-year clean-up effort that was the foundation for the present restoration effort by KIRC (Slay, 2009).

The restoration effort is centered on revegetating the island, reducing erosion, and limiting run-off onto adjacent reefs. Restoration efforts to mitigate sediment runoff to streams and gulches by restoring native vegetation and minimizing erosion have focused on two watersheds, Kaulana and Hakioawa, on the northeast and northwest sides of the island, respectively. Stream flow and sediment gages were installed by the U.S. Geological Survey Pacific Islands Water Science Center in each of the watersheds, and a weather station was established upland of the watersheds. For this study, turbidity monitors were installed on the insular shelf off the two watersheds to monitor the overall quality of reef waters and their changes in response to rain and stream flow discharge events.

Project Objectives

The objective of these deployments was to understand how turbidity varied temporally on the insular shelf adjacent to two stream drainages and to provide insight into the effectiveness of watershed restoration efforts at decreasing the amount of sediment delivered to the coral reef ecosystems. This study is the result from discussions and a signed agreement in 2005 between the KIRC and the U.S. Geological Survey (USGS) to provide assistance in measuring turbidity in the island's coastal waters.

Study Area

The island of Kahoʻolawe is the smallest of the eight main Hawaiian Islands and generally lies in the rain shadow of the island of Maui (fig.1). Due to this shadowing, the average annual precipitation on the island ranges from 250 to 500 mm. Its location south of Molokaʻi, Lanaʻi, and Maui provides shelter from the north Pacific storm waves during the winter and some protection from northeast trade winds during the spring and summer. The Hakioawa watershed is on the northeast side of the island and consists of 310 hectares; the Kaulana watershed is on the northwest side of the island and consists of 255 hectares.

Nearshore coral reefs at Hakioawa are on the northeastern part of the island and are more exposed to northeast trade winds and waves than those at Kaulana, resulting in potentially stronger currents in this area. Nearshore coral reefs at Kaulana are in the lee of the predominant trade winds, but are more exposed to northwest waves generated as winter storms propagate across the north Pacific Ocean.

Both watersheds were impacted by vegetation loss and severe erosion due to extensive grazing by feral goats (1793-1993) and bombing by the U.S. Navy (1938-1990), resulting in the introduction of large quantities of terrigenous sediment to the nearshore environment. Examples of the impacts to the nearshore environment by the bombing and loss of vegetation and sediment delivery to the coast are shown in figure 2A - E.

Operations

This section provides information about the personnel, equipment and vessel used during the deployments. See table 1 for a list of personnel involved in the experiment.

Scientific Party

USGS scientists aided KIRC scientists with the planning and setup of the turbidity meters, as well as evaluating preliminary deployment sites for the turbidity meters. The final instrument locations, deployments, cleaning, and recovery of the turbidity meters were conducted by KIRC scientists on the KIRC vessel, *R/V Hakilo*.

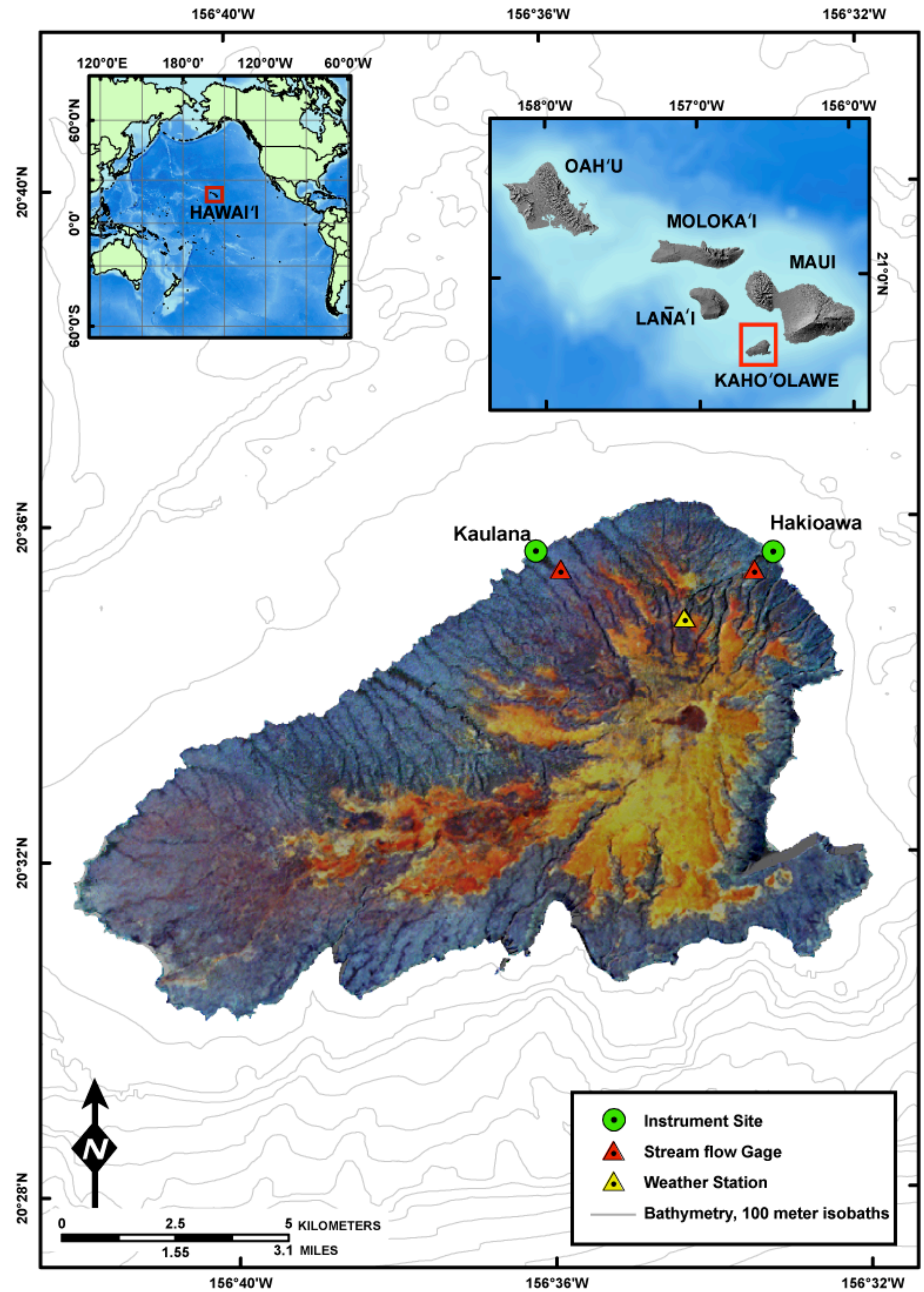

Figure 1. Map of the study area in relation to the main Hawaiian Island chain and the locations of the instruments. Kaho'olawe is partially sheltered from the large North Pacific swells during the winter and relatively protected from the northeast trade winds during the summer by the surrounding islands of Maui, Moloka'i and Lana'i.

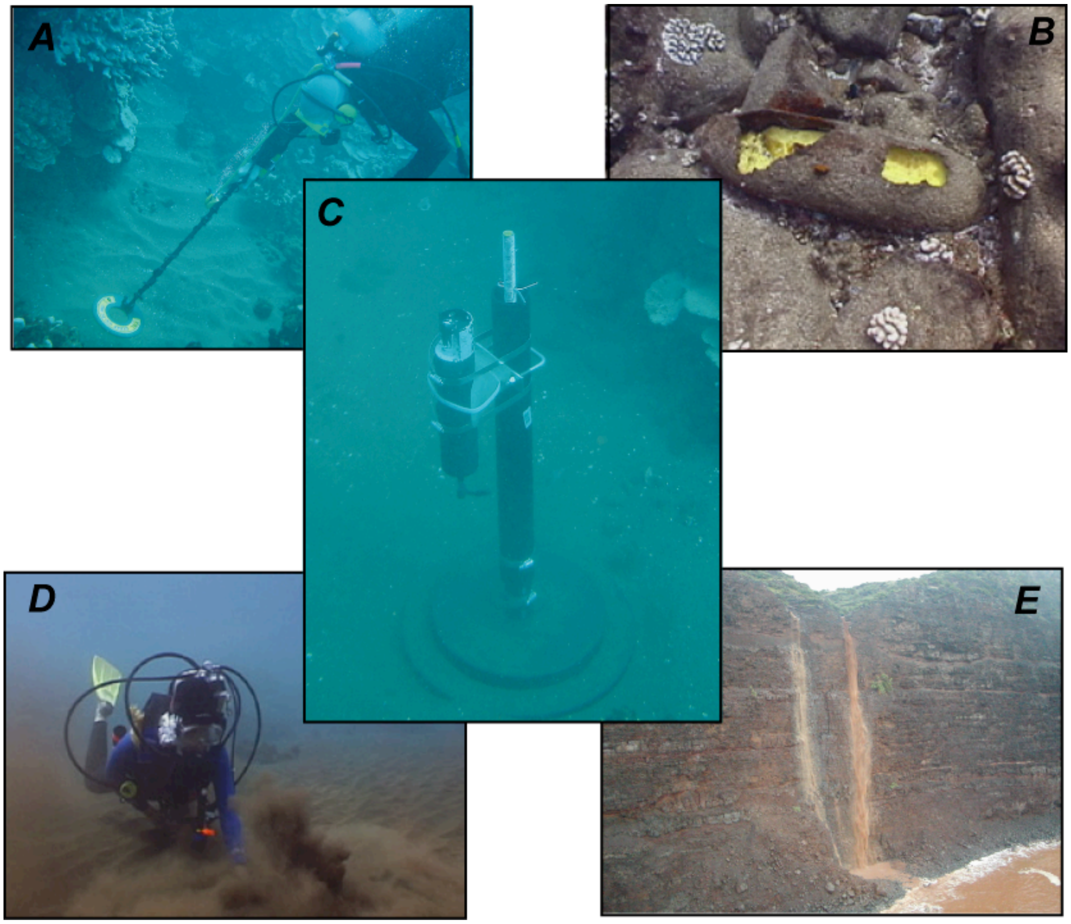

Figure 2. Photographs of the equipment used in the study and other environmental conditions. *A*, U.S. Navy diver scanning the seafloor for unexploded ordnance offshore Kaho'olawe; *B*, An example of an unexploded ordnance on the seafloor; *C*, Aquatec self-logging optical backscatter sensor (SLOBS) mounted underwater; *D*, Kaho'olawe Island Reserve Commission diver demonstrating the large quantities of terrigenous sediment on the seafloor offshore of Kaho'olawe; *E*, A waterfall of sediment-laden water discharging into coastal waters on Kaho'olawe. All photographs courtesy of Kaho'olawe Island Reserve Commission.

Equipment and Data Review

Turbidity sensors were placed on the shallow reef on the north side of Kaho'olawe (fig.1) offshore of the Hakioawa and Kaulana watersheds. The locations at Hakioawa (20.5932° N, 156.5521° W) and Kaulana (20.59403° N, 156.6022° W) where the instruments were deployed from November 2005 to June 2008 are shown in figure 1. The depths of the instrument sites at Kaulana and Hakioawa are 7.6 m and 8.5 m, respectively. A summary of the instrument sensors and deployment and recovery dates are provided in tables 2 and 3.

The two oceanographic instruments used in this study were Aquatec/Seapoint 210-TYT self-logging optical backscatter sensors (SLOBS), as shown in figure 2C. The SLOBS collected single-point measurements of turbidity, with each resulting data point being averaged from eight samples every 5 minutes. Instrument specifics and sampling schemes are listed in appendix 1.

Far-field oceanographic and meteorological forcing for the study period was compiled from NOAA's northwest Kaua'i buoy (National Data Buoy Center, 2009). The buoy, station identification #51001, is deployed in approximately 3 km of water, 170 km west-northwest of the island. It makes hourly measurements of wind speed (m/s), wind direction (°True), wave height (m), wave period (s), mean wave direction (°True), sea-level barometric pressure (mb), and air and sea-surface temperature (°C). Water discharge (m^3/s), suspended-sediment concentration (mg/L), and total sediment load (metric tons/day) were measured by the USGS Pacific Islands Water Science Center (2009) stream flow gaging station #16682000 at Kaulana 31 m above sea level. Only water discharge (m^3/s) is measured at station #16681000 Hakioawa, 23 m above sea level (fig.1). Local meteorological data was measured at a Remote Automated Weather Station (RAWS, 20.5803° N, 156.5711° W) approximately 366 m above sea level in the northern part of the island (fig. 1). The RAWS recorded daily measurements of wind speed (m/s) and direction (°True), atmospheric pressure (mb), air temperature (°C), and precipitation (mm).

Data Acquisition and Quality

The turbidity instruments were deployed for more than 2.5 years from November 17, 2005 (2005 Year, Day 322), to June 20, 2008 (2005 Year, Day 1267). Several data gaps occur due to battery issues, severe weather, and degraded water clarity for deploying and retrieving the instruments. The sensors collected measurements every 5 minutes, resulting in more than 200,000 measurements at the Hakioawa site and over 150,000 measurements at the Kaulana site.

The SLOBS turbidity data appeared to be mostly of high quality throughout the deployment. The turbidity data at the Kaulana site were more frequently degraded due to biofouling, limiting the datasets to a few weeks at a time. The remoteness of the island, along with severe meteorological and oceanographic conditions that often inhibited the frequent cleaning of the SLOBS optical lenses, contributed to the biofouling of the instruments, resulting in low data quality. The data at Hakioawa appeared to have relatively little biofouling due to more frequent cleaning and possibly the influence of more energetic oceanographic processes, as discussed in greater detail below.

Results and Discussion

This section reviews the data collected by the instruments during the deployments and addresses the significance of the findings to better understand the environmental conditions in the study area.

Oceanographic and Atmospheric Forcing

Daily measurements of wind speed and direction, precipitation, barometric pressure, and air temperature were measured by the RAWS for the period of deployment (fig. 3). The mean, standard deviation, minimum, and maximum values for the data are presented in table 4. The daily data shows the seasonal warming and cooling typical for the Hawaiian Islands, with cooler air temperatures during the winter months and warming into the summer months. The wind pattern for this area is also consistent for the region, with northeast to southeast winds predominating throughout the study period, and less frequent south winds during the passage of low-pressure systems, generally during the winter months. The greatest amount of precipitation also correlated with winter low pressure systems, with lesser amounts than the rest of the year likely due to orographic precipitation of trade-wind moisture.

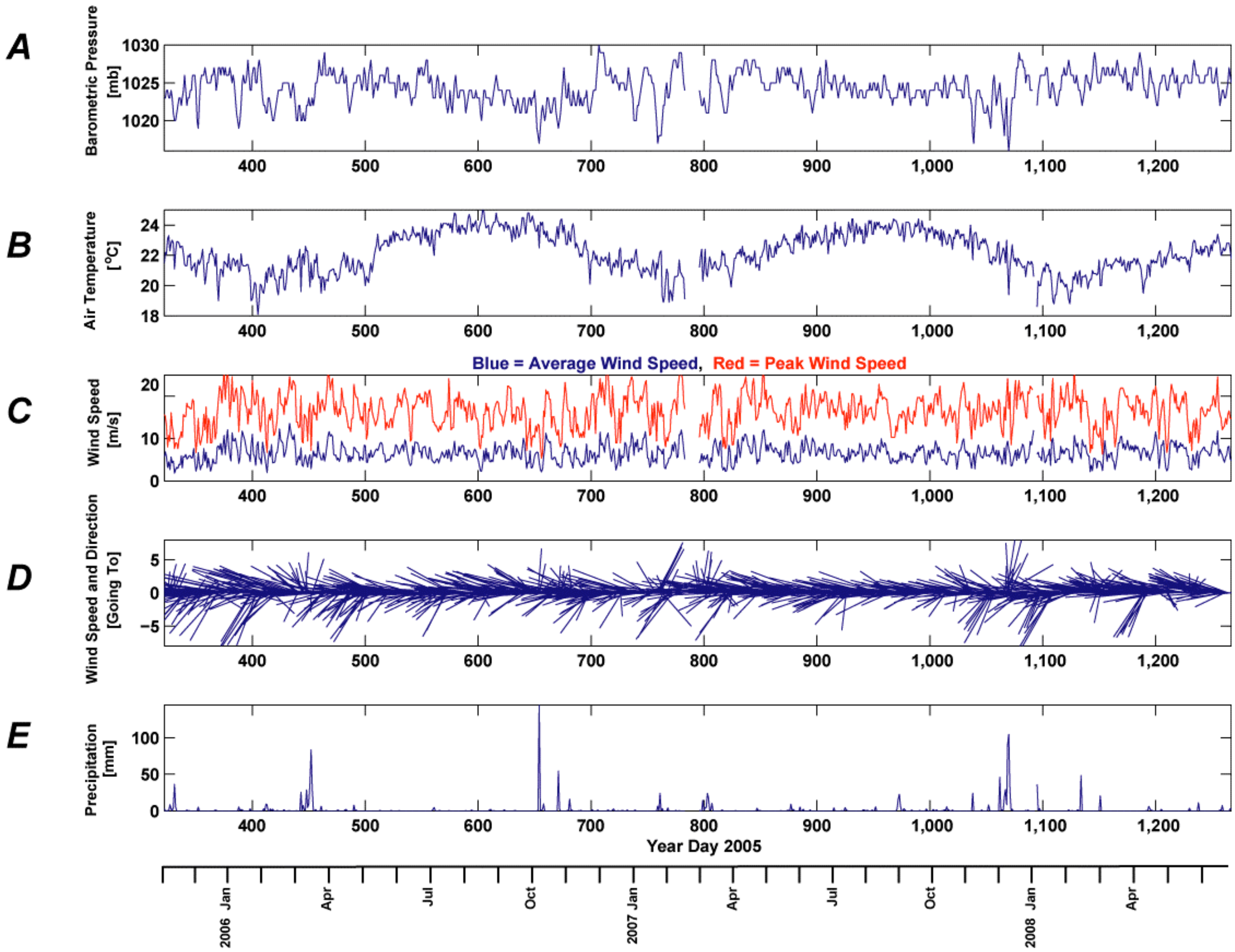

Figure 3. Remote Automated Weather Station daily meteorological data located near Hakioawa, Kaho'olawe. *A*, barometric pressure, in milibars; *B*, air temperature, in degrees Celsius; *C*, wind speed, in meters per second; *D*, wind direction, in meters per second from degrees true north; *E*, precipitation, in milllimeters.

Waves

The wave data from the NDBC buoy #51001 northwest of Kaua'i gives a sense of the wave climate in the vicinity of the main eight Hawaiian Islands during the instrument deployments (fig.4). The location of Kaho'olawe in relation to the other islands limits the amount of impact from north Pacific swells and large northeast trade-wind waves at the study sites. The wave and wind statistics for the deployment are shown in table 5. Without local wave data near the instrument sites on the north side of Kaho'olawe, it is difficult to extrapolate the impact of waves on the resuspension of sediment from the sea floor and the resulting turbidity.

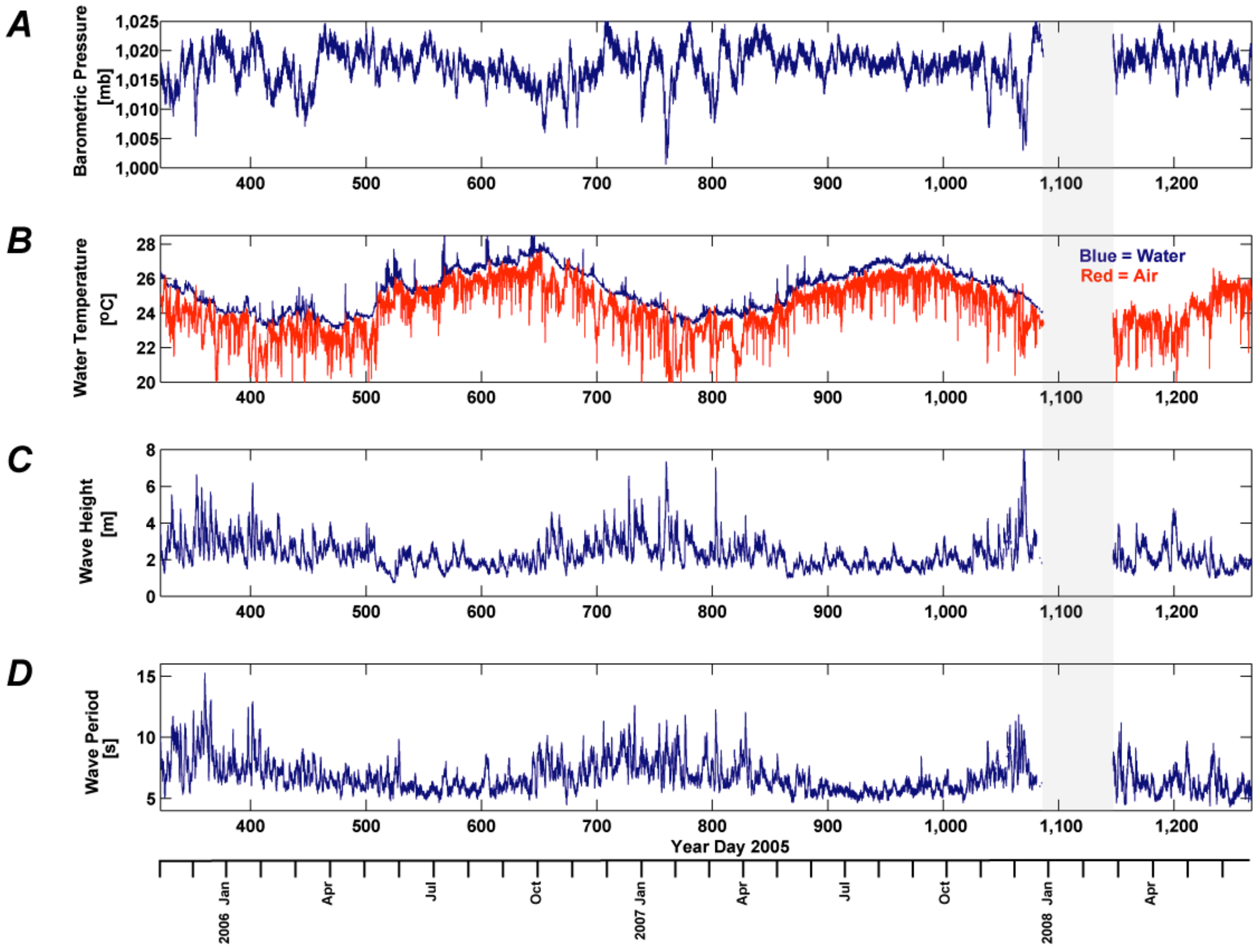

Figure 4. Daily deep-water oceanographic and meteorological data during the study period from the NDBC (2009) buoy #51001. *A*, barometric pressure, in millibars; *B*, water temperature, in degrees Celsius; *C*, wave height, in meters; *D*, wave period, in seconds.

Tides

Typical tides for the Hawaiian Islands are micro-tidal, mixed, semi diurnal with two uneven high tides and two uneven low tides per day; thus the tides change about every 6 hours. While tide information was not acquired directly at the Kaulana and Hakioawa sites, the mean tidal range for the Kahoʻolawe from the NOAA website (*http://co-ops.nos.noaa.gov/tides04/tab2wc3.html*) is roughly 0.46 m, while the spring tidal range is 0.65 m.

Stream flow and Sediment Discharge

The USGS Pacific Islands Water Science Center terrestrial water and sediment gages provided daily mean values of water discharge (m^3/s), suspended-sediment concentration (mg/L) and total suspended-sediment load (metric tons/day), as shown in fig. 5 (*http://waterdata.usgs.gov/nwis/nwisman*). The mean, standard deviation, minimum, and maximum statistics for these data are presented in table 6. The mean discharge for Hakioawa was 5 times greater than Kaulana. If the two sites have similar amount of sediment available for transport, then the suspended-sediment concentration and suspended-sediment load may be greater at Hakioawa due to the capacity of the greater water discharge to transport more sediment.

Soil erosion rates for the Kaulana watershed based on data from the stream flow and sediment gage are 363 metric tons/year from October 1, 2006 to September 30, 2007 (2005 Year, Days 639 - 1003) and 159 metric tons/year from October 1, 2007 to September 30, 2008 (2005 Year, Days 1004 - 1369). The soil erosion rates from a previous study in 1993 were 389 metric tons/year at Kaulana and 948 metric tons/year at Hakioawa (Kaho'olawe Island Conveyance Commission, 1993).

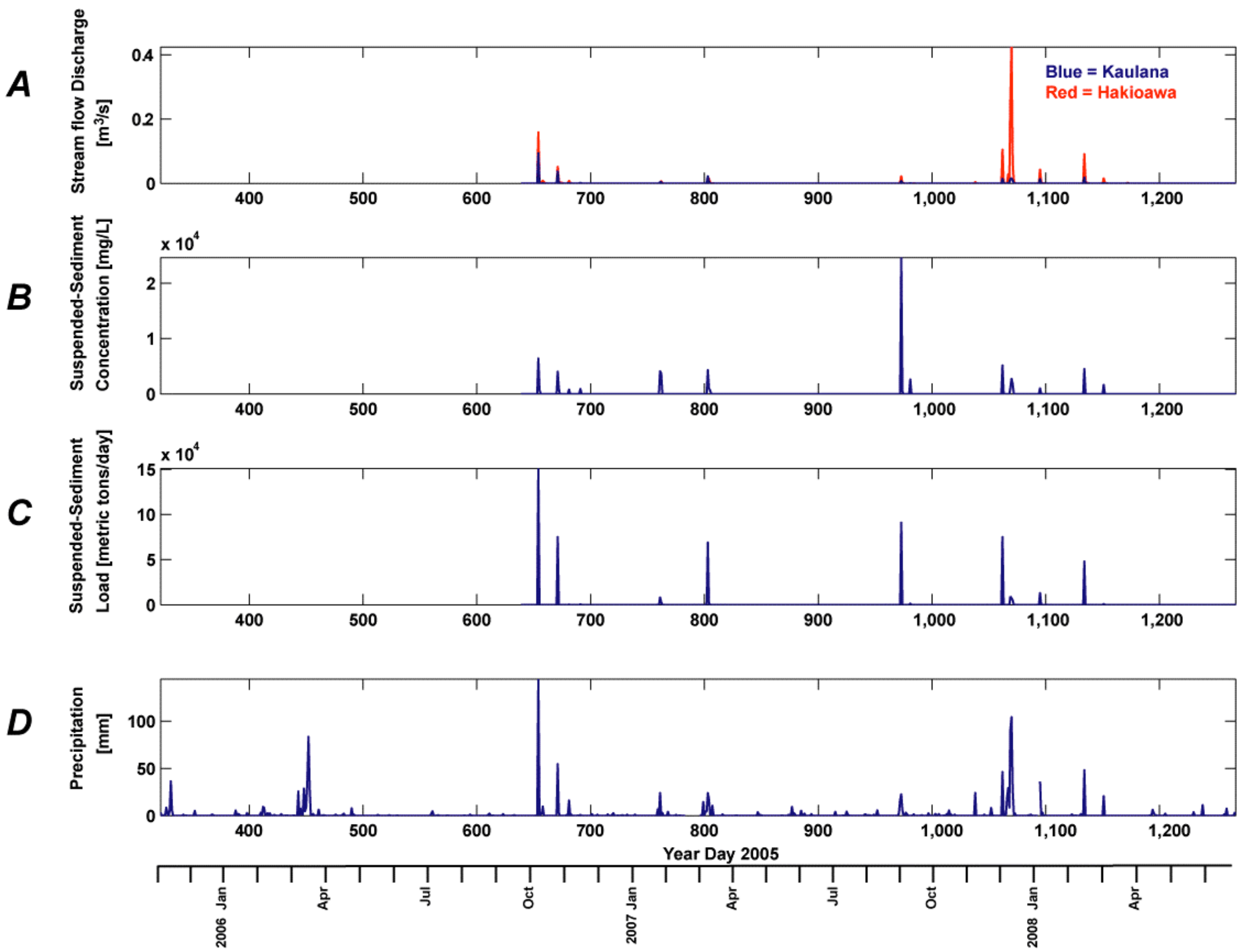

Figure 5. Daily water discharge and sediment data for the Kaulana and Hakioawa watershed during the study period from the U.S. Geological Survey Pacific Islands Water Science Center (2009). *A*, stream discharge from Hakioawa (red) and Kaulana (blue), in meters cubed per second; *B*, suspended-sediment concentration, in milligrams per liter; *C*, suspended-sediment load, in metric tons per day; *D*, precipitation, in millimeters.

Temporal Variability in Turbidity at Kaulana and Hakioawa

Concurrent, reliable data were recorded for 784 days (2005 Year, Days 322 - 1155; 49 days removed due to biofouling) at Kaulana and 945 days (2005 Year, Days 322 - 1267) at Hakioawa for the turbidity instruments. During that time period, the turbidity at the Kaulana area ranged between 0.03 NTU and 213.31 NTU, with a mean turbidity ±1 standard deviation of 16.80±24.40 NTU (table 7). The turbidity statistics at the Hakioawa site for the study period ranged between 0.05 NTU and 606.58 NTU, with a mean turbidity ±1 standard deviation of 17.5±31.96 NTU.

In general, the oceanic waters were more turbid on the eastern side of the island at the Hakioawa site. The highest turbidity levels were measured at Hakioawa, which appeared to be somewhat correlated to changes in precipitation, stream discharge, and sediment load at the

Kaulana gaging station. A few events showed rapid, large increases (>600 NTU) in turbidity, followed by an equally rapid return to low turbidity, clear water values (fig. 6, 2005 Year, Day 340 and 990). The rapid return to pre-event levels could indicate stronger, more energetic waves and currents in this area during these times.

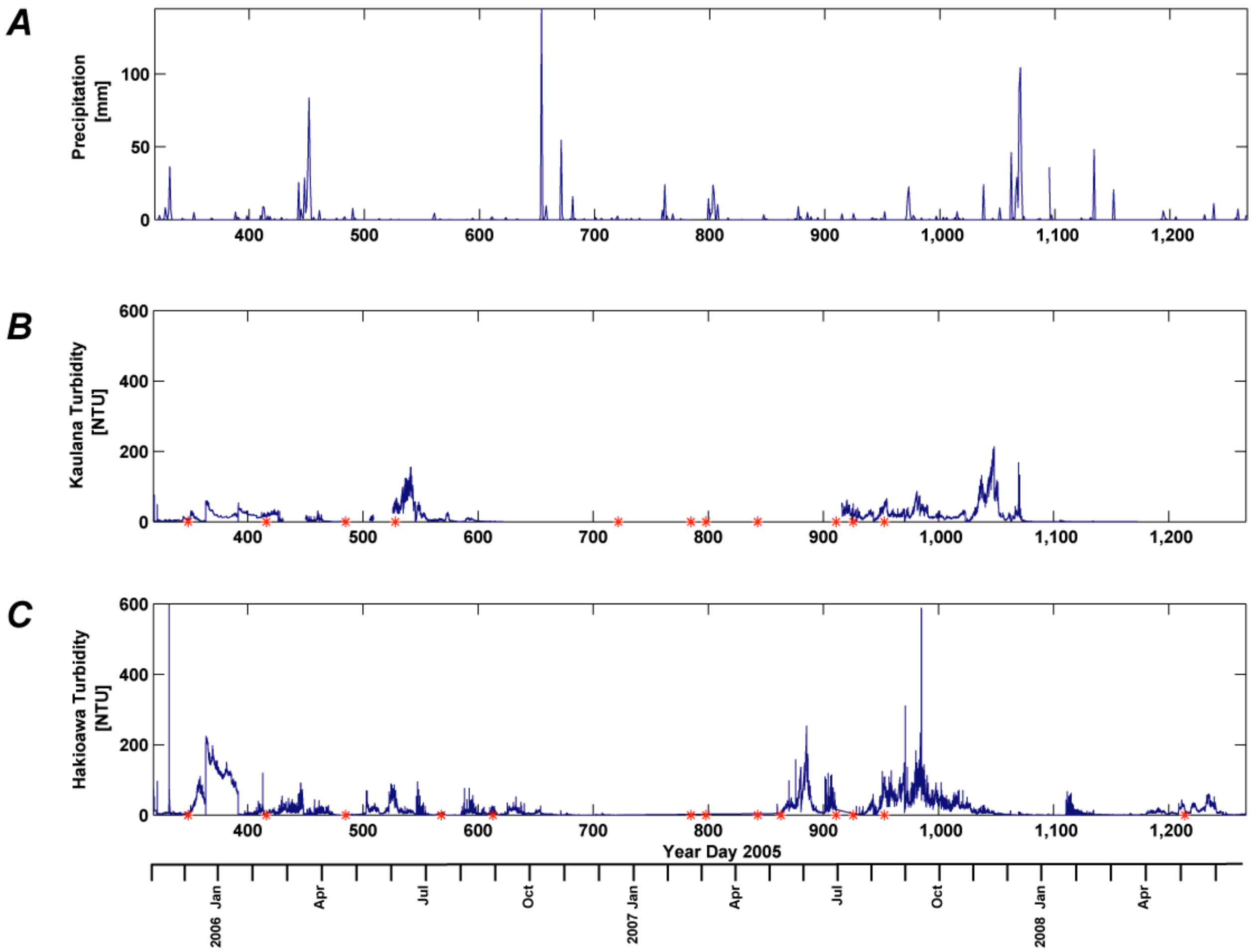

Figure 6. Hourly turbidity data from Kaulana and Hakioawa and daily precipitation data from the Hakioawa Remote Automated Weather Station. *A*, precipitation data from the Remote Automated Weather Station for the period of instrument deployments, in millimeters; *B*, turbidity at Kaulana for the entire study period with cleaning dates marked by a red star (*) and data with biofouling removed, in Nephelometric Turbidity Units; *C*, turbidity at Hakioawa for the entire study period with cleaning dates marked by a red star (*), in Nephelometric Turbidity Units.

The Kaulana site had chronic, moderate levels of turbidity, as opposed to large episodic increases in turbidity due to precipitation or runoff (fig. 6). The Kaulana instrument lens also had higher levels of biofouling that made assessment of turbidity more difficult for this area. Monthly averages of turbidity for the two sites show the basic trends for the area during the period of study (fig. 7). Hakioawa had the higher mean turbidity for the study period, with the highest values occurring in the winter months. Kaulana had lower turbidity values than Hakioawa, although they followed similar temporal trends. Overall, the mean monthly turbidity showed little discernable seasonal trend during the 2 years of data collection.

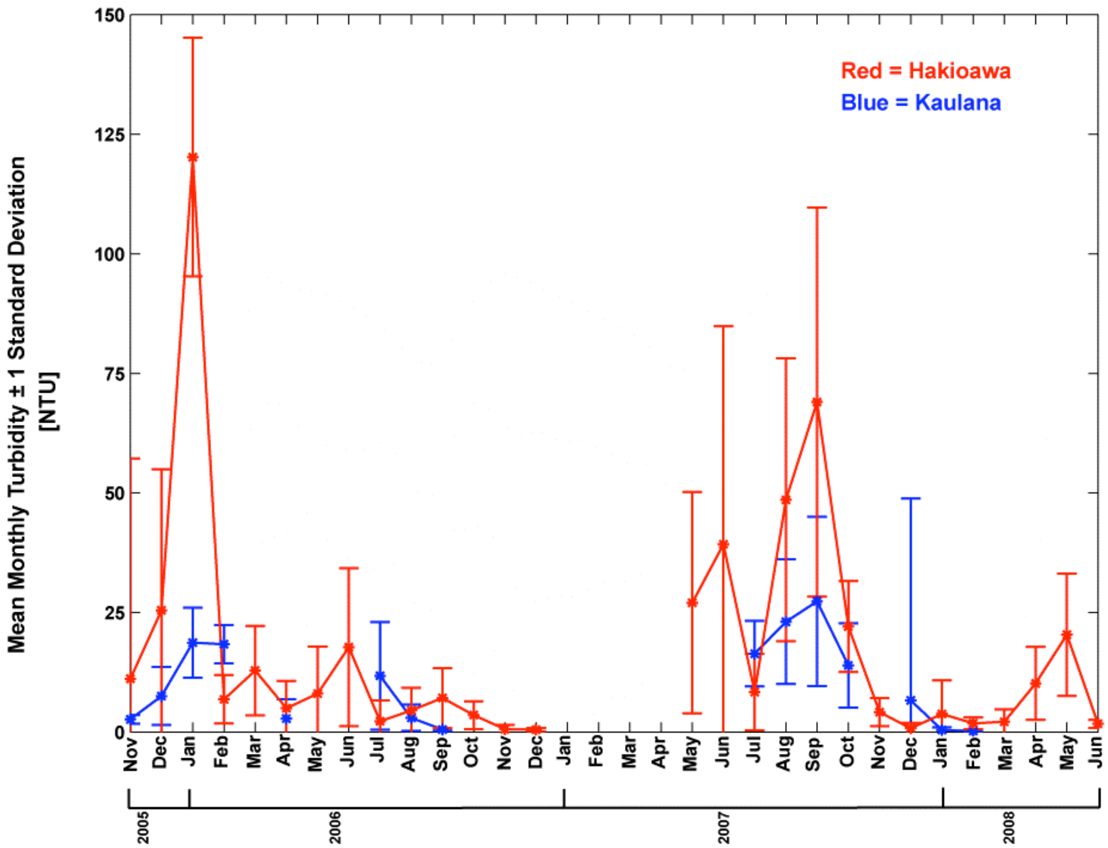

Figure 7. Monthly averages with standard deviations from the hourly turbidity data from Kaulana (blue) and Hakioawa (red) for the entire deployment period, in Nephelometric Turbidity Units. The monthly averages show higher and more variable turbidity was measured off Hakioawa than off Kaulana. The gap in the data is due to biofouling of the self-logging optical backscatter sensor lens resulting in no data.

All of the mean turbidity values recorded during this dry summer period exceed the State of Hawai'i Department of Health's Administrative Rules, Title 11, Chapter 54, Water Quality Standards for "open ocean out to 600 foot depth". The maximum allowable wet season mean turbidity levels, which are roughly twice those of dry season levels, is 0.50 NTU. The mean turbidity near the seafloor for both sites on Kaho'olawe exceeded the maximum acceptable mean level by more than 30 times on average (table 7). In general, the turbidity levels measured off Kaho'olawe are the highest that have been recorded in the Hawaiian Islands by the USGS's Coral Reef Project (*http://coralreefs.wr.usgs.gov/*) between 2000 and 2009. USGS sediment studies on the islands of Kaua'i, Maui, Hawai'i and Moloka'i, although all measured during different times of the year and during different years, did not show turbidity values as high as those measured by the SLOBS off of Kaho'olawe (see *http://walrus.wr.usgs.gov/coralreefs/pubs.html* for a list of various reports). A long-term study conducted by the USGS on the island of Moloka'i showed that fine-grained, terrigenous sediment trapped on the south Moloka'i reef flat is resuspended and transported by the combination of trade winds and high tides on almost a daily basis (Ogston and others, 2004; Presto and others, 2006). The mean daily suspended sediment concentrations during those studies was 5 to 70 mg/L (roughly equal to 5 to 50 NTU), with the highest values reaching >120 mg/L (roughly equal to 100 NTU).

Conclusions

In all, almost a half a million measurements of turbidity were made offshore of two watersheds on the northern side of Kaho'olawe, Hawai'i, during the 2.5-year period between November 13, 2005 and June 20, 2008. Key findings from these measurements and analyses include the following.

1) Both sites had long-lasting periods (weeks to months) of high levels of turbidity. Hakioawa had higher levels of turbidity than Kaulana, and these periods of high turbidity appeared to be better correlated to precipitation events than those at the Kaulana site. The short-duration, high-turbidity events at the Hakioawa site are likely due to large injections of sediment followed by rapid flushing by waves and/or currents. Conversely, the longer-duration, moderate turbidity events at the Kaulana instrument site may indicate slower flushing in that area by waves and/or currents. Without the instruments to measure waves for resuspension and currents for advection of sediment, it is difficult to determine the causes of elevated turbidity in the water.

2) There is no discernible long-term trend in turbidity at the Hakioawa and Kaulana sites over the period of study. The sediment erosion rates from the 1993 study and the 2007 and 2008 sediment gage data show a slight decreasing trend in sediment mobilization within the Kaulana watershed, but it is unknown whether that decrease was caused by rainfall patterns, restoration efforts, or a combination of factors. It also appears that towards the end of the study period in late 2007 and 2008, precipitation in the watersheds was not strongly correlated with turbidity.

3) It is recommended that anti-biofouling wipers be used on the lenses of SLOBS for future long-term monitoring of oceanic turbidity to prevent biofouling. The use of wipers will result in more precise quantitative information on the extent and intensity of turbidity events for comparison to established water-quality standards, and will be useful for correlating with rainfall, stream flow, and restoration efforts.

4) In comparison to other study sites (north Kaua'i, west Maui, south Moloka'i), Kaho'olawe has very high suspended-sediment concentrations and turbidity, especially considering the low levels of precipitation and stream discharge. The abundant exposed sediment supply on the denuded island surface is probably a major contributing factor.

Acknowledgments

This work was carried out in conjunction with the KIRC by the USGS's Coral Reef Project as part of an effort in the U.S. and its trust territories to better understand the affect of geologic processes on coral reef systems. Dean Tokishi (KIRC) was instrumental for the data collection and cleaning of the instruments, sometimes during adverse conditions. We would also like to thank Nancy Prouty (USGS) and Susie Cochran (USGS), who contributed numerous excellent suggestions and a timely review of our work.

References Cited

Kaho'olawe Island Conveyance Commission, 1993, Kaho'olawe Island: Restoring a cultural treasure: Final Report of the Kaho'olawe Island Conveyance Commission to the Congress of the United States. 158 p.

National Data Buoy Center, 2009. Historical hourly data for NW Hawai'i Station #51001, online dataset: National Oceanographic and Atmospheric Administration, date accessed 3/01/2009, at *http://www.ndbc.noaa.gov/station_history.php?station=51001*.

Ogston, A.S., Storlazzi, C.D., Field, M.E. and Presto, M.K., 2004, Currents and suspended sediment transport on a shallow reef flat: South-central Moloka‘i, Hawai‘i; Coral Reefs, v. 23, p. 559-569.

Pacific Islands Water Science Center, 2009, Daily stream flow and sediment discharge data for Hawai‘i, online dataset: U.S. Geological Survey, date accessed 3/01/2009, at *http://waterdata.usgs.gov/hi/nwis/sw/*.

Presto, M.K., Ogston, A.O., Storlazzi, C.D., and Field, M.E., 2006, Temporal and spatial variability in the flow and dispersal of suspended-sediment on a fringing reef flat, Moloka‘i, Hawai‘i, Estuarine Coastal and Shelf Science, v. 67, p. 67-81.

Slay, H, 2009, Hawaii: Hakioawa and Kaulana watersheds - Restoring native vegetation reduces sediment entering coastal waters, online report: Environmental Protection Agency, date accessed 06/01/2009, at *http://www.epa.gov/nps/success/state/hi_kaho.htm*.

State of Hawai‘i, Department of Health, 1989, Hawaii Administrative Rules, Title 11, Chapter 54: Water Quality Standards, Honolulu, HI, p. 1-67.

Additional Digital Information

For additional information on the instrument deployments, please see:
http://walrus.wr.usgs.gov/infobank/k/k105kw/html/k-1-05-kw.meta.html

For an online PDF version of this report, please see:
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For more information on the U.S. Geological Survey Western Region’s Coastal and Marine Geology Team, please see:
http://walrus.wr.usgs.gov/

For more information on the U.S. Geological Survey’s Coral Reef Project, please see:
http://coralreefs.wr.usgs.gov/

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Tables

Table 1. Experiment personnel.

Person	Affiliation	Responsibilities
Mike Field	USGS	Chief scientist
Curt Storlazzi	USGS	Research Oceanographer
Kathy Presto	USGS	Oceanographer
Lyman Abbott	KIRC	Natural Resources Technician
Jamie Bruch	KIRC	Natural Resources Technician
Dean Tokishi	KIRC	Ocean Resources Specialist, diver
Charlie Lindsey	KIRC	Maintenance Assistant and Vessel Operator

Table 2. Instrument sensors.

Site name	Elevation [m]	Sensors
Kaulana	-7.6	Aquatec self-logging optical backscatter turbidity meter (SLOBS)
Hakioawa	-8.5	Aquatec self-logging optical backscatter turbidity meter (SLOBS)
Hakioawa	366	Remote Automated Weather Station (RAWS)
Kaulana	31	USGS stream flow and sediment discharge station # 16682000
Hakioawa	23	USGS stream flow discharge station #16681000

Table 3. Instrument deployment and recovery dates.

Site name	Deployment date	Recovery date
Kaulana	11/17/2005	01/26/2006
Kaulana	01/26/2006	05/2/2006
Kaulana	05/02/2006	09/22/2006
Kaulana	06/07/2007	10/20/2007
Kaulana	10/20/2007	03/18/2008
Hakioawa	11/17/2005	01/26/2006
Hakioawa	01/26/2006	06/29/2006
Hakioawa	06/29/2006	12/31/2006
Hakioawa	05/09/2007	06/30/2007
Hakioawa	06/30/2007	07/17/2007
Hakioawa	07/17/2007	01/15/2008
Hakioawa	01/15/2008	06/20/2008

Table 4. RAWS meteorological statistics.

Parameter	Mean ± 1 standard deviation	Minimum	Maximum
Wind Speed (m/s)	6.54±2.44	1.82	13.5
Wind Direction (°T)	96.5±43.2	1.0	356
Precipitation (mm)	1.47±8.43	0	144
Barometric Pressure (mbar)	1,024.34±2.11	1,016	1,030
Air Temperature (°C)	22.2±1.3	18.1	25.1

Table 5. NDBC Buoy #51001 wave and wind statistics.

Parameter	Mean ± 1 standard deviation	Minimum	Maximum
Wind Speed (m/s)	6.77±2.51	0	18.00
Wind Direction (°T)	109.8±69.8	0	360
Wave Height (m)	2.28±0.81	0.74	8.75
Average Wave Period (s)	6.7±1.3	4.2	15.3
Wave Direction (°T)	164.7±117.6	1	360

Table 6. USGS stream flow and sediment discharge statistics.

Parameter	Mean ± 1 standard deviation	Minimum	Maximum
Kaulana Stream Discharge (m^3/s)	0.0004±0.0043	0	0.0930
Hakioawa Stream Discharge (m^3/s)	0.0220±0.0220	0	0.4200
Kaulana suspended sediment concentration (mg/L)	117.13±112.01	0	24,600.00
Kaulana suspended load (metric tons/day)	0.81±8.04	0	136.97

Table 7. Turbidity statistics.

Site name	Mean ± 1 standard deviation	Minimum	Maximum	10 percent exceedance	2 percent exceedance
Kaulana SLOBS (NTU) *	16.80±24.40	0.04	213.30	40.17	100.25
Hakioawa SLOBS (NTU)	17.51±31.96	0.05	606.58	51.27	128.66

* Due to excessive biofouling, data was clipped from days 430-449, 487-503, and 510-524 for the statistics.

Appendix 1

Self-Logging Optical Backscatter Sensor (SLOBS) Information

Aquatec/Seapoint 210-TYT SLOBS; s/n 024-031, 024-032, 024-033, 024-045

Sampling Frequency:	2 Hz
Measurements per Burst:	8
Time Between Bursts:	00:05:00.00

Data Processing:

The SLOBS data were post-processed for visualization and analysis by removing all instantaneous (only one data point in time) data spikes that exceeded the deployment mean + 3 standard deviations.