Project Period	08/16/2010 - 01/31/2012
Award Amount	$16,432.00
Matching Contributions	$21,741.00
Project Location Description (from Proposal)	This project will take place in Guanica Bay and the adjacent waters which are directly impacted by pollution from the Guanica watershed.
Project Summary (from Proposal)	Conduct the first Lagrangian velocity measurements and numerical simulations of the hydrodynamics of Guánica Bay to support efforts aimed at improving water quality. Project will take place in Guánica Bay and the adjacent waters directly impacted by pollution from the Guánica watershed.
Summary of Accomplishments	The main objective of this project was to understand the physical processes leading to pollutant transport and mixing in Guánica Bay, and this was achieved by conducting the first ever dedicated field observations and hydrodynamic numerical modeling of circulation in Guánica Bay. We built 8 inexpensive GPS-tracked Lagrangian drifters using commercially available hardware and electronics, and several drifter deployments were carried out in and near the Bay under varying physical forcing scenarios. In addition, a 30 day deployment of an acoustic wave and current profiler (AWAC) at the Bay entrance provided long-term observations of the vertical structure of ocean currents in Guánica Bay. These observations as well as the hydrodynamic modeling using the CMS-Flow circulation model have elucidated the dominant mechanisms in the Bay which are responsible for the transport and mixing of the sediment-laden Rio Loco river plume. Finally, several outreach activities including a teacher workshop and five seminars to public schools in Guánica served to communicate the water quality problem of Guánica Bay to its residents and primary users.
Lessons Learned	The following are lessons learned from the present project: 1. We must do a better job of communicating with resource managers in explaining to them the importance of research to determine better conservation practices 2. A significant outreach effort was conducted, however, much more needs to be done to reach a wider audience so that Guanica residents and residents along the watershed are better educated about ways to improve water quality in Guanica 3. Much more research is necessary to fully understand how changes in the water quality of the Rio Loco outflow can impact or improve the health of coral reef ecosystems. It is not a linear relationship between reducing incoming sediments and improving water clarity and quality.

Conservation Activities	Students impacted by outreach activities
Progress Measures	Other (Number of students)
Value at Grant Completion	100
Conservation Activities	Hydrodynamics study of Guanica Bay
Progress Measures	Other (% of Bay studied)
Value at Grant Completion	100

Conservation Outcome(s)	Increased stewardship of natural resources
Conservation Indicator Metric(s)	Other (# of students impacted by outreach)

Baseline Metric Value	0
Metric Value at Grant Completion	100
Long-term Goal Metric Value	1000
Year in which Long Term Metric Value is Anticipated	2015
Conservation Outcome(s)	Government officials briefed about mixing characteristics of Bay
Conservation Indicator Metric(s)	Other (# of officials)
Baseline Metric Value	0
Metric Value at Grant Completion	10
Long-term Goal Metric Value	10
Year in which Long Term Metric Value is Anticipated	2011
Conservation Outcome(s)	Improved understanding of circulation in Guanica Bay
Conservation Indicator Metric(s)	Other (# of field measurements)
Baseline Metric Value	0
Metric Value at Grant Completion	4
Long-term Goal Metric Value	4
Year in which Long Term Metric Value is Anticipated	2011

Final Programmatic Report Narrative

Instructions: Save this document on your computer and complete the narrative in the format provided. The final narrative should not exceed ten (10) pages; do not delete the text provided below. Once complete, upload this document into the on-line final programmatic report task as instructed.

1. Summary of Accomplishments

In four to five sentences, provide a brief summary of the project's key accomplishments and outcomes that were observed or measured.

The main objective of this project was to understand the physical processes leading to pollutant transport and mixing in Guánica Bay and this was achieved by conducting the first dedicated field observations and numerical modeling of circulation in Guánica Bay. We built 8 inexpensive GPS-tracked Lagrangian drifters using commercially available hardware and electronics, and several drifter deployments were carried out in and near the Bay under varying physical forcing scenarios. In addition, a 45-day deployment of an acoustic wave and current profiler (AWAC) at the Bay entrance provided long-term observations of the vertical structure of ocean currents in Guánica Bay. These observations as well as the hydrodynamic modeling using the CMS-Flow circulation model have elucidated the dominant mechanisms in the Bay responsible for the transport and mixing of the sediment-laden Rio Loco river plume. Finally, several outreach activities including a teacher workshop and five seminars to public schools in Guánica served to communicate the water quality problem of Guánica Bay to its residents and primary users.

2. Project Activities & Outcomes

Activities

- *Describe and quantify (using the approved metrics referenced in your grant agreement) the primary activities conducted during this grant.*
- *Briefly explain discrepancies between the activities conducted during the grant and the activities agreed upon in your grant agreement.*

Field observations: Lagrangian drifters

Eight inexpensive Lagrangian drifters were built using commercially available GPS tracking units and inexpensive hardware. As explained later on in section 3, four shallow water and four deep-water drifters were built. The shallow water drifters were used near the river entrance and the deep-water drifters were used outside the river entrance where there was less risk of entanglement with debris from the river plume. Four drifter deployments were conducted during different physical forcing scenarios, totaling over 70 hours of drifter measurements. Figure 1 shows pictures of the drifters (top left: deep water drifter, top right: shallow water drifter) and during drifter deployment inside Rio Loco. Note that in the picture in the bottom right panel the drifter has flowed through the river and out the river mouth and is propagating towards the debris field outside the river entrance. Figure 2 shows all of the post-processed drifter tracks including data from all field experiments. Note that there are no continuous tracks from inside the river to the main Bay region since the drifters would commonly get stuck in the debris field near the river entrance. Drifters had to be redeployed outside the debris field so they could continue sampling the trajectory of the river plume.

In general, the largest drifter velocities measured occurred near the river entrance and range from 40-120 cm/s, gradually decreasing with distance from the river mouth. Far from the influence of the river outflow, currents ranged from 5-20 cm/s, being higher in the entrance of the Bay.

Figure 1. Pictures from Lagrangian drifter deployments in Guánica Bay.

Figure 2. All Lagrangian drifter trajectories obtained from the present project

Field observations: Acoustic Doppler Current Profiler

An acoustic wave and current profiler (AWAC) was deployed for 45 days (April 15-May30 2011) on the seabed at the entrance of Guánica Bay at a depth of 20 feet. This instrument measured water velocity for the full water column, acoustic backscatter (which can be used as an approximate proxy for suspended particle concentration), and wave data. The vertical resolution or bin size of the AWAC was set at 0.5 meters, and the temporal resolution was one hour. Figure 3 (left) shows Dr. Canals and lab technician David Carrero preparing for the AWAC deployment, while the picture on the right shows the condition of the AWAC after recovery from the seabed. Note the significant amount of bio-fouling on the instrument frame and on the instrument itself; an indication of the large concentration of nutrients and fast algal growth in the Bay.

Figure 3. Pictures showing the deployment (left) and recovery (right) of the AWAC instrument deployed in the Bay entrance.

The deployment produced a very large and valuable dataset, of which only a very brief description can be provided in the present report. Figure 4 summarizes the hydrodynamic conditions and the physical forcing phenomena during the AWAC deployment. The top panel shows a time series of the vertical structure of the currents (blue and red colors) at the Bay entrance, covering the whole deployment period. Blue colors represent a negative flow, which corresponds to a southerly current direction, meaning flow out of the Bay, while red colors represent the opposite (water flowing into the Bay). Overlaid on the top panel is a black line depicting the tidal elevation measured by the AWAC at the deployment site. As expected, the tidal signal is dominated by a diurnal signal. The green line represents the river flow rate measured at the Las Latas USGS station and while it does not include all of the river flow rate, it is certainly indicative of large rainfall events and / or dam releases at the Luchetti Dam. The time period of the AWAC deployment was selected because the month of May usually brings about significant rain events and we wanted to correlate the river pulses to the hydrodynamics of the Bay. The bottom two panels in Figure 3 show the wind magnitude (middle panel) and wind direction (bottom panel) measured at the CariCOOS Ponce Buoy. The plots are included to highlight the important role that wind forcing plays in the vertical structure of the water column.

On average, currents are on the order of 10-15 cm/s and are dominated by a diurnal tidal signal. Note, however, that there is a large vertical shear from 4/22 through 4/27, a period which was characterized by very strong winds. This suggests that a strong return flow was induced by the wind leading to strong vertical mixing. Further evidence of strong vertical shear is evident around 5/22-5/27 and seems to be correlated with river pulses.

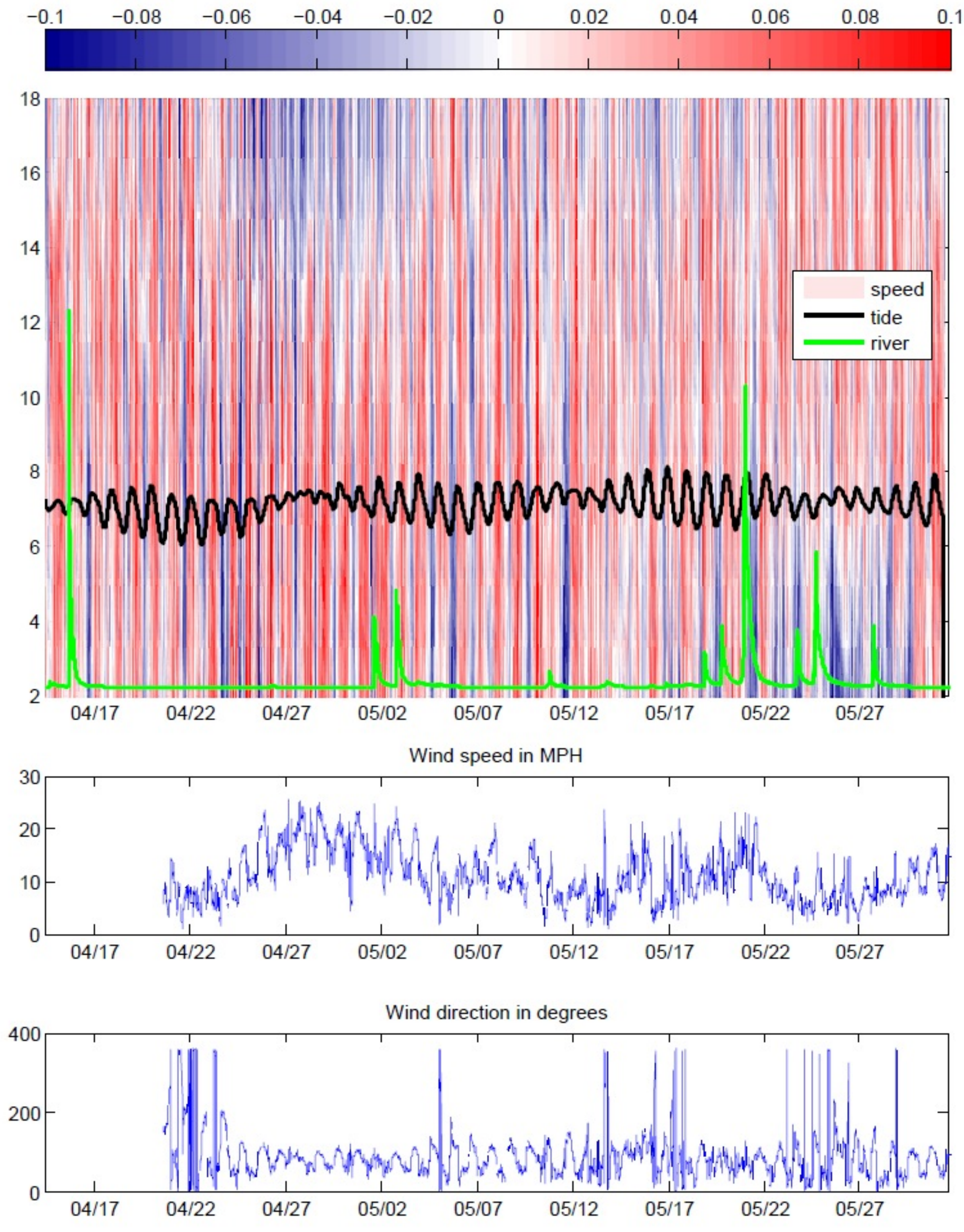

Figure 4. Results from the 30-day ADCP deployment at the Bay entrance (top) and comparison with the wind conditions (middle panel) and the wind direction (bottom panel) at the CariCOOS Ponce Buoy.

Numerical simulations

We have implemented a coastal engineering model, the USACE Coastal Modeling System, which is an integrated model suite for the calculation of circulation, waves, sediment transport, pollutant mixing and morphology change (Buttolph et al. 2006). CMS-Flow uses a finite-volume approach to solving the depth-integrated two-dimensional equations of continuity and momentum (Buttolph et al. 2006). It solves these equations on an unstructured, multi-level telescoping quadtree (mass-conserving, implicit integration) rectangular mesh (Wu et al. 2010), which allows for local grid refinement in areas where high spatial gradients are expected such as near the Bay entrance.

The model was forced by tidal sea level forcing at the open ocean boundary, flow rate forcing at the Rio Loco river mouth, and by spatially constant but time-dependent surface wind stress obtained from CariCOOS Buoy A in Ponce, PR. These preliminary simulations have focused on determining the sensitivity to tidal and wind forcing and then gradually increasing the number of physical forcing boundary conditions. The flow rate forcing condition at Rio Loco is imposed 200 meters upstream of the river mouth. The resolution in the channel and the river mouth is set at 1 meter gradually increasing to 8 meters as the river meets the Bay.

CMS is a depth-averaged model and is unable to reproduce baroclinic dynamics in the case of strongly stratified estuaries. It can, however, simulate 2D salinity transport assuming strong vertical mixing. Even though this is a major assumption, our model results are useful to better understand the contribution of river input to the hydrodynamics and flushing characteristics of the system. Figure 5 shows output from the numerical simulation; colored contours represent water salinity with the red contours indicating fresher water and the blue colors depicting salty water. This figure shows the spreading of the Rio Loco plume during a heavy rainfall event. The gray and black trajectories represent field observations of drifter trajectories from a day with comparable river flow rate. Note that the trajectories are very similar to the modeled trajectory of the freshwater plume. In summary, the following are the most important results from the numerical modeling study:

- In simulations in which only tidal forcing is considered, currents outside the Bay are very weak when compared to the drifter results. At locations outside the Bay, significantly larger velocities occur as a result of wind stress forcing. This is consistent with the results of Tyler and Sanderson (1996), who showed that wind-driven currents are the dominant mode of current variability in SW Puerto Rico.
- There is an increase in the lateral mixing field including coherent vortex circulations within the Bay when wind forcing is provided to the model
- Even though CMS flow is a 2D model, it seems to describe fairly well the main trajectory of the Rio Loco plume when compared to drifter observations

Further details from the numerical simulations may be found in Canals (2011).

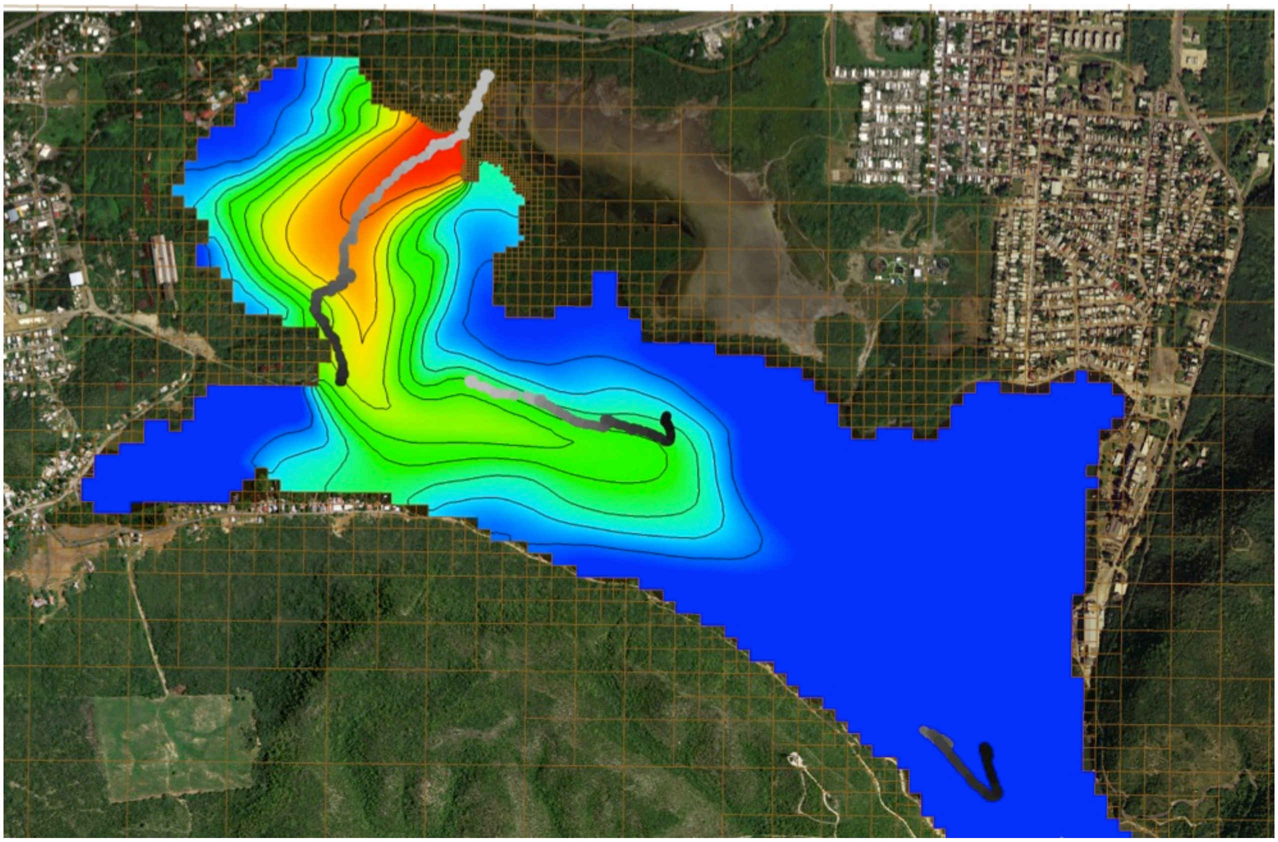

Figure 5. Numerical simulation of the 2D spreading of the Rio Loco river plume during a heavy rainfall event; colors indicate fresh (red colors) or salty (blue colors) water. The gray and black trajectories represent field observations of drifter trajectories from a day with comparable river flow rate. Note that the trajectories are very similar to the modeled trajectory of the freshwater plume.

Outreach Activities:

Teacher workshop

A teacher workshop was offered on December 2011, and over 15 teachers from the Guánica municipality's public schools attended the event. The workshop took place in the Ocean Engineering Laboratory at the University of Puerto Rico at Mayaguez and was offered by Dr. Canals. Figure 6 shows pictures from the event. The teachers were give 4 one-hour lectures on the following topics: basic ocean waves, basic ocean currents, introduction to the Guánica watershed and the hydrodynamics of Guánica Bay, the latter being an overview of the results from the present project. Besides the lectures the workshop featured discussion sessions focusing on how to better educate Guánica students about the importance of their coastal resources. The teachers were also given a tour of the lab facilities including an oceanographic buoy (as seen in Figure 6), which was a first time experience for all the teachers involved.

Student seminars

Five talks were offered to students from the public schools Jose Rodriguez de Soto (1st-6th grade) and the Teresita Siurano school (7th-9th grade). Figure 7 shows pictures from some of the talks. The talks focused on elementary oceanographic concepts such as waves and currents and how to protect their coastal resources. Students were particularly interested in tsunamis and how the "dirty water" coming from the Rio Loco impacted the fish that their parents captured on their fishing trips.

Figure 6. Pictures taken during the Guánica Bay Teacher Workshop in December 2011, which marked the conclusion of the present project.

Figure 7. Pictures from two of the talks offered by Dr. Canals to public school students in Guánica.

Discussion of Metrics:

Conservation Activity #1: *Hydrodynamic study of Guánica Bay*
Progress Measures: Other (% of Bay studied)
Value at Grant Completion: 100 %

This metric was successfully achieved by applying a numerical model that covered the whole Guánica Bay region and took into account the bathymetric complexity of the Bay. In addition, the drifter deployments covered the most important circulation features of the Bay.

Conservation Activity #2: *Students impacted by outreach activities*
Progress Measures: Other (Number of students)
Value at Grant Completion: 100

During the five talks offered to public schools students over 150 students were impacted, so this metric was successfully completed.

Outcomes

- *Describe and quantify progress towards achieving the project outcomes described in your grant agreement. (Quantify using the approved metrics referenced in your grant agreement or by using more relevant metrics not included in the application.)*
- *Briefly explain discrepancies between what actually happened compared to what was anticipated to happen.*
- *Provide any further information (such as unexpected outcomes) important for understanding project activities and outcome results.*

Conservation Outcome #1*: Increased stewardship of natural resources*
Conservation Indicator Metric: Other (# of students impacted by outreach)
Baseline Metric Value: 0
Metric Value at Grant Completion: 100
Long-term Goal Metric Value: 1000
Year in which Long Term Metric Value is Anticipated: 2015

Discussion: As previously mentioned, well over 100 students were impacted by talks given to public schools. Even after the end of the present project, Dr. Canals is working closely with public school teachers to continue educating students from Guánica public's schools. On average, Dr. Canals offers two talks per semester to public school students in Guánica.

Conservation Outcome #2: *Government officials briefed about mixing characteristics of Bay*
Conservation Indicator Metric: Other (# of officials)
Baseline Metric Value 0
Metric Value at Grant Completion 10
Long-term Goal Metric Value 10
Year in which Long Term Metric Value is Anticipated: 2011

Discussion: During the duration of the present project a total of 7 government officials ranging from the Guánica Dry Forest Reserve Manager to enforcement officials were briefed about the results of the present project. As Dr. Canals continues offering talks and presenting the results of this project it is expected that more than 10 officials will have been briefed on the results by the end of 2012.

Conservation Outcome #3: *Improved understanding of circulation in Guánica Bay*
Conservation Indicator Metric: Other (# of field measurements)
Baseline Metric Value 0
Metric Value at Grant Completion 4
Long-term Goal Metric Value 4
Year in which Long Term Metric Value is Anticipated: 2011

Discussion: This long-term outcome was successfully achieved by obtaining the first dedicated field observations of coastal circulation in and around Guánica Bay. This is a very important and highly valuable dataset that will undoubtedly be used in the future for other water quality studies in Guánica Bay since understanding the dispersal patterns is extremely important in understanding how to reduce sediment loads to coral reefs.

3. Lessons Learned

Describe the key lessons learned from this project, such as the least and most effective conservation practices or notable aspects of the project's methods, monitoring, or results. How could other conservation organizations adapt their projects to build upon some of these key lessons about what worked best and what did not?

Field observations: The Lagrangian drifter observations were successful, however, the large drifter design that was initially proposed proved ineffective near the river entrance, mainly because it would frequently get snagged on the large quantity of floating debris such as trees and bamboo branches. As a result, smaller drifters with a shallower draft (and slightly more expensive) had to be built to be able to measure the velocity of the water inside the river and to observe the near-field spreading of the river plume. Despite the new design some drifters would also get trapped in the debris field and had to be redeployed. Regarding the acoustic Doppler current measurements, we learned that although we obtained excellent vertical profiles, sometimes we missed the very thin buoyant river plume at the Bay entrance. This was mainly due to the blanking depth near the ocean surface, which is typical of acoustic current meters. Alternate techniques may be necessary to correctly observe this very thin layer.

Numerical simulations: While the model performed well from a qualitative perspective, further study is required to quantify model performance regarding the transport of sediments. In addition, although it is much more expensive, a fully three-dimensional model such as ROMS may be a useful tool for future studies to examine three-dimensional spreading of the river plume.

4. Dissemination

Briefly identify any dissemination of lessons learned or other project results to external audiences, such as the public or other conservation organizations.

Besides the talks and workshops described in section 1, other dissemination activities were conducted. An overview of the present project, including the main results, was presented at the Guánica Bay Research Workshop that took place in December 2011 at the Department of Marine Sciences of the University of Puerto Rico. In addition, a poster that focused on the numerical simulations (Canals, 2011) was presented at the 2011 ASLO Aquatic Sciences Meeting in San Juan Puerto Rico. A peer-reviewed publication is currently in progress and it is expected that it will be submitted to a peer-reviewed journal by December 2012.

References

Buttolph, A. M. B., Reed, C. W., Kraus, N. C., Ono, N., Larson, M., Camenen, B., Hanson, H., Wamsley, T. & Zundel, A. K. (2006), Two-dimensional depth-averaged circulation model CMS-M2D: Version 3.0, Report 2: Sediment transport and morphology change, Technical Report ERDC/CHL TR-06-09, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Canals, M. (2011), The hydrodynamics of Guánica Bay, American Society of Limnology and Oceanography Aquatic Sciences Meeting, San Juan, PR, February 2011.

Tyler, R. H. and B. G. Sanderson (1996), Wind-driven pressure and flow around an island, Cont. Shelf Res., Vol. 16, Issue #4, pp 469-488.

Wu, W., Sánchez, A. & Zhang, M. (2010), An implicit 2D depth-averaged finite-volume model of flow and sediment transport in coastal waters, in 'ICCE Conference', Shanghai, China.

5. Project Documents

Include in your final programmatic report, via the Uploads section of this task, the following:

- *2-10 representative photos from the project. Photos need to have a minimum resolution of 300 dpi and must be accompanied with a legend or caption describing the file name and content of the photos;*
- *report publications, GIS data, brochures, videos, outreach tools, press releases, media coverage;*
- *any project deliverables per the terms of your grant agreement.*

POSTING OF FINAL REPORT: *This report and attached project documents may be shared by the Foundation and any Funding Source for the Project via their respective websites. In the event that the Recipient intends to claim that its final report or project documents contains material that does not have to be posted on such websites because it is protected from disclosure by statutory or regulatory provisions, the Recipient shall clearly mark all such potentially protected materials as "PROTECTED" and provide an explanation and complete citation to the statutory or regulatory source for such protection.*