Final Project Report (3/30/12)

"Storm Water Runoff & Sedimentation into Coastal Bays with Coral Reefs: Comparisons between Developed and Underdeveloped Watersheds, US Virgin Islands"

Submitted by:

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Introduction & Objectives:

In the US Virgin Islands, sediment from storm-water runoff constitutes the largest pollutant of coastal waters by volume and is thought to be the primary cause of coral reef degradation. The factors governing the quantity, duration and type of sedimentation that may potentially affect a particular coral reef are complex and variable. Developing the most effective watershed runoff and sediment management strategies requires a thorough site-specific knowledge of the unique processes that impact the quantity, quality (type), and temporal variability of runoff and sedimentation into an individual reef system. Therefore, detailed and comprehensive monitoring of both sedimentologic & physical processes affecting individual reefs is a critical compliment to ecological monitoring of coral reef health.

The research objective of our study was to establish a baseline of data from which to evaluate how development in watersheds on St. John in the USVI have impacted the amount and chemistry of terrestrial runoff and the quantity, quality (type), and spatial variability of sedimentation in bays with reefs. In addition, we proposed to link bay sedimentation to storm-water runoff by conducting storm-water sampling directly above our sediment traps. Our approach was to collect and compare sediments and storm-water runoff samples within and among watersheds above two bays with reefs—one drained by developed watersheds (Coral Bay) and one drained by a relatively pristine undeveloped watersheds (Great Lameshur). We focused our sampling to target locations with monitored reefs and locations where extensive watershed construction was planned or is or underway.

A sediment study we conducted in 2007 (Aug.-Nov.) and 2008/9(Aug.-Mar.) demonstrated that sediment flux rates in Lameshur Bay in the VI National Park were consistent with rates recorded for reefs not subjected to human activities. We requested funding from the NOAA CRC Program to continue this important work during the 2009 fall rainy season and to expand our monitoring efforts to include several areas in Coral Bay that had not been studied previously. Coral Bay is a rapidly growing rural community on a 3,000-acre watershed that drains into a bay with coral reefs and mangroves, some of which are part of the V.I. Coral Reef National Monument. This development may increase storm water pollution into the sensitive bay. Our preliminary work in 2007-8 also revealed the necessity of linking our sedimentation data with "up-watershed" monitoring of storm-water flux and composition. Therefore we proposed to expand our research program to include direct sampling of watershed sediments and storm water. In addition, we examined how water quality (turbidity, TSS, TOM) in the ghuts and bays following storm (sediment runoff events) compared to background (non-storm) conditions. We also deployed current meters and collected rain data.

Our outreach goal was to establish an ongoing research & educational partnership between the University of San Diego and USVI community and governmental partners including the Coral Bay Community Council, V.I. Resource Conservation & Development Council, Inc. (V.I.R.C. & D), the University of the Virgin Islands, and Clean Islands International/VIERS. By conducting programs with K-12 students attending "eco-camp", and by presenting our research to the local residents of Coral Bay, our activities increased public awareness about the link between watershed activities and the conservation of coral reefs. In addition, several University of San Diego graduate and undergraduate student researchers participated in research projects associated with the research. Ultimately, data collected as part of this grant (in combination with previously and subsequently collected data) will provide tangible data for territorial and local environmental managers to inform policy decisions.

Modification of the originally proposed research plan:

We made two modifications to our proposed research plan: 1) elimination of sampling in Fish Bay, and 2) postponement terrestrial/ghut (ephemeral stream) and storm sampling from the fall of 2009 to the fall of 2010.

Our original proposal was to conduct sediment and water quality monitoring in three bays on St. John: Fish Bay, Coral Bay, and Lameshur Bay. As discussed through emails and a telephone conference with the Program Officer, Jennifer Koss in July of 2009, we modified our scope of work to conduct more intensive sampling (additional sites) in Coral and Lameshur Bays only. In July, 2009 the Virgin Islands Resources Conservation & Development Council, Inc. (V.I. RC&D) and partners were awarded a grant from NOAA Coastal & Marine Habitat Restoration (ARRA) for their project entitled the "USVI Coastal Habitat Restoration through Watershed Stabilization" (http://www.usvircd.org/NOAA-ARRA_Grant.htm). As part of this program, Dr. Tyler Smith and his research group at the University of the Virgin Islands (CMS) were contracted to conduct sediment trap and composition monitoring in Fish Bay. Therefore, it did not make sense for us to conduct sediment and water-quality monitoring in Fish Bay as we had originally proposed. Instead we added additional sites in Coral Bay and focused our sampling for this program on Coral Bay. Because Coral Bay is below a developed watershed and Lameshur Bay is below an undeveloped watershed, it will still be possible for us to compare results between developed and undeveloped watersheds.

A second modification of the proposed research plan was necessary because we did not receive funding for the grant until September of 2009, over 2 months after the start date of the proposal. In our original proposal, Dr. Thomas Kretzschmar of CICESE and his graduate student proposed to participate in our August 2009 field season. Their role was to set up ghut (ephemeral stream) and terrestrial water & sediment sampling stations. However, because the funding was not awarded until September 2009 they were unable to participate in our August 2009 field season. We therefore postponed the fieldwork for terrestrial, ghut, and storm sampling to the summer and fall of 2010.

RESEARCH ACTIVITIES & RESULTS:

A. FIELDWORK: Sediment & water quality sampling and in-field laboratory analyses (August, 2009-March 2010):

In August of 2009 following watershed and submarine surveys, Gray and a team of student researchers set up 26 sediment traps at 14 stations in 4 areas of 2 bays (Great Lameshur, Little Lameshur, Coral Bay, and Hurricane Hole) for ongoing sediment monitoring in St. John (Figs. 1 & 2; Table 1). At 6 shore locations, "storm" sediment traps were set up to monitor sedimentation during discrete storm events. At 7 locations, paired traps of differing trap heights above the substrate (30 and 60 cm) were deployed to examine the effect of trap height on sediment accumulation. During previous field seasons, the shore traps were deployed at only 30 cm above the bay-floor (to maximize their proximity to the ghut outfall), rather than 60 cm above the bay floor as in deeper locations (bay and reef sites). By deploying paired short (30 cm) and tall (60 cm) traps at these locations this year, we hoped to evaluate the relative impact of re-suspension over new sediment delivery. In both bays, traps were deployed in mangrove, shore, bay and reef environments (Table 1).

Within Coral Bay, sites were chosen to sample below watersheds with different degrees of development. For example the Plantation Hill site (TC-10; Fig. 1) drains a sub-watershed with no upslope development and only minimal development at the base of the slope. The Calabash Boom site (TC-1) is below an active construction site with sediment ponds to reduce sediment delivery to the shore. The Shipwreck Landing site (TC-3) is below a developed (un-mitigated) steep watershed (Fig. 2). We sited two sampling stations in the mangrove areas of Coral Bay Harbor (TC-5 & TC-8; Fig. 1), which drain the largest watershed. In 2009 we expanded our monitoring in Coral Bay to include the pristine mangrove areas in Hurricane Hole, where healthy and diverse coral communities inhabit the mangrove in spite of limited light penetration. Great Lameshur Bay is below a watershed that is totally within the VI National Park, and is thus largely undeveloped (except for a few roads and the VIERS camp) (Fig. 2). In Great Lameshur Bay, sediment traps were deployed along a transect from the mangrove & ghut (drainage) outfall to the reefs (Fig. 2). In 2009, we also added three traps in the shore area of Little Lameshur Bay (TL2-5; not plotted on Fig. 2), which drains an adjacent, undeveloped watershed within the Virgin Islands National Park. Our reef sampling sites in Lameshur Bay include two traps at Yawzi Point and one trap at Tectite Reef (TT-1; not pictured in Fig. 2).

From Sept. 2009- March 2010, Nick Przyuski, our research assistant in residence at the Virgin Islands Environmental Resource Station (VIERS) collected water and sediment samples at regular intervals every 23-25 days with the help of local field assistants. For each of the nine collection periods from January –March 2010, sediments (suspended, trapped, and bottom) and water samples were processed at the VIERS (Virgin Islands Environmental Resource Station) laboratory following methods outlined in our proposal. Dried and frozen sediments and water samples were sent to the University of San Diego for further chemical and geological analyses at the University of San Diego and CICESE. The original NOAA proposal included only funding for field research through December of 2009. We were able to extend our '09-'10 field sampling season three extra months (January –March) due to additional funding from ARRA/NOAA.

Some sediment traps ("storm traps") were deployed during short periods (< 5 days) of storm activity to capture the short-term storm sediment input. This year they were deployed from 9/2/09 to 9/7/09 and again for a smaller storm from 11/11/09-11/15/09. Unfortunately, due to logistical limitations, we were unable to deploy the storm sediment traps during the larges rain/runoff event that occurred in December of 2009. In addition to sediment trap and marine water sampling stations, we deployed two acoustic current meters (Falmouth 2D ACM) on the north and south side of Coral Bay to monitor circulation within the bay (Fig. 7) and a rain gage on the roof of the VIERS lab in Lameshur Bay.

B. FIELDWORK: Watershed & storm event sampling (July –Dec., 2010)

From July 18th-Aug. 13th, 2010, Gray and a team of student researchers from USD and CICESE in Ensenada, Mexico conducted fieldwork in St. John. Our field activities focused on setting up storm water sampling stations and collecting terrestrial & ghut (ephemeral stream) sediment and water samples for chemical and geological analyses. We also set up storm sediment traps and trained our new VIERS research volunteer (Whitney Sears) and part-time field assistants to conduct storm sampling during the fall 2010 rainy season. Since August 2010, Whitney Sears, our research assistant in residence at the Virgin Islands Environmental Resource Station (VIERS) for 2010-11 and a part-time field assistant (Matt Knoblock) collected samples and data during three major storm runoff events that occurred in 2010.

During the summer to fall of 2010, there were an unusually high number of storms in St. John, some of which brought significant rainfall and sediment runoff into the bays (Figs. 9-12). The following major storm events occurred: a) low pressure system: 7/20/10-7/23/10; b) Hurricane Earl: 8/30/10-8/31/10; c) Tropical Storm Otto: 10/5/10-10/7/10; and d) cold front: 11/6-11/9/10. Except for Hurricane Earl, which brought mostly wind and little rain to the island, all of these events resulted in unprecedented sediment runoff into the bays and turned the color of the bays brown (Figs 9-12). For most of the storm events, we conducted storm water gut sampling and turbidity surveys of the bays. For each of these storms our research assistants observed and sampled the guts in Coral Bay and Lameshur Bay at 24-hour increments during the storm and collected runoff water samples, photos, and measured the depth of water in the ghuts (Fig. 12). In addition, "storm sediment" traps were uncapped at the beginning of the storm and recapped following the storm to assess storm sediment accumulation.

C. RESULTS & DISCUSSION

a) Total sediment trap accumulation: Analyses of mean total sediment accumulation rates (in mg/cm^2/day) determined for each 23-25 day sampling period for sediment traps in mangrove, shore, bay, and reef environments are shown in Figures 3A-3C. Total sediment accumulation rates ranged from less than <1 to ~800 mg/cm^2/day. The highest accumulation rates were measured in the shore and mangrove locations and the lowest accumulation rates were measured in the bay and reef locations (Figs. 3B & 3C). The trap height had a strong effect on the sediment flux. Shore traps deployed at only 30 cm above the bay floor are more likely that the taller 60 cm traps to collect sediment that has been re-suspended by waves (Fig. 3C). Therefore, our final analyses/interpretation of the data will rely on data from the taller (60 cm) traps.

The highest mean accumulation rates for the fall season were recorded in the 30 cm traps at the Coral Bay shore sites. Within Coral Bay, the sediment accumulation rates were highest at the Shipwreck shore site, which is below a developed steep watershed with no mangroves or sediment retention ponds (Fig. 3C). The sediment accumulation rates were lowest at two locations in Coral Bay below less or undeveloped watersheds (Plantation Hill TC-10) and Hurricane Hole (THH-1) (Figs. 3C). Sediment accumulation rates on the Coral Bay reefs were relatively low (< 10 mg/cm^2/day) and consistent with sediment accumulation rates recorded on reefs below undeveloped watersheds in the Virgin Islands National Park (Fig. 3A & 3B). However, sediment on the North and South Reefs of Coral Bay contained and average of 26 % and 16% terrigenous sediment, respectively. When the mean sediment accumulation rates for the 09-10 field season were compared between Lameshur and Coral Bays, there did not appear to be large differences in the total accumulation rates for the reef, or mangrove sites, but sediment accumulation at the Coral Bay shore sites was usually 10's to 100's of times higher than at the Lameshur Bay shore sites (Figs 3A-C).

Some sediment traps ("storm traps") were deployed during short periods (< 5 days) of storm activity to capture the short-term storm sediment input. This year they were deployed from 9/2/09 and 9/7/09 and again for a smaller storm from 11/11/09-11/15/09. Storm sediment input was always higher than for the integrated 25-day sediment accumulation for non-storm periods (Fig. 4)

b) Sediment composition (%): The sediment composition for all samples collected during the 2009/10 sampling season indicated that for Coral Bay, the mangrove sites and the Shipwreck shore site contained the highest proportion of terrigenous sediment (>70%), while the Calabash Boom shore sites and reef sites generally contained <40% terrigenous material (Fig. 5). It is interesting that the Coral Bay North Reef site always contained higher proportions of terrigenous material (20-25%) than the South Reef site

(Fig. 5). Even though the accumulation rate at the Coral Bay Reefs were generally low, the proportion of terrigenous material at the Coral Bay reefs was always much greater than at our reefs below undeveloped watersheds (Yawzi & Tectite Reefs in Lameshur Bay) (Fig. 5).

c) Terrigenous sediment accumulation: Mean terrigenous sediment accumulation at the shore sites was highest under the developed watersheds on the south shore of Coral Bay (Calabash Boom and Shipwreck) than in the Coral Bay Harbor below the largest developed watershed of Coral Bay (Fig. 6A). This may be due to the fact that the Calabash and Shipwreck watersheds are steep watersheds or the fact that the mangroves lining Coral Bay Harbor may be capturing and reducing influx of terrigenous sediment into the bay. However, terrigenous sediment accumulation at both Coral Bay locations was higher than in below the undeveloped, Lameshur Bay shore sites (Fig. 6A). Terrigenous sediment accumulation at the reef sites in both Coral Bay and Lameshur bay were low (<1.5 mg/cm2/day), but were consistently higher at the Coral Bay (developed) reefs than at the Lameshur Bay reefs during the 2009-10 sampling season (Fig. 6B). Terrigenous sediment accumulation peaked at both the shore and reef locations following a storm in December 2009 (Figs 6A & 6B).

d) Sediment texture: Sediments collected at the shore locations were coarser (mean grain size: > 100 microns) than at the mangrove or reef sites (mean grain size: <100 microns) (Figs.7A & 7B). Sediment collected at the shore sites (TC-1 & 3)were predominantly sand with moderate silt and minor clay. Sediments collected at the mangrove and reef locations (TC-5 & TC-11) were predominantly silt with moderate sand and minor clay (<13 %) (Fig. 7A). There did not appear to be consistent pattern of textural variability over time between sites.

e) Environmental data: Data for currents in Coral Bay (Fig. 8) show as seasonal shift in the direction and strength of the currents as they flow through and interact with the geography of the bay. This change in current dynamics may correspond to the change in the trade wind direction from predominantly southeasterly in the fall to predominantly easterly in the late winter-spring. Daily rainfall for 2010 and monthly cumulative rainfall for 2009-11 in Lameshur Bay are presented in Figures 9A and 9B. The summer/fall rainy season of 2010 produced unusually high rainfall amounts compared to historical averages and our four-year time series (Figs 9A & 9B), with the highest rainfall delivered by TS Otto, which passed over St. John between 12/7/10-10/9/10.

f) Turbidity/TSS/TOM. The objective of turbidity/TSS/TOM analyses was to address the following questions: 1)What is TSS (Total Suspended Sediments) and SOM (Suspended Organic Matter)? 2) Is there a measurable difference in TSS and SOM in bays below watersheds that have undergone different degrees of human development? 3) Is there a difference in TSS between storms (runoff events) and fair weather conditions? To address these questions, we collected water samples and took multimeter readings at all sampling sites during regular 26-day sediment samplings. The seasonal means of TSS measured during regular sampling periods for the field season are depicted in Fig. 13. These show the that highest TSS was measured at the shoreline of the Shipwreck site and that all shore TSS values were higher below developed watersheds in Coral Bay compared to below undeveloped watersheds in Lamehshur Bay (Fig. 13). The proportion of the TSS that is non-organic matter (likely terrigenous) was also highest in the shore locations below the developed compared to the undeveloped locations (Fig. 13). To determine how turbidity (TSS) increased after storm events, we sampled TSS following storms during the fall of 2010. When we arrived in St. John on July 19th, 2010, there was a record-breaking rainfall event from 7/20/10-7/23/10. This storm turned the water in the bays brown with suspended sediment (Fig 10). In Little Lameshur Bay, a new ghut formed (Fig. 10). We conducted TSS sampling immediately following the storm in Coral and Great Lameshur Bays at our regular sampling sites and along transects from the ghut outfalls to the reefs. A comparison of storm water turbidity on 7/20 and 7/21 to background (fair weather) turbidity on 8/10/10 is shown in Figure 14. The TSS values of storm water samples ranged from 45.3mg/L to 729.8mg/L (Fig. 14). By contrast, the TSS values of non-storm event samples range from 1.5 to 32.5mg/L (Fig. 14), demonstrating an increase in turbidity between 20 to 32 times during storm events compared to background conditions. Though the waters clear out after a few days, on the short term, these high turbidity levels could be detrimental to corals.

g) Bioavailable heavy metal analysis of sediment. A pilot study was conducted to determine the concentrations and spatial variability of bioavailable heavy metals in terrigenous sediments in order to determine if some metals could be traced from the watershed to the marine environment. Terrigenous samples collected during July and August of 2010 included soil streambeds (ghut) samples, and suspended sediments in storm-water runoff (Figs. 15A & 15B). In the laboratory, we extracted the metals using EDTA (kinetics metal extraction approach) and measured Cd, Cr, Co, Cu, Mn, Ni, and Zn on an ICP-OES. Bulk (un-sieved) sediment samples were analyzed from Coral Bay, Shipwreck Bay, and Great Lameshur Bay from different elevations in the watershed and in the bay (Figs. 15A & 15B). Bioavailable metals concentrations in marine sediments measured thus far have not exceeded threshold levels set by the EPA (USEPA 2005). In general, several metals tend to accumulate in lower ghuts and mangroves, although this is not true for all metals. For instance, Cobalt seems to decrease in relative abundance as it goes down the watershed and into the marine environment (Fig. 15A & B). Metals weathered from rocks likely flow down the watershed in rain events and pass over sediments, slowly adding more adsorbed metals.

h) Geological and chemical analyses of sediment. The concentrations and spatial variability of major elements and heavy metals in terrigenous rocks and sediments (whole rock) was examined to determine if some metals could be traced from the watershed to the marine environment. Robert Harrington, a USD MS student analyzed rocks and sediment by X-ray fluorescence (XRF) to determine trace and major element concentrations (Table 2). Rocks from both Coral Bay and Little Lameshur Bay watersheds are within the Water Island Formation geologic unit. During our surveys we found two major bedrock units in our study area, basalt and plagiorhyolite. A mixing diagram of zirconium vs. scandium concentrations within each sediment and rock sample (Fig. 16) illustrate that sediments plot between the end member bedrock types (basalt and the plagiorhyolite) suggesting that the watershed sediments are a mixture of both of these bedrock types. A similar trend was observed for other elemental ratio graphs including: Cr vs. V, Co vs. Zr, Cu vs. Co, V vs. Zr, Cr/Zr vs. Ba/Y, Rb/Ba vs. Sr/Cu. As these sediments move down through the watershed and into the bay we expect to see these metal concentrations change depending on the sediments interaction with rock, soil, rainwater, seawater, plants, and anthropogenic materials. Some elements increased with transport down the watershed and others decrease (Figs. 17A & 17B). However, the pattern of variation varies between the two study areas. These data provided a basis for ongoing chemical and geological watershed work in 2011 and 2012 that was funded on subsequent grants.

i) Hydrochemistry of stormwater samples. As part of his MS thesis project at CICESE, Napolean Gudino, a student of Dr. Thomas Kretzschmar conducted an assessment of the geochemistry of the major cations in storm water runoff collected during storm events in 2010 (7/26/10, 9/12/10 and 10/5/10). His study tests the hypothesis that the water/rock interaction (as traced by the chemistry of storm water runoff) is accelerated/modified by the level of human development on the drainage watershed due to the presence of dirt roads. As part of his study, he collected and analyzed 30 storm water samples that were collected during three major storms, which passed over St. John between July and October of 2010. Major elements (Na, CA, Si, Mg, and K) dissolved in the storm water samples were determined using a Varian Liberty 100 ICP-OES. Chloride content was determined using a Dionex 2000 Ion Chromatograph equipped with a separation column for anions and was used to correct for contamination with sea-salt & spray. His preliminary results are given in Tables 3. We expect further interpretation and analyses of these results to be presented in his MS thesis, which will be completed by the end of the summer, 2012.

C. SUMMARY OF RESEARCH RESULTS AND RESEARCH OUTCOMES

Our research has produced the following research results:

a) Regular 26-day sediment and water quality monitoring was established in multiple sites in Coral and Lameshur Bays. Some of these sites were new sites that had not previously been the target of monitoring.
b) Storm-event sampling protocols were established and tested during the 2010 rainy season.
c) Data from the 2009-10 field season confirmed previous results that there were higher total and terrigenous sediment accumulation rates in all environments below developed watersheds and during periods of high rainfall. Generally, there were higher total and terrigenous sediment accumulation rates below the Shipwreck watershed in Coral Bay. Total and terrigenous sediment accumulation rates were relatively low on all reefs.
d) Higher average turbidity and TSS were measured at all shore locations below the developed bays during regular sampling periods. The suspended sediments under developed watersheds were comprised of a greater proportion of non-organic matter (inferred to be terrigenous). Storm events increased TSS concentrations up to 30 times above background (non-storm) conditions.
e) The watershed rocks and sediments appear to be the source for some of the bioavailable metals found in the marine sediments. However, we did not find concentrations of heavy metals above EPA standards. Though it should be noted that we only measured the concentrations of bioavailable metals in a limited number of samples.
f) This study characterized the lithology, mineralogy and major element composition of the terrigenous rocks and sediments that comprise the terrigenous component of the marine sediments.

Research outcomes (Table 4):

a) One scientific manuscript has been submitted (Gray et al., 12th International Coral Reef Symposium Proceedings), and one is in preparation (Table 4).
b) Data from this study have contributed to seven presentations or posters at scientific meetings (Table 4).
c) Data from this study have contributed to three invited presentations by S. Gray (Table 4).
d) Three NOAA Coral Reef Conservation proposals for ongoing studies to build on this work have been submitted and two have been funded (Table 4).
e) Data from this study are contributing to four ongoing MS theses.
f) Data from this study have contributed to undergraduate senior thesis for five USD Marine Science students (Table 4).

OUTREACH

A. ARRA partnership. Funding from this NOAA GCRC grant has provided an opportunity for our research group to partner with other USVI groups to fund watershed erosion mitigation and continued sediment monitoring. Partnership with the Virgin Islands Resources Conservation & Development Council (V.I. RC&D), the Coral Bay Community Council, and researchers at the Center for Marine and Environmental Studies (CMES) at the University of the Virgin Islands (Tyler Smith and Marcia Taylor) and the University of Texas at Austin (Carlos Ramos Sharron), resulted in funding from the NOAA Coastal & Marine Habitat Restoration and the American Recovery and Reinvestment Act (ARRA). VI RC & D has supported our efforts to obtain funding to continue our sedimentation studies at sites outside those being funded for marine monitoring by ARRA through letters of support for our research proposals. Every two weeks, I participated in conference calls with the ARRA research partners during which we discuss the mitigation and monitoring (Table 5). Our data and reports are posted on the VIRCD website (http://www.usvircd.org/NOAA-ARRA_Grant.htm). Data from this NOAA GCRC study is providing critically important control and baseline data that will be used as a benchmark for pre- mitigation and treatment and control comparisons.

B. Coral Bay Community Council (CBCC), EPA CARE & Coral Bay community. We have worked closely with the Coral Bay Community Council (CBCC) to ensure that the data we collected for this project would be of maximum use to their community efforts for watershed management. The CBCC has strongly supported our efforts to obtain continued funding for ongoing research by providing letters of support. In August of 2009, we joined their EPA watershed management CARE grant team (http://www.coralbaycommunitycouncil.org/) and conducted meetings with their EPA/CARE storm-water engineer, Joe Mina to plan our sampling strategy so as to obtain data from locations that are of interest to the Coral Bay Watershed Management Plan. On November 16th of 2009, I presented at a workshop in St. Thomas entitled “EPA CARE Land & Sea Research Seminar and Leadership Conference”, which brought together researchers studying the impact of watershed erosion in the USVI with environmental managers and public officials (Table 5). We continue to work with members of the Coral

Bay Community who volunteer as field assistants and provide discounted use of their boats.

C. Other community and educational outreach activities. Funding from this grant has provided the opportunity for us to share information about our research findings about the impact of land-based sources of pollution to other researchers, university and K-12 students and faculty, and members of the community (Table 5). Our outreach has targeted the local (USVI) community as well San Diego, around the country and even Mexico. The fact that our field research is sited at VIERS (Virgin Islands Environmental Resource Station) provides an opportunity to speak to visiting K-12, university and community groups who visit VIERS from around the country/world. Table 5 summarizes several community and educational outreach activities and a media interview my research team has conducted. Two notable outreach activities we conducted in August of 2009 were the VIERS Eco Camp and the St. John Youth Rally (Fig. 18; Table 5).

D. Student research projects. Two USD and two CICESE Masters students are conducting MS thesis research that was supported by this grant (Table 4). In addition, 5 undergraduate USD Marine Science and Environmental Studies students conducted senior seminar studies that included data generated by this grant. Three of the students presented public presentations of their research as Marine Science Senior Seminar Presentations and posters at the Creative Collaborations Conference at USD that was held in April of 2010 (Table 5). Four undergraduate and graduate students presented talks and posters about their research at the 91st Annual Western Society of Naturalists meeting held from 11/11/10-11/14/10 in San Diego (Table 4). Examples and photos from this project are used as a case study to illustrate concepts in several of the classes I teach including: Geological Oceanography, Environmental Geology, and Introduction to Earth Science.

Table 1. *Sampling locations, sediment trap height and sampling interval for sediment traps.*

Bay	Station	Environment	Trap	Trap Height (cm)	Collection interval	Lat. 18' N. (min.)	Long. 64' W. (min.)
Coral	Calabash Shore	Shore	TC-1	30	26-day	19.811	42.277
			TC-1B	60	26-day	19.814	42.271
			TC-1S	30	storm	19.808	42.280
	Shipwreck Shore	Shore	TC-3	30	26-day	19.978	42.430
			TC-3S	30	storm	19.978	42.425
			TC-3B	60	26-day	19.980	42.431
	Plantation Hill Shore	Shore	TC-10	30	26-day	20.184	42.736
			TC-10B	60	26-day	20.187	42.733
	South Mangrove	Mangrove/bay	TC-8	60	26-day	20.720	42.931
			TC-8S	60	storm	20.721	42.931
	North Mangrove	Mangrove/bay	TC-5	60	26-day	20.795	42.849
			TC-5S	60	storm	20.793	42.849
	North Reef	Reef	TC-11	60	26-day	20.278	42.241
	South Reef	Reef	TC-12	60	26-day	20.018	42.072
Hurricane Hole	Hurricane Hole Shore	Mangrove	TH-1	30	26-day	20.988	41.471
			TH-1B	60	26-day		
G. Lameshur	G. Lameshur Mangrove	Mangrove	TL1-M	60	26-day		
			TL1-MS	60	storm		
	G. Lameshur Shore	Shore	TL1-2	30	26-day		
			TL1-2S	30	storm		
	G. Lameshur Bay	Bay	TL1-5	60	26-day	19.107	43.434
	Tectite Reef	Reef	TT-1	60	26-day	18.585	43.315
	Yawzi Reef	Reef	TY-1	60	26-day	18.910	43.512
			TY-2	60	26-day	18.901	43.540
L. Lameshur	Little Lameshur Shore	Shore	TL2-5	30	26-day	19.193	43.645
			TL2-5B	60	26-day	19.183	43.643

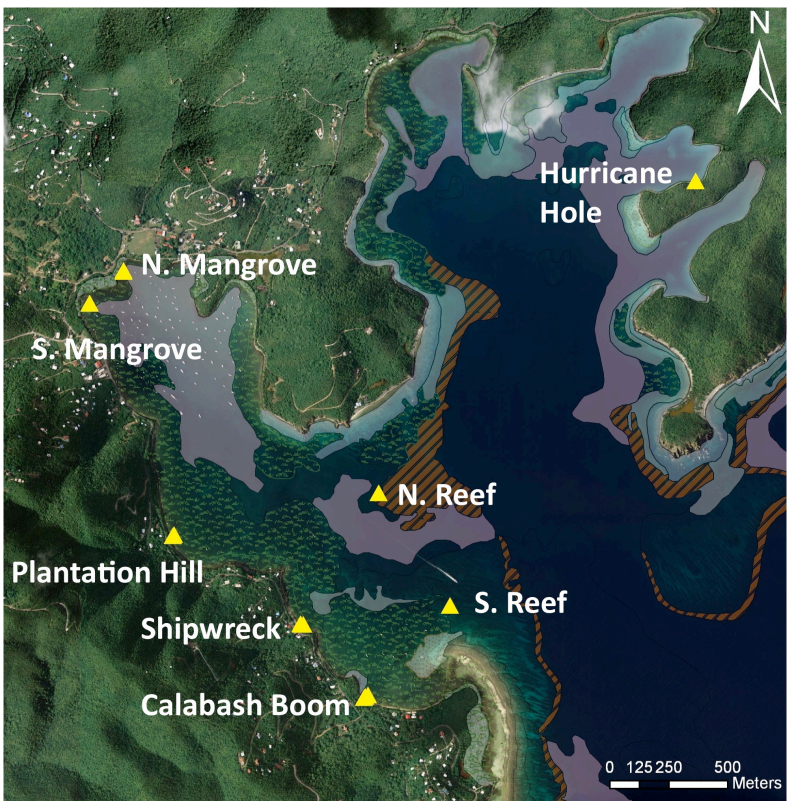


Figure 1. *Sampling locations in Coral Bay and Hurricane Hole.*

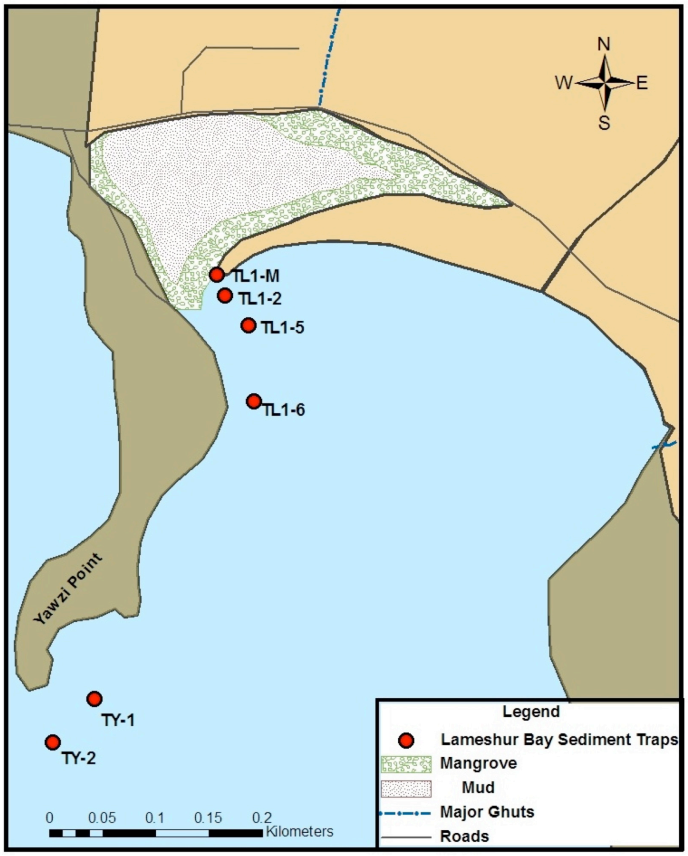


Figure 2. *Sampling locations in Great Lameshur Bay.*

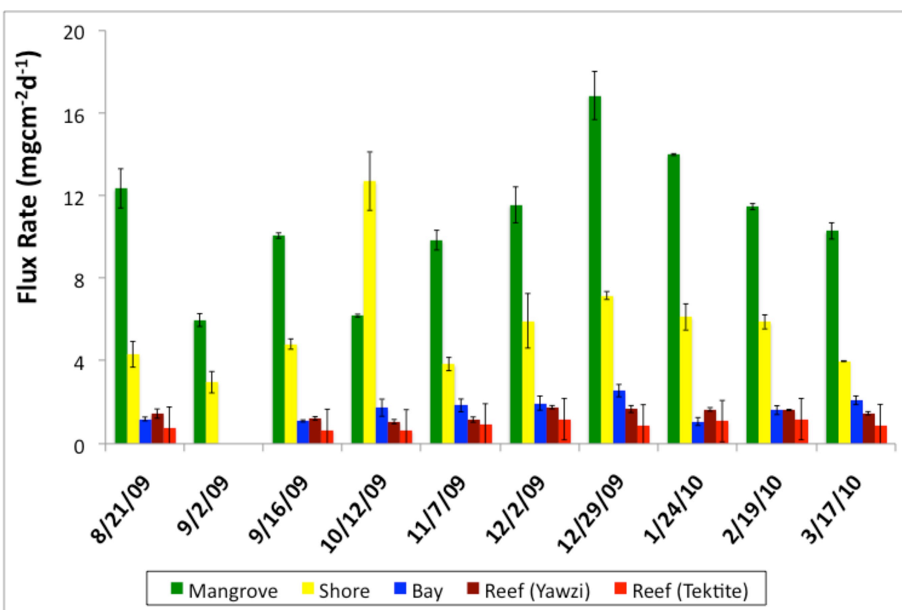


Figure 3A.*Variation in mean sediment accumulation (mg/cm2/day) over ten 23-26 day sampling periods 8/09-3/10 for Lameshur Bay.*

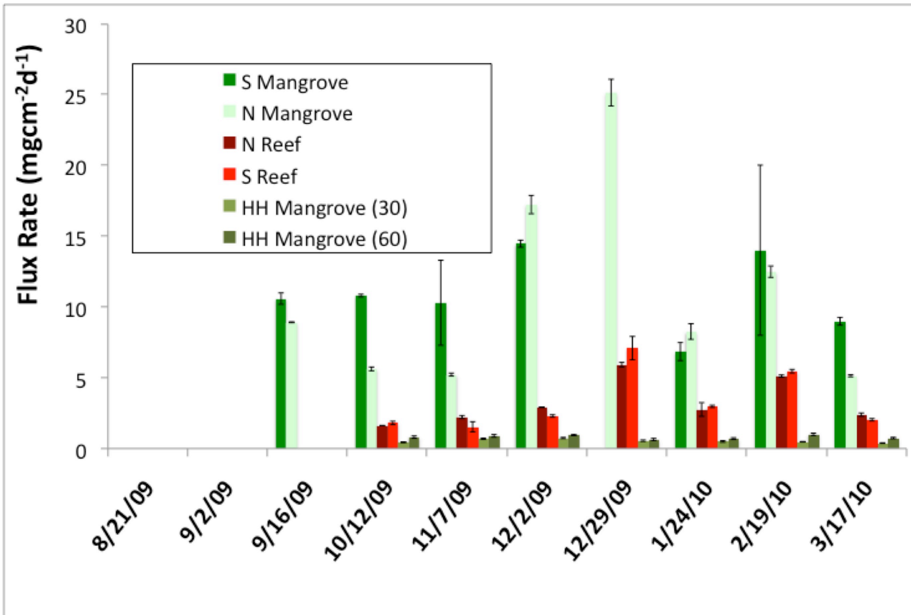


Figure 3B. *Variation in mean sediment accumulation (mg/cm2/day) over ten 23-26 day sampling periods from 8/09-3/10 for the Coral Bay and Hurricane Hole Mangrove and reef traps. The trap height (30 cm or 60 cm) for the HH traps is indicated*

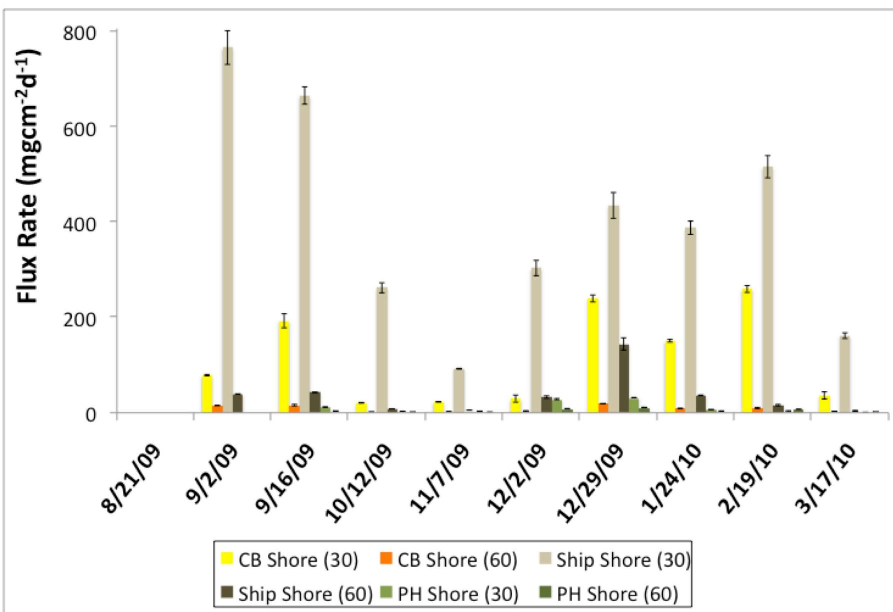


Figure 3C. *Variation in mean sediment accumulation (mg/cm2/day) over ten 23-26 day sampling periods from 8/09-3/10 for the Coral Bay shore traps. The trap height (30 cm or 60 cm) is indicated (abbreviations: CB: Calabash Boom, Ship: Shipwreck).*

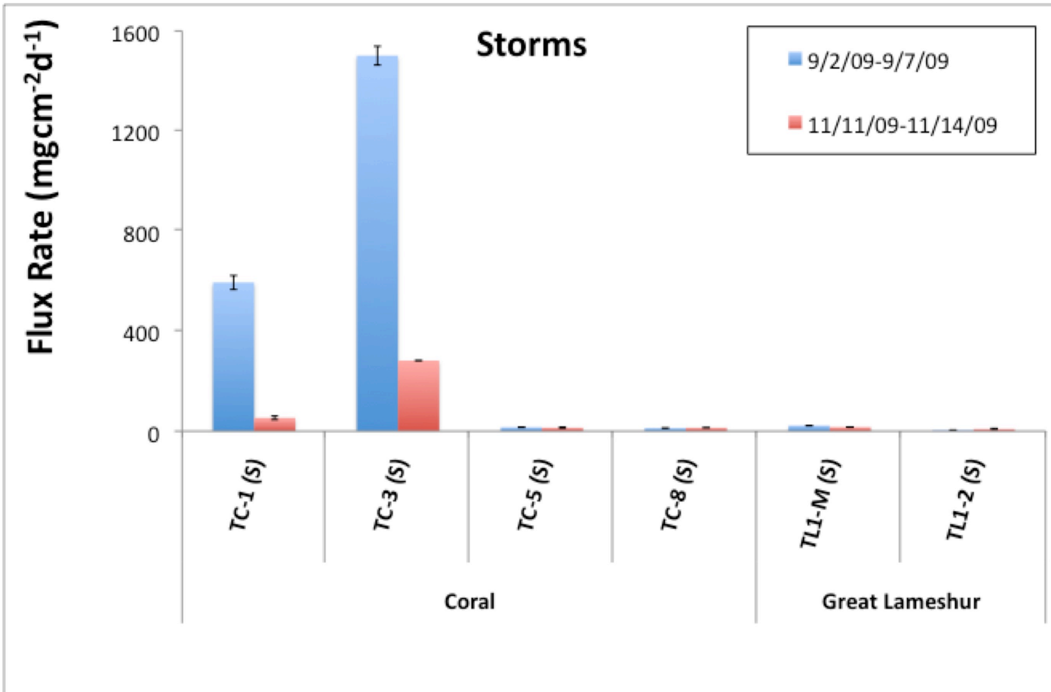


Figure 4. *Short-term sediment flux rates recorded during two short (less than 4 days) storm events during the fall of 2009.*

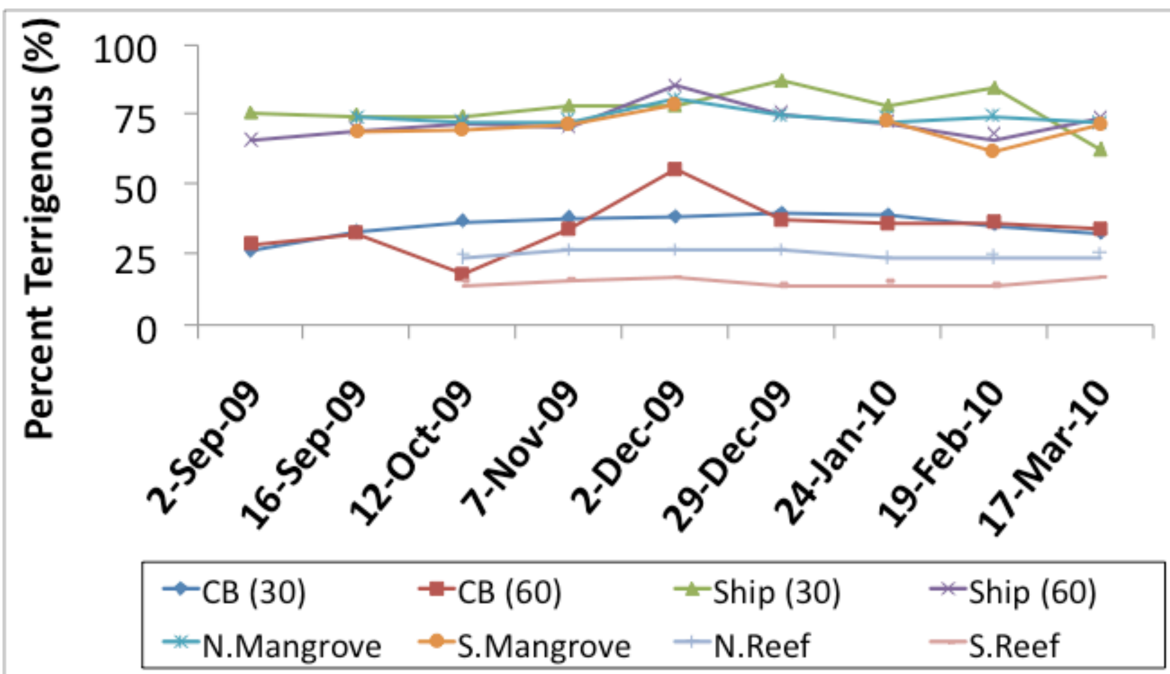


Figure 5. *Variation in the percentage terrigenous sediment for each of the 2009/10 sampling periods for Coral Bay.*

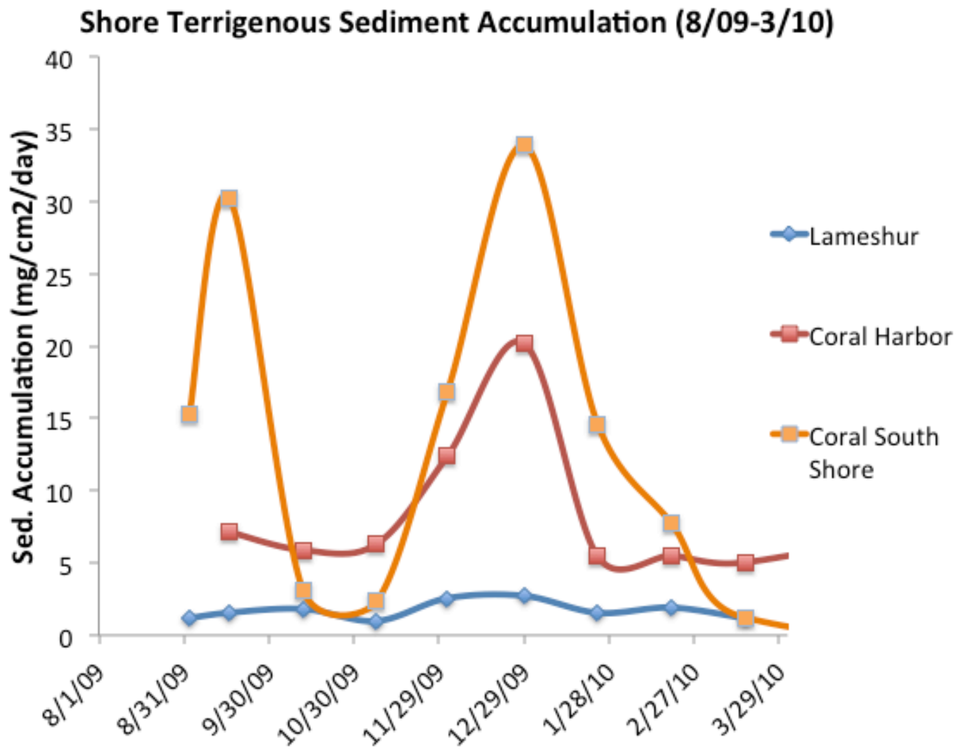


Figure 6A. *Mean shore terrigenous accumulation at Lameshur Bay, Coral Harbor (TC-5, TC-8) and along the South Shore of Coral Bay (TC-1B, TC-3B and TC-10B).*

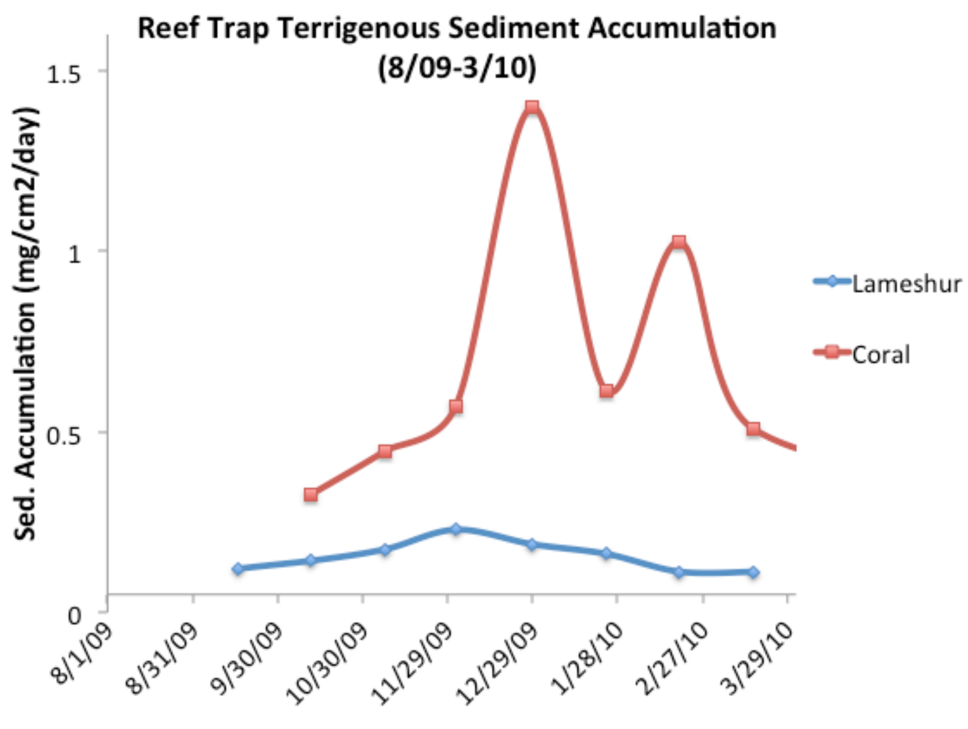


Figure 6B. *Mean reef terrigenous accumulation at the Lameshur Bay (TY-1, TY-2, TT-1) and Coral Bay reefs (TC-11, TC-12).*

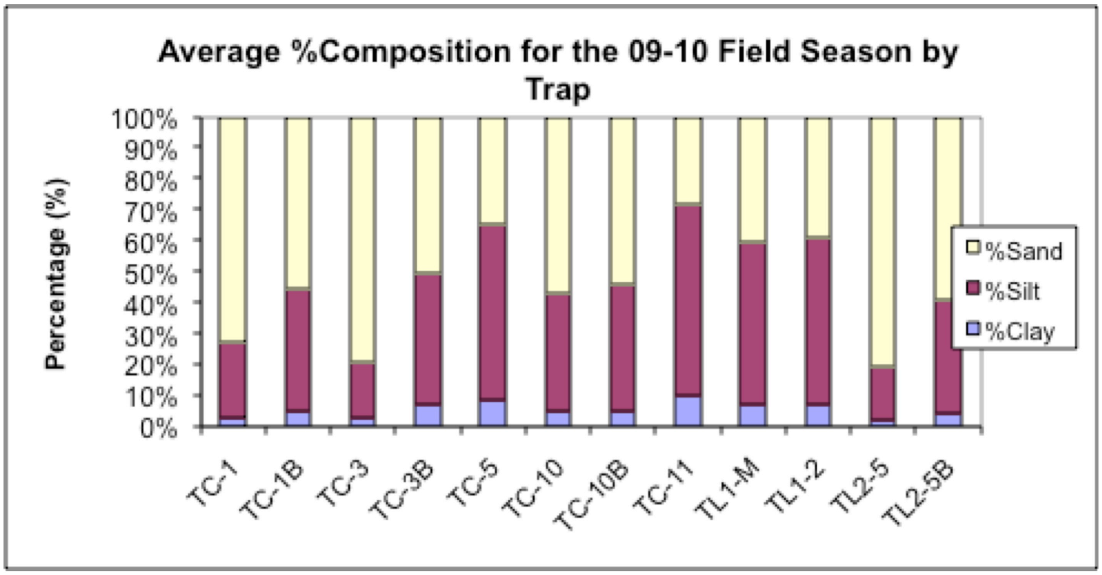


Figure 7A. *Mean relative percentage clay, silt and clay collected at each sediment trap site for the 2009-10 field season.*

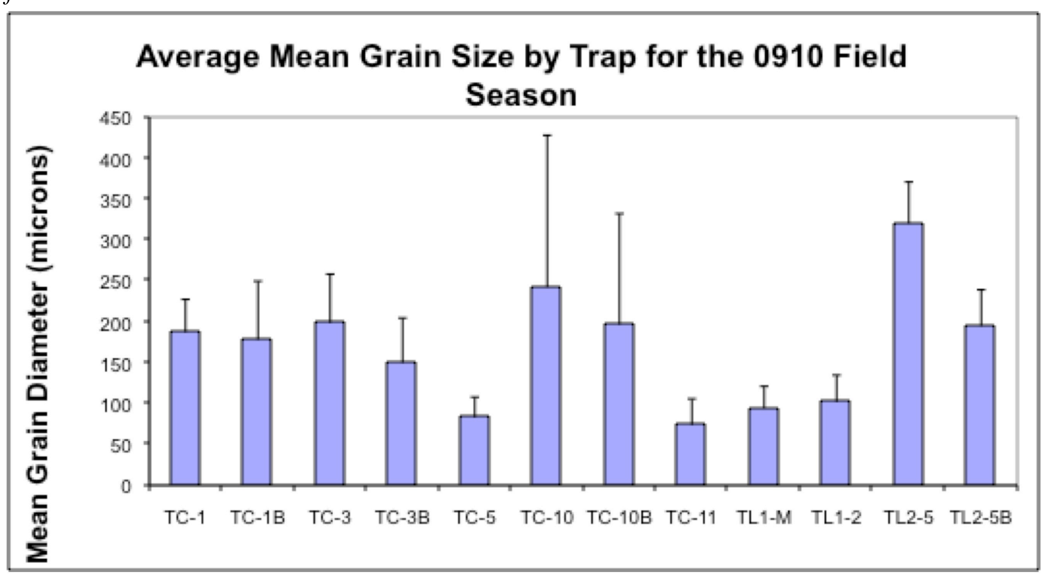


Figure 7B. *Mean grain size of sediment collected at each trap during the 2009-10 field season.*

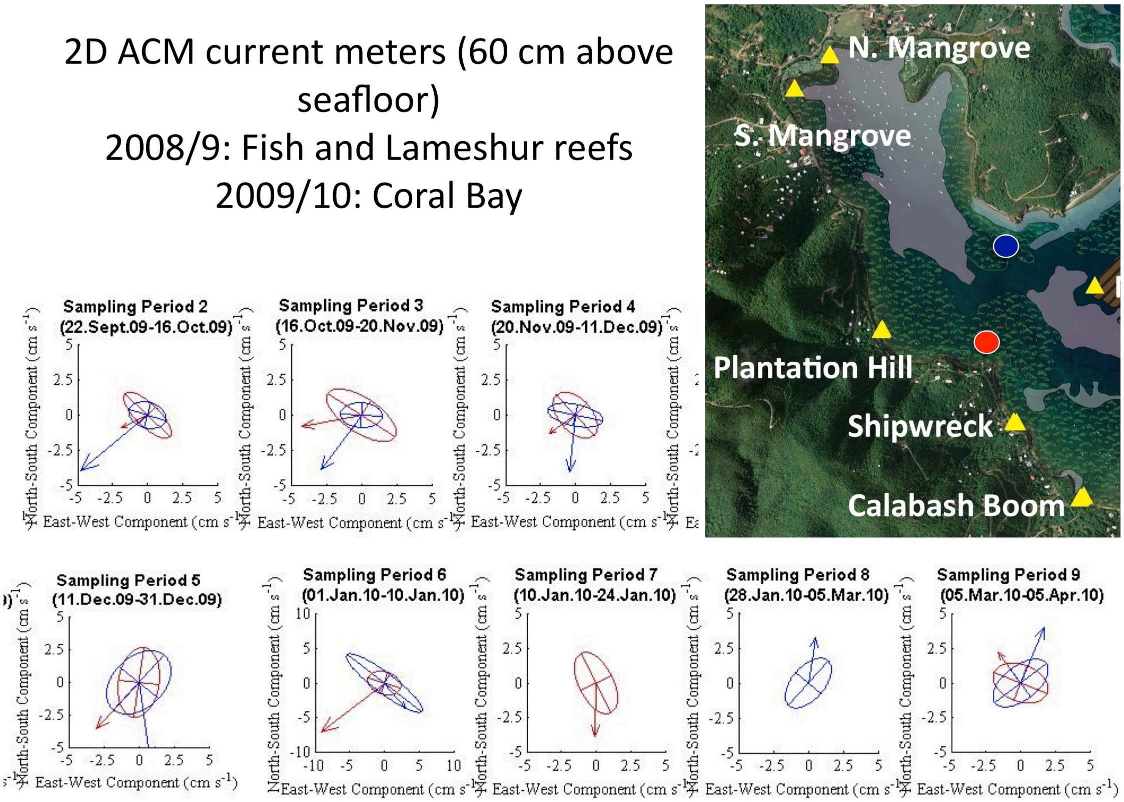


Figure 8. *Current meter data (mean speed and direction) for each sampling period for two 2D ACM meters deployed on the north (blue symbol) and south (red symbol) side of the mouth of coral bay harbor.*

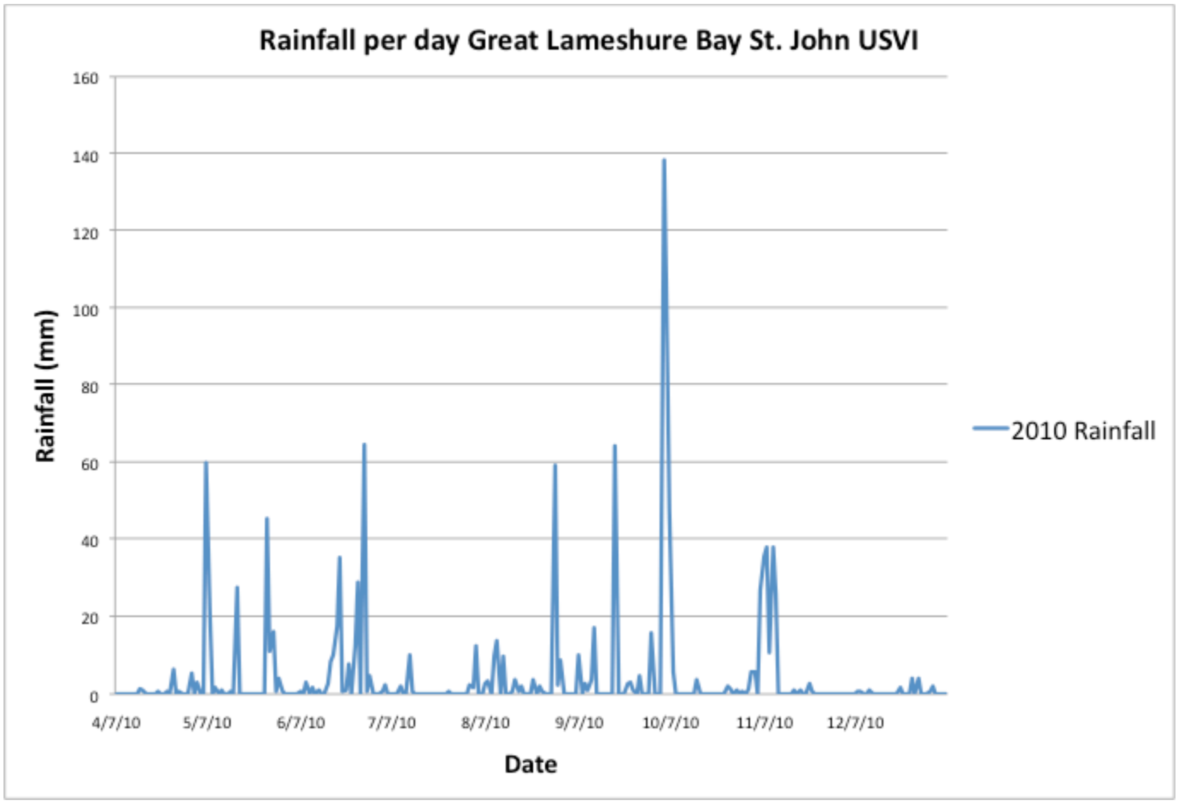


Figure 9A. *Rain data collected on the roof of the VIERS lab during the fall of 2010. Note that no data was collected between 7/15/10-7/26/10 so one of the major summer rainfall events (7/20/10-7/23/10) was not recorded by our rain gauge. The peak in rainfall from October 7th-9th, 2010 represents rainfall associated with Hurricane Otto.*

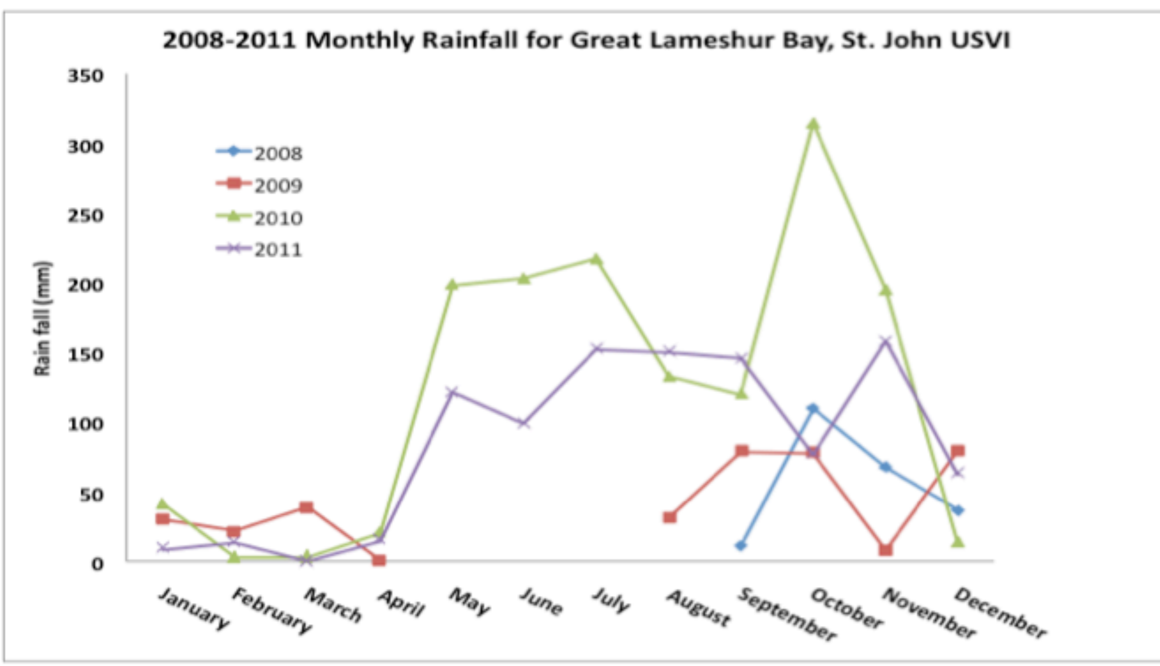


Figure 9B. *Cumulative monthly rainfall on the roof of the VIERS lab from 2008-11. Note that no data was collected between 7/15/10-7/26/10 so during that time period were substituded from a Coral Bay rain gage. These data illustrate that 2010 was the rainiest season during the 4 years of monitoring.*

Figure 10. Above: *After heavy July rainfall due to a low- pressure system: 7/20/10-7/23/10 and a new gut formed on the west side of Little Lameshur bay. High discharge during these storms waters in the gut made it difficult to collect water samples.* ***Below:*** *Algal growth along the shoreline of Little Lameshur Bay following input of nutrients from the new Little Lameshur Bay ghut associated with the heavy rains from 7/20/10-7/23/10.*

Figure 11. *Photos showing the effects of terrestrial runoff. Above left: Brown sediment plume in Coral Bay following 10/7/10 storm; Above right: landslide south of Coral Bay on 10/9/10. Below left: Sediment plum in Little Lameshur Bay following 7/21/10 storm; Below right: runoff in the gut above South Plantation Hill during the 10/7/10 storm.*

Figure 12. *Photos and water depth measurements were taken at regular intervals during and following major runoff events. These photos above were taken following Tropical Storm Otto between 10/5/10-10/14/10 showing the maximum and decreasing flow along the dirt road in the Lameshur Bay watershed from VIERS camp to VIERS lab.*

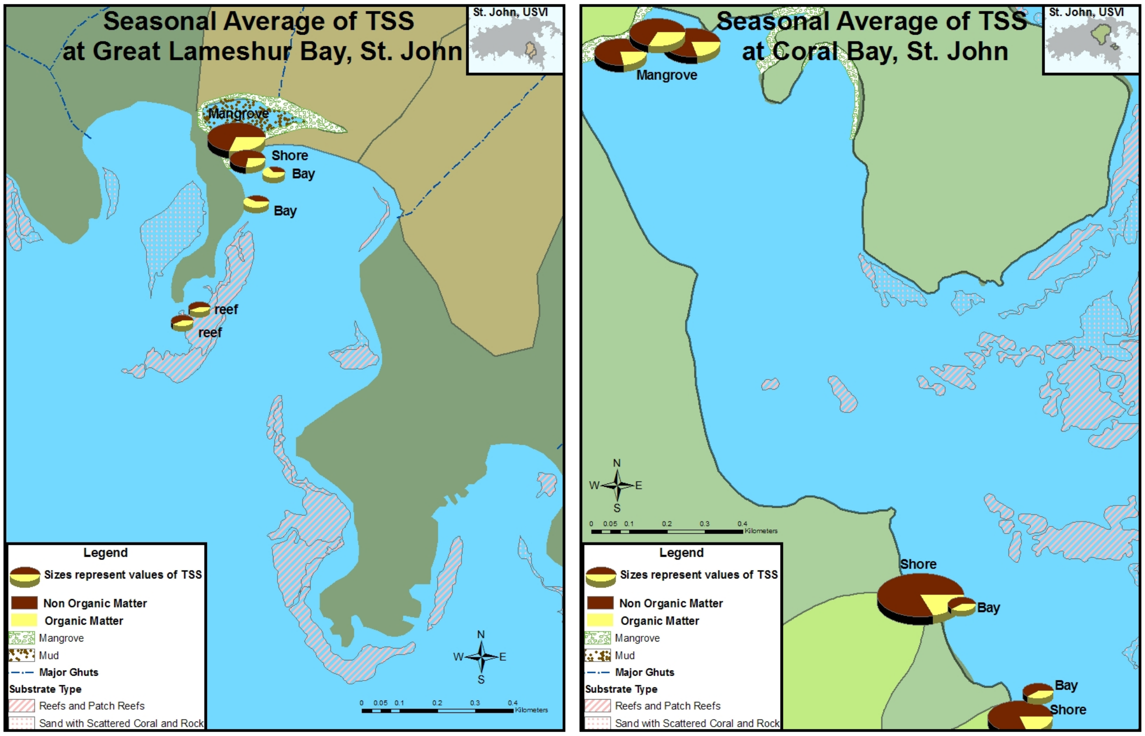
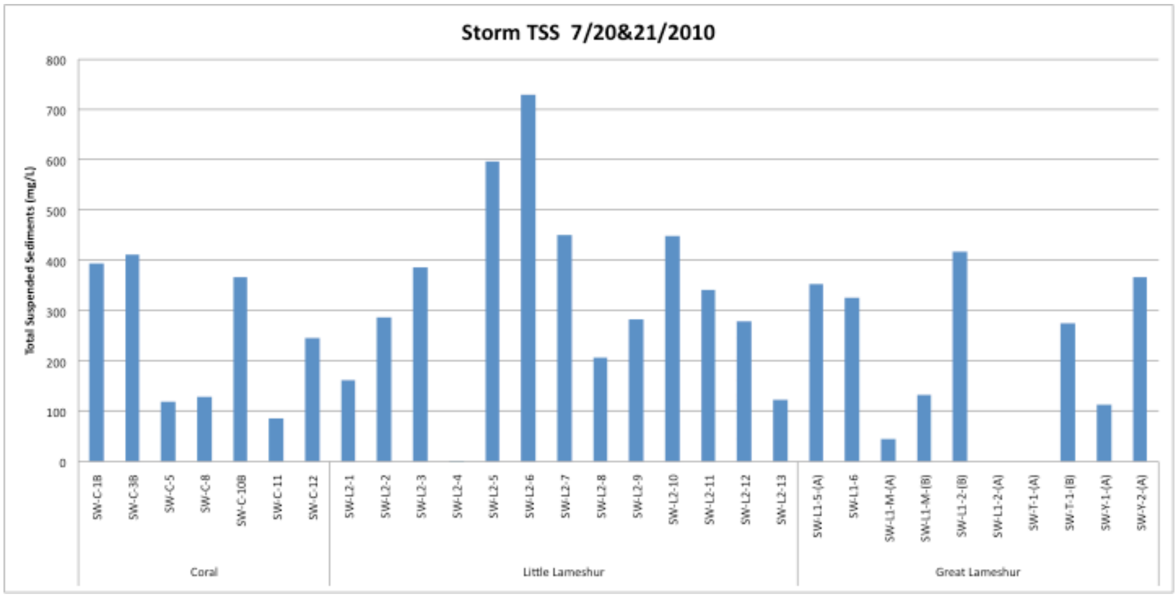


***Figure 13**. Map of Great Lameshur Bay (LEFT) and Coral Bay (RIGHT) St. John, USVI showing locations of regular sampling (26 days) for TSS and total organic matter (TOM). The pie diagrams at each illustrate the proportion of the total suspended sediment that is organic (yellow) and non organic (rust). The size of the pie represents the seasonal mean value of TSS during generally fair-weather (non-storm) conditions. The highest TSS is found at the Shipwreck shore site.*



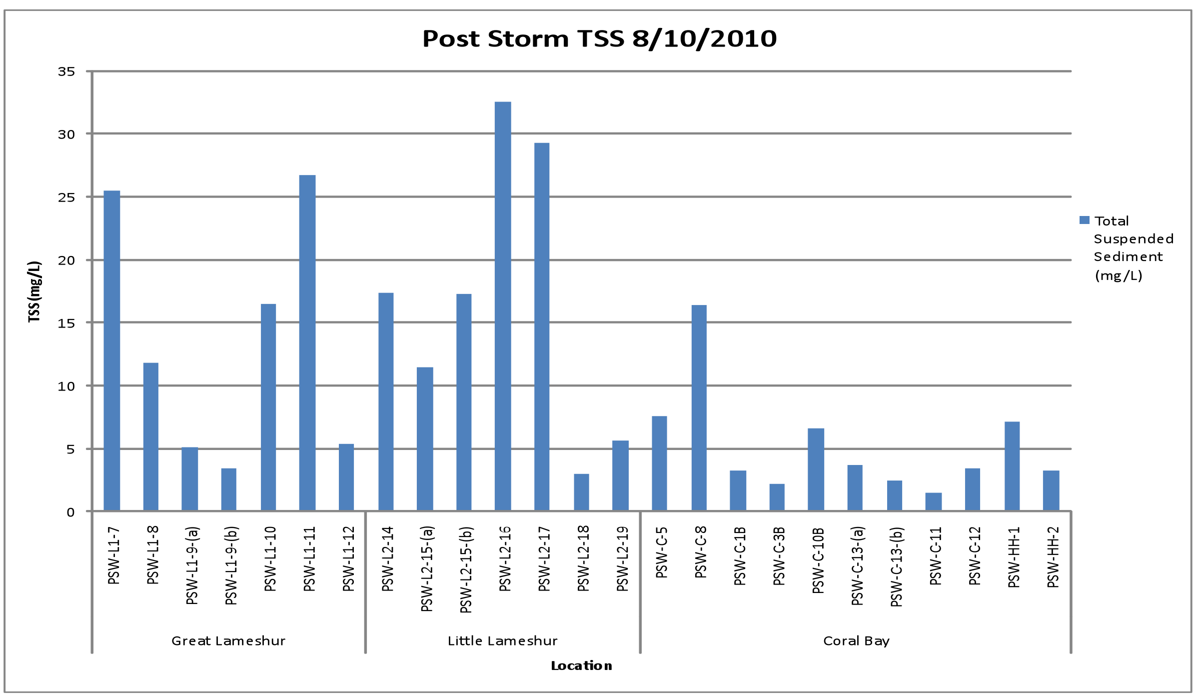


Figure 14. *Comparison of total suspended sediments (TSS) in mg/L for water samples collected at the sites shown in Figure 6 following the 7/20-7/21 storm event (ABOVE) compared to fair weather (background) conditions on 8/10/2010 (BELOW). Note that TSS following the 7/20-7/21storm event was up to 32 times higher than background (non-storm) conditions.*

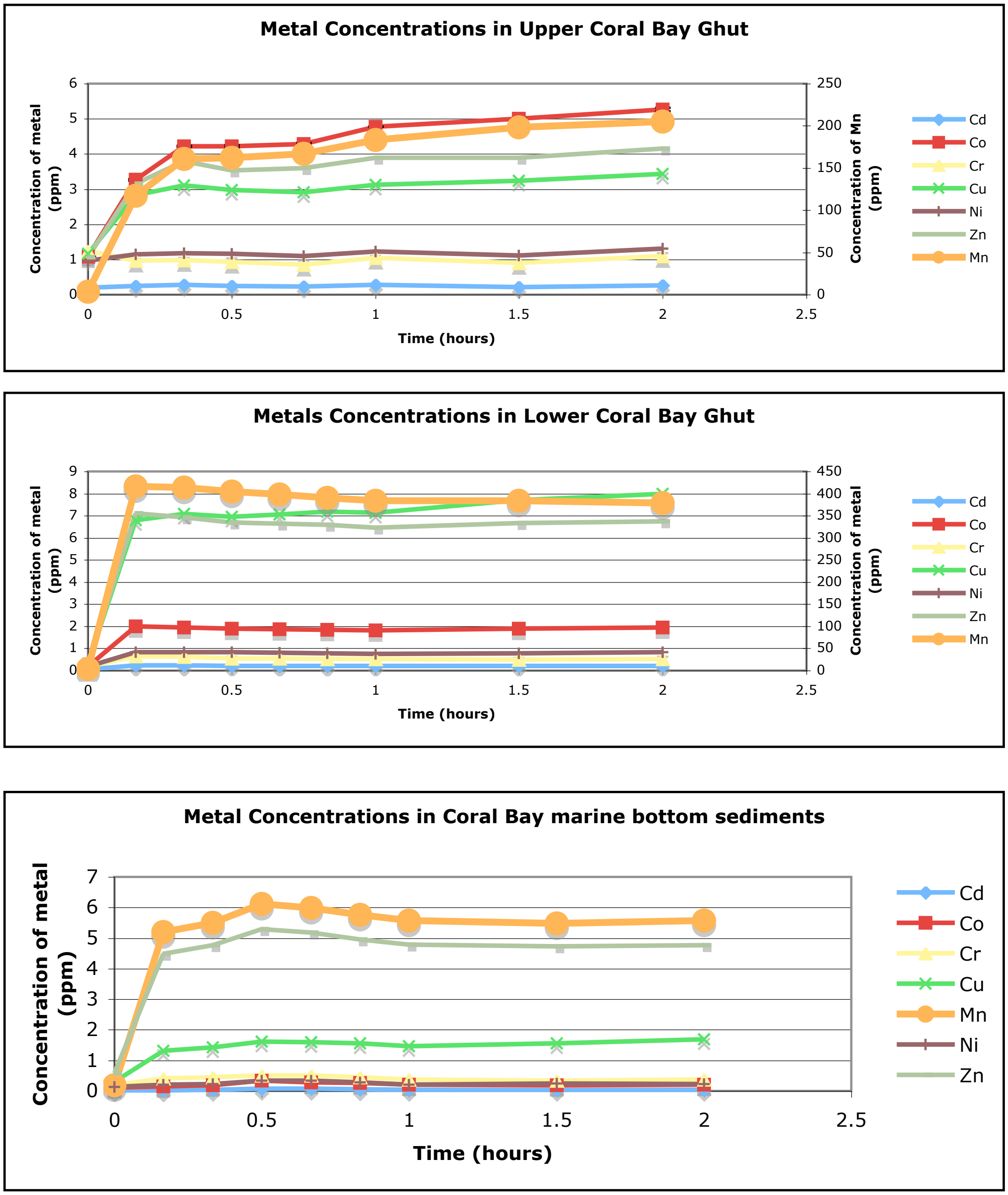


Figure 15A. *Metal concentrations in Coral Bay in the upper watershed (above), the lower watershed, and in the marine environment (below). Mn is plotted on the secondary y-axis with it's own scale. The x-axes gives the time since exposure to EDTA.*

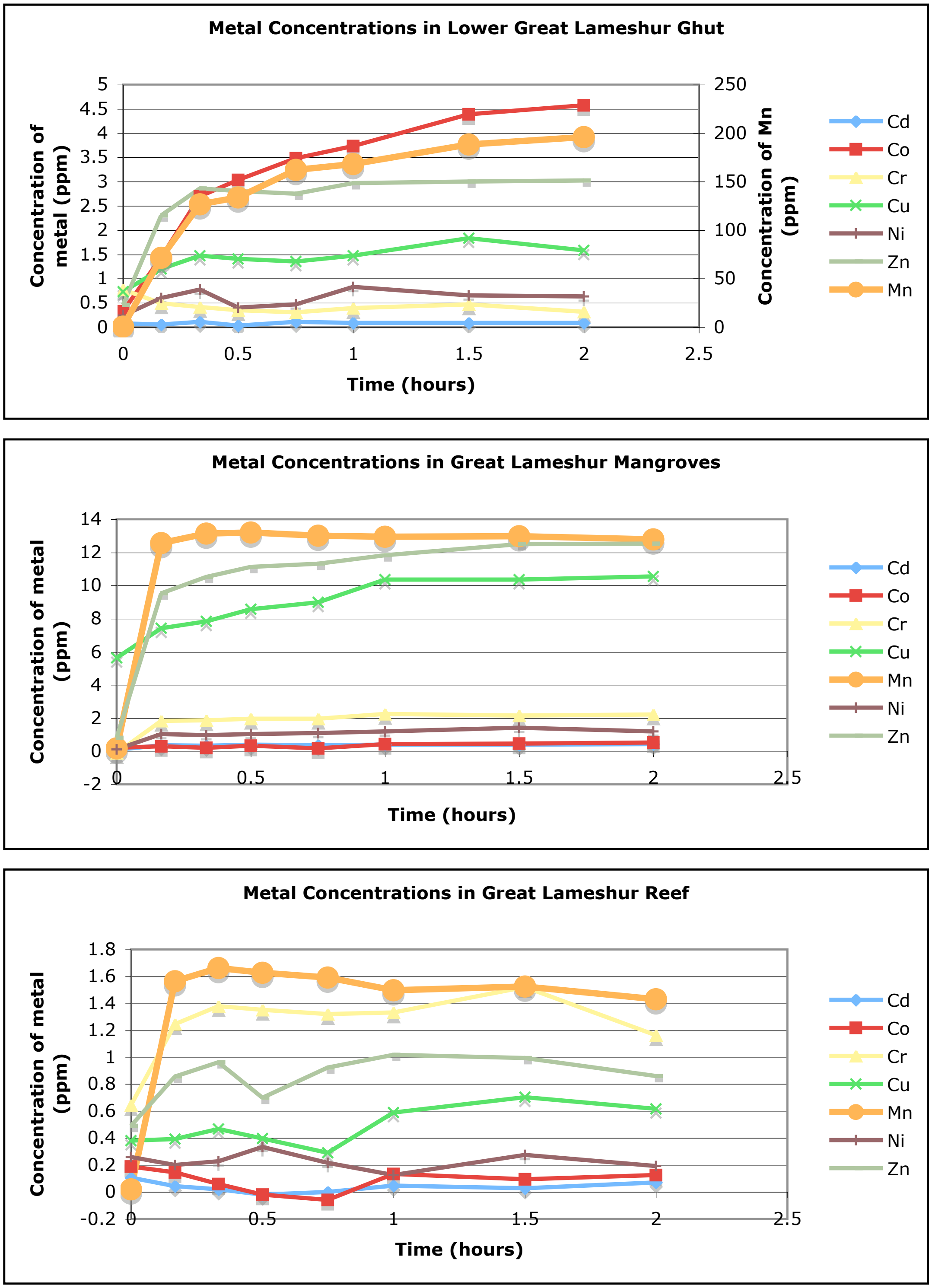


Figure 15B. *Metal concentrations in Great Lameshur Bay watershed in the upper watershed (above), the lower watershed, and in the marine environment (below). Mn is plotted on the secondary y-axis with it's own scale. The x-axes gives the time since exposure to EDTA.*

Sample name	Total	LOI	*LOI*	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	MnO	TiO2	P2O5
	w/ meas LOI	Measured	*diff from 100%*										
		(%)	*(%)*	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
WG-L2-30B	99.05	36.57	*37.51*	16.2	2.13	0.66	40.39	1.4	0.23	1.35	0.01	0.07	0.04
WWS-CB-37	100.79	6.76	*5.98*	62.25	14.17	7.46	2.34	3.44	1.1	2.28	0.13	0.76	0.11
WS-L2-26B	101.00	12.17	*11.16*	63.57	12.48	4.44	2.06	1.67	1.21	2.73	0.09	0.48	0.1
WS-L2-29B	98.98	33.34	*34.37*	22.35	3.07	0.8	36.53	1.23	0.28	1.23	0.01	0.09	0.04
WG-CB-32B	101.04	3.91	*2.87*	68.22	13.42	5.52	2.51	3.02	0.9	2.87	0.11	0.49	0.08
WG-CB-38	99.93	3.19	*3.28*	66.69	13.22	6.18	3.26	3	0.92	2.75	0.12	0.51	0.09
WR-CB-66B	99.27	2.60	*3.32*	50.5	16.45	9.69	7.31	7.24	0.13	4.63	0.14	0.53	0.05
WWS-CB-31B	99.95	6.41	*6.47*	64.56	12.64	5.4	3.83	2.78	1.13	2.47	0.1	0.5	0.12
WG-L2-27B	100.01	2.99	*2.98*	72.79	11.71	4.36	1.54	1.77	1.03	3.3	0.12	0.35	0.04
WR-L2-21	101.09	0.99	*-0.1*	78.5	10.59	3.22	0.32	1.23	2.88	3.1	0.08	0.15	0.03

Table 2. *Major element abundances for sediment and rock samples from Coral and Lameshur Bay.*

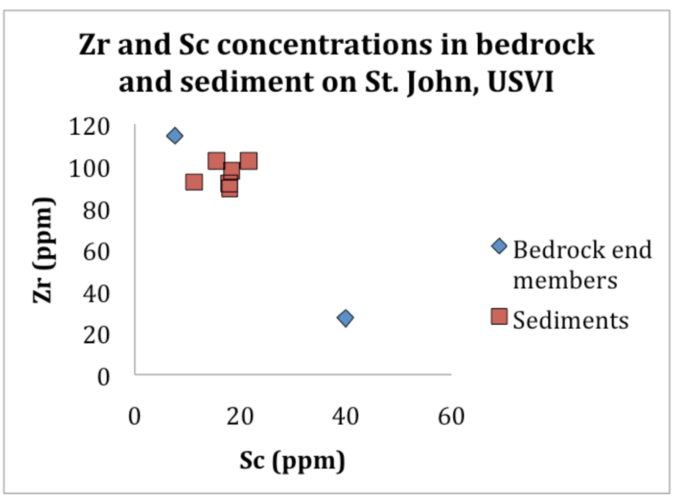


Figure 16. *Chemical mixing diagram for sediment samples from St. John, U.S. Virgin Islands. Sediments samples (red squares) plot between the concentrations of two distinct bedrock units (blue diamonds).*

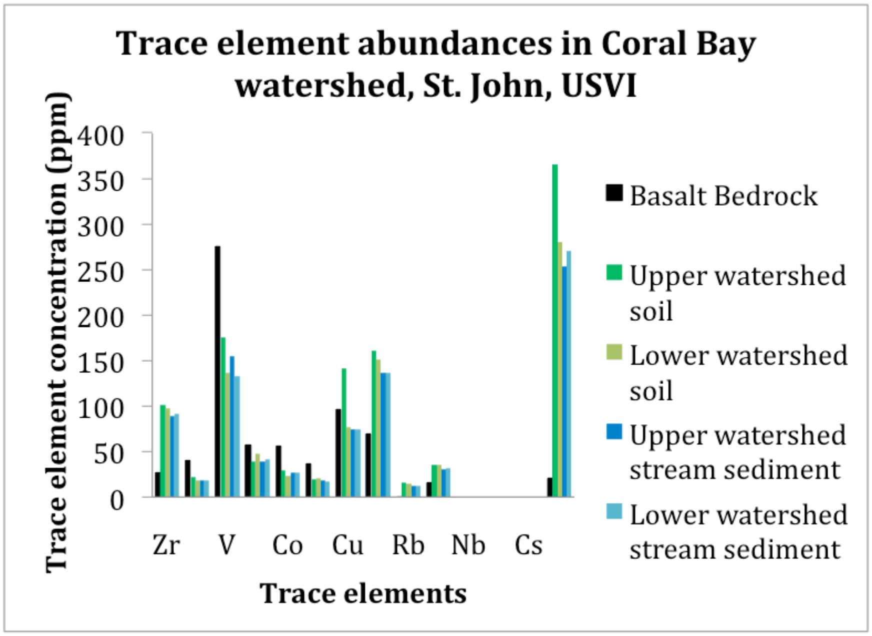


Figure 17A. *Trace element abundances of bedrock and sediment samples from Coral Bay watershed, St. John, U.S. Virgin Islands.*

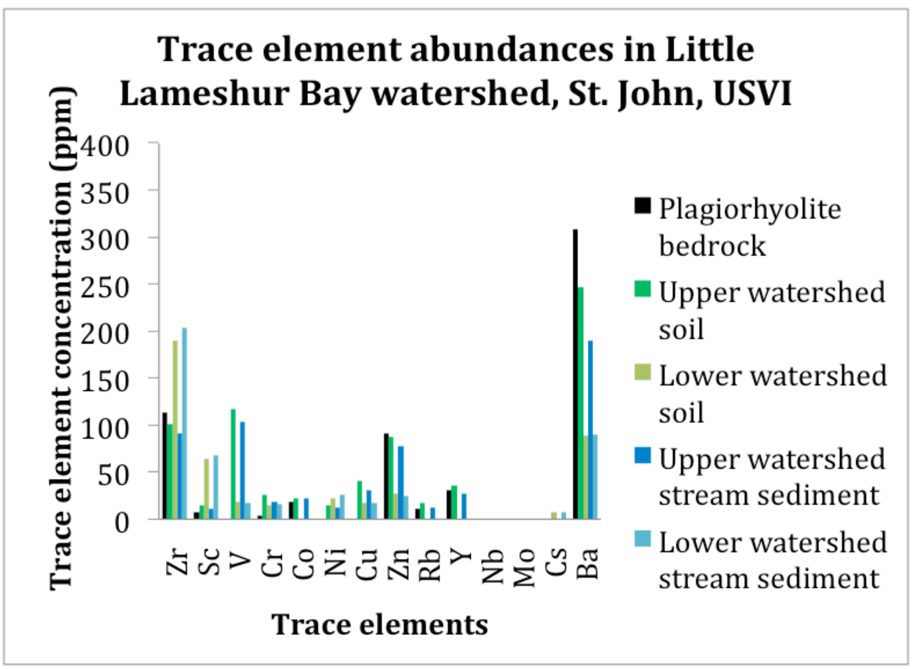


Figure 17B. *Trace element abundances of bedrock and sediment samples from Little Lameshur Bay watershed, St. John, U.S. Virgin Islands.*

***Table 3.** Major element concentrations in storm water samples collected in Little Lameshur Bay (above) and Coral Bay (below) during several Fall, 2010 storms.*

	ID	Date	Ca	Mg	Na	K	Si
L	SW-EN-1A	20-VII-10	5.38	3.10	10.12	3.45	7.12
A	SW-EN-2A	20-VII-10	6.07	2.57	0.33	3.56	6.73
M	SW-EN-3A	20-VII-10	5.87	2.52	0.40	3.35	7.01
E	SW-EN-4A	20-VII-10	3.15	1.23	15.44	4.16	6.82
S	SW-EN-9A(A)	20-VII-10	7.05	2.91	11.92	4.59	5.77
H	SW-EN-5A	20-VII-10	2.77	1.80	10.02	2.15	7.59
U	SW-EN-6A	20-VII-10	3.07	1.16	13.76	3.14	6.65
R	SW-EN-7A	20-VII-10	5.84	2.02	6.17	3.00	6.80
	SW-EN-8A	20-VII-10	5.52	2.12	5.98	3.73	7.21
B	SW-EN-2A	21-VII-10	2.38	0.11	5.88	1.39	7.85
A	SW-EN-3A	21-VII-10	2.21	0.13	5.61	0.76	10.84
Y	SW-EN-4A	21-VII-10	2.89	1.29	7.85	2.88	10.70
	SW-EN-5A	21-VII-10	7.65	2.41	3.76	2.40	12.82
	WW-L2-22A	26-VII-10	5.93	2.72	0.35	7.71	10.51
	WW-L2-25(A)A	26-VII-10	6.36	4.82	12.82	5.05	14.09
	MEAN		4.81	2.03	7.13	3.42	8.57
	MAX		7.65	4.82	15.44	7.71	14.09

	ID	Date	Ca	Mg	Na	K	Si
C	SW-CB-1 (B)	IX-12-2010	13.21	11.74	56.80	14.35	1.56
O	SW-CB-5	IX-12-2010	14.31	13.95	67.89	9.00	5.97
R	No ID	No ID	2.85	3.44	24.21	3.50	8.24
A	SW-CB-1	X-5-2010	7.48	4.68	18.66	5.17	6.15
L	SW-CB-3	X-5-2010	3.17	4.58	27.76	2.98	8.38
	SW-CB-7	IX-19-2010	11.14	6.22	20.32	5.85	5.57
B	SW-CB-3	IX-19-2010	3.29	5.58	34.18	4.62	9.58
A	SW-CB-3(B)	X-5-2010	3.77	4.79	35.87	3.56	10.32
Y	SW-CB-5	X-6-2010	8.30	4.55	15.45	4.58	6.42
	SW-CB-3	X-5-2010	3.41	3.56	25.79	2.64	8.94
	SW-CB-2	X-7-2010	5.20	4.43	21.02	3.78	7.13
	SW-CB-3	IX-12-2010	3.23	3.15	23.14	2.67	8.52
	SW-CB-5	IX-12-2010	14.49	14.31	66.84	8.73	5.63
	SW-CB-1	X-5-2010	13.68	12.26	60.24	13.81	1.14
	SW-CB-3(B)	IX-19-2010	4.07	4.27	29.25	4.75	8.80
	SW-CB-7	IX-19-2010	10.16	5.81	31.49	7.09	3.18
	Mean		7.61	6.71	34.93	6.07	6.60
	MAX		14.49	14.31	67.89	14.35	10.32

Table 4. Research outcomes.

Scientific Journal Articles (resulting partially from this work):

1. Gray, S.C., Sears, W.T., Kolupski, M.L., DeGrood, A.M., and Fox, M.D. (2012, in review). Factors affecting land-based sedimentation in coastal bays, US Virgin Islands. *12th International Coral Reef Symposium, Proceedings, Cairns, Australia*.

Scientific Abstracts & Presentations (resulting from this work):

1. Gray, S.C., Sears, W.T., Kolupski, M.L., DeGrood, A.M., and Fox, M.D. (2012). Factors affecting land-based sedimentation in coastal bays, US Virgin Islands. *12th International Coral Reef Symposium, July 9th-13th, 2012, Cairns, Australia*.
2. Kolupski, M.L., Fox, M.D. Gray, S.C. DeGrood, A.M. (2010). The land-sea connection: composition & accumulation rates of terrigenous sedimentation on coral reefs in coastal bays on St. John, U.S. Virgin Islands. AGU/ASLO Ocean Sciences Meeting, 2/22-2/26, Portland, Oregon.
3. Kolupski, M.L., Fox, M.D. Gray, S.C. DeGrood, A.M. (2010). The land-sea connection: accumulation rates, composition, and resuspension of sediment. California Estuarine Research Society (CAERS) 2010 Joint Annual Meeting, San Diego, CA, 3/8/10-3/9/10.
4. DeGrood, A.M.*, Kolupski, M.L.*, Fox, M.D.**, and Gray, S.C. (2010). Temporal and spatial variation in sediment texture on coral reefs, US Virgin Islands. *91st Annual Western Society of Naturalists Meeting, San Diego, CA 11/11-11/14/10*.
5. Kolupski, M.L.*, Fox, M.D.**, and Gray, S.C. (2010). Connecting the land to the sea: sedimentation and resuspension on coral reefs, St. John, US Virgin Islands. *91st Annual Western Society of Naturalists Meeting, San Diego, CA 11/11-11/14/10*.
6. Quilley, R.G.*, Przyuski, N.W.**, and Gray, S.C. (2010). A comparison of sedimentation and turbidity in mnagrove environments among areas of variable human impact, St. John, US Virgin Islands. *91st Annual Western Society of Naturalists Meeting, San Diego, CA 11/11-11/14/10*.
7. Rawling, D.W.*, Fox, M.D.**, and Gray, S.C. (2010). Can sediment texture be used as a proxy to measure terrigenous (land-derived) sediment flux on coral reefs? *91st Annual Western Society of Naturalists Meeting, San Diego, CA 11/11-11/14/10*.

Invited Presentations:

1. Smith, T., and Gray, S. C. "Water quality and sedimentation research in the US Virgin Islands" US Coral Reef Task Force Meeting, Silver Spring, MD (2/24/12),
2. Gray, S.C. "Potential impacts of watershed development & mitigation on marine sedimentation in St. John, US Virgin Islands" US Geological Survey Pacific Science Center Brown Bag Seminar, Santa Cruz, CA (6/22/10).
3. Gray, S.C. "Potential impacts of watershed development & mitigation on marine sedimentation in St. John, US Virgin Islands" Vermillion Sea Field Station, Bahia Los Angeles, Mexico (6/28/10).

Proposals Submitted:

1. NOAA Coral Reef Conservation Program Domestic Coral Reef Conservation Grants (Recommended for funding): "Post-mitigation monitoring to determine the impact of watershed erosion control on LBSP to coral reefs, USVI" $75,000 with $75,000 in cost share (2012-2013).
2. NOAA Coral Reef Conservation Program Domestic Coral Reef Conservation Grants: "Effects of Watershed Erosion Control on Land Based Sources of Pollution to Coral Reefs in RCP Priority Sites" $94,844 with $94,933 in cost share (2011-2012).
3. NOAA General Coral Reef Conservation: "A comparative analysis of sedimentation and water quality in mangrove, shore, and reef environments below a developed vs. an

undeveloped watershed in the US Virgin Islands" $49,999 with $50,353 in cost share (2010-2011).

MS theses (in progress)

Sears, W.; Guidino Elizondo, N. (Centro de Investigacion Cientifica de Educacion Superior de Ensenada, Baja California: CICESE); Araiza Delgado, E. (CICESE).

Undergraduate senior theses (completed)

DeCarlo, T., Hseih, Y., Chapman, C., Quilley, R.*, De Grood, A.

Figure 18. *Photographs of community outreach activities. Our team conducted a workshop for youth at the Virgin Islands Environmental Resource Station (VIERS) "Ecocamp" (8/6/09-8/8/09) in St. John, USVI and manned a booth promoting awareness of land-based pollution at a community youth ralley in Cruz Bay, USVI (8/14/09).*

Table 5. *Log of outreach activities.*

Date	**Location**	**Presenter**	**Type of Event**	**Audience** **Type & (Number)**
Bimonthly	Conference Call	ARRA partners	Conference Calls	ARRA Partners
8/6/09	VIERS, St. John, USVI "Ecocamp"	Gray	Formal presentation	Middle/HS students (USVI)
8/7/09-8/8/09	VIERS, St. John, USVI "Ecocamp"	Gray & Team	Lab demo/activity	Middle/HS students (USVI)
8/7/09	VIERS, St. John, USVI "Ecocamp"	Gray	Media interview	St. John Source newspaper
8/14/09	Cruz Bay, USVI, "Youth Ralley"	Gray & Team	Informational booth	80 USVI youth & community members
10/15/09	Hubbs SeaWorld Research Institute	Gray	Formal presentation	Researchers, students, community (50)
11/16/09	Univ. Virgin Islands, St. Thomas, USVI "Land & Sea" Research Seminar	Gray	Formal presentation at environmental workshop	Environmental managers, researchers, community members (35)
12/4/09	USD, San Diego	Gray	formal presentation	Faculty (50)
2/22/10	Portland, OR	Kolupski	Poster presentation at scientific meeting (AGU/ASLO Ocean Sciences)	Scientists (100's)
3/8/10	San Diego, CA	Kolupski	Invited formal presentation at scientific meeting (CARES: Cal. Estuarine Res. Soc.)	Scientists (40)
3/27/10	Univ. of San Diego	DeGrood (undergraduate)	Senior Seminar Presentation	Faculty & students (40)
4/10/10	Univ. of San Diego	Quilley (undergraduate)	Senior Seminar Presentation	Faculty & students (40)
4/23/10	Univ. of San Diego	Quilley (undergraduate)	Poster Presentation @ USD Conference	Faculty & students (200)
4/23/10	Univ. of San Diego	Hseih	Poster	Faculty & students

		(undergraduate)	Presentation @ USD Conference	(200)
4/23/10	Univ. of San Diego	DeGrood (undergraduate)	Poster Presentation @ USD Conference	Faculty & students (200)
6/22/10	Santa Cruz, CA, US Geological Survey	Gray	Invited formal presentation: USGS	Scientists (40)
6/28/10	Bahia de los Angeles, Mexico	Gray	Invited formal presentation: marine field station	Scientists and high school students (30)