# Human Impacts to Coastal Ecosystems in Puerto Rico (HICE-PR): Río Grande de Manatí Watershed
# A remote sensing, hydrologic, ecologic, and socio-economic assessment with management implications

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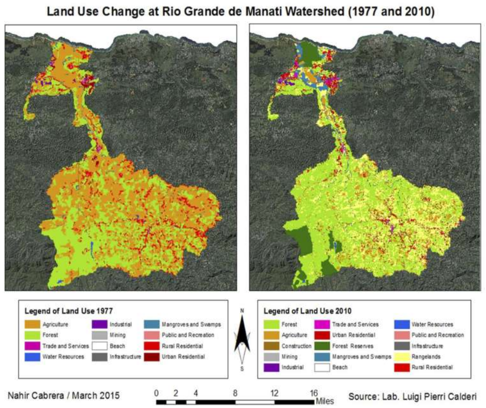
**Abstract:**

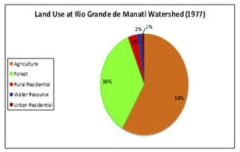
Coastal ecosystems such as beaches, coral reefs, mangroves and seagrasses have suffered the effects of anthropogenic stresses associated with land cover and land use change (LCLUC) in Puerto Rico. One of the main goals of HICE-PR is to evaluate the impacts of LCLUC on the quality and extent of Coastal Marine Ecosystems (CMEs) in two priority watersheds of Puerto Rico (Manatí and Guánica). During the project's first year, we performed a preliminary evaluation of LCLUC, CMEs, hydrological, and socio-economic components in the Manatí watershed. An assessment of historical land use (LUC) and shoreline changes associated with the watershed was conducted using remote sensing and Geographic Information Systems (GIS). Field data were collected to assess beach morphology, river suspended sediments and key watershed attributes for subsequent economic valuation. Preliminary results revealed a reduction in agricultural land use along the watershed from 1977 to 2010, primarily due to conversion to forest (53%). An identification of dynamic historical shoreline changes was found in beaches located west of the river mouth. Shifts from accretion to erosion were identified between 1971 and 2010 with major erosion (2-54 m) in the beach observed from 1995 to 2003. Hydrologic data acquisition has been initiated to calibrate the Surface Water Assessment Tool (SWAT) to model the impacts of historic LCLUC on water and sediment fluxes from the two watersheds to the CMEs. To define key attributes for the Choice Experiment modeling exercise, we have conducted initial Manatí watershed site observations to identify those areas where direct interaction was frequently observed between residents and visitors and river-related ecosystem services. Each site was visited to conduct informal data gathering on those attributes most valued by watershed residents and visitors. LCLUC, river discharge, sediment influx, river-related ecosystem services and their relationship to CME distribution and value will be evaluated during the second year of the project.

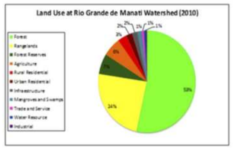
**Project goals:**

- To conduct an interdisciplinary study using sound mapping technologies and hydrological modeling to infer how anthropogenic activities related to land cover/land use changes have modified riverine inputs into the coastal and marine ecosystems (CMEs) associated with two priority watersheds in the north and south coasts of Puerto Rico.
- A secondary goal combines outputs from field measurements within CMEs, ecological modeling and economic valuation methods to assess degradation of CMEs associated with the selected watersheds.
- Additionally, we will demonstrate the use of these remote sensing and modeling tools to stakeholders (local agencies, managers, community) via workshops allowing for technology transfer and future collaboration with the PI's.

## Image Analysis (LU/LC changes)

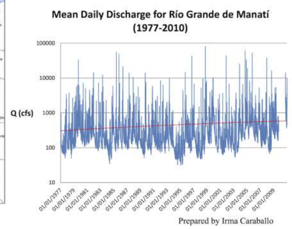



Land use distribution showed changes along the Río Grande de Manatí watershed from 1977 to 2010. A major reduction in agriculture land use was identified (from 58% to 6%). This land was converted mainly to forest and rangeland during this period. Relationships between the river discharge and land use changes will be assessed during the second year of the project.

## Watershed Hydrology

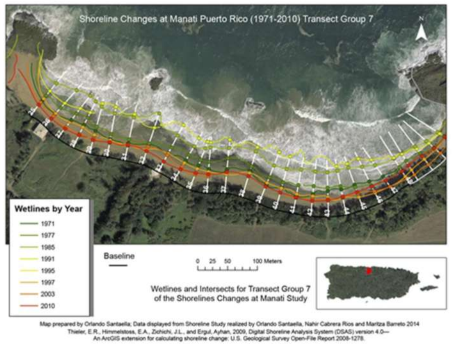


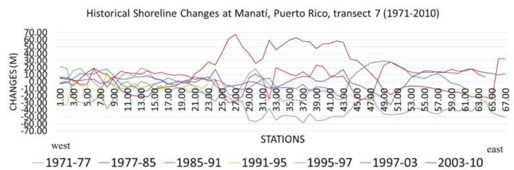

Location of the RGM watershed.
Source: PR Planning Board.
Prepared by: Joel Meléndez, October 2014.

With a total drainage area of 235 square miles, the Río Grande de Manatí is one of the largest in Puerto Rico (see map above). Compared to other rivers in the Island, its flow regime is considered natural (see hydrograph above), despite having two small hydroelectric reservoirs that transfers about 2000 ac-ft to other watersheds to the south. Through the use of the Surface Water Assessment Tool (SWAT) Model we propose to simulate the effects of historic land use changes on the water and sediment flux to coastal ecosystems. A suspended sediment sampling training program was initiated to gather field data to calibrate the SWAT model (see pictures above). For the first time, terrestrial watershed processes will be linked to coastal processes. By linking stakeholders, we expect to increase awareness and to strengthening decision-making processes to promote the sustainable use and future development of the natural resources of this tropical dynamic landscape.

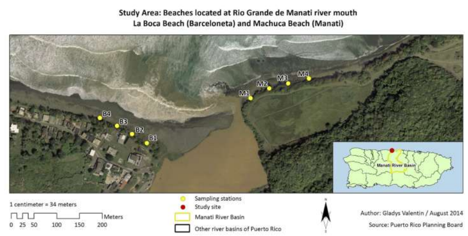
## Coastal Marine Component (CMC)

### Historical Shoreline Changes



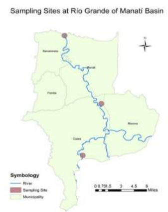

Major shoreline changes were observed eastward of Río Grande de Manatí river mouth (shoreline accretion from +10 to 50 meters) from 1985 to 1991. Erosion (2-54 m) in the beach was observed from 1995 to 2003. Minor morphological beach changes were measured near to the river mouth, except for 1991-95 period where loss of sand was identified. Terrigenous beach sand was mainly found near the river mouth. Mixed biogenic and terrigenous sand was mainly identified to the easterward of the river mouth (2004-2010). Possible association between shoreline changes and LCLUC/hydrological process will be defined during the second year of the project (Y2).



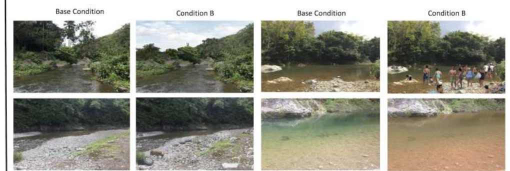

## Socio-Economic Analysis

One of the approaches proposed in this project is to assess human impacts in the Manatí watershed and to identify and value ecosystem services or attributes that may be readily apparent to residents and visitors as a result of direct interaction with the watershed, for instance, recreation cultural services. Conducting surveys in recreation areas would ensure respondent familiarity with the environmental goods or services (attribute) being valued. Once respondents identify particular attributes, we can use an Environmental Economics method to estimate its value. One of the more innovative methods is Choice Experiments, which will be used to estimate the value assigned by residents and visitors to key attributes in recreational areas of the Manatí watershed. We have completed the following tasks during the first year of the project:

- Conducted fieldwork and informal interviews with key informants to examine locations where direct human interaction with the watershed was observed on a regular basis, mainly recreation activities.
- Designed a modified stratified sampling strategy along the watershed. We defined three sampling circles with a 1 km radius, upstream, midstream and at the river mouth (see beside).
- Conducted informal interviews at the sampling sites to determine which watershed attributes were most important to residents and visitors. We have found that the presence of litter, the absence of water turbidity, the lack of agglomeration, and the presence of dense vegetation and shade were highly valued and recognized by our respondents.




- Identified four watershed photos to represent the best case scenario of key attributes (no litter, low turbidity, no people and dense vegetation) and these photos, not the sites, were in turn altered to present the worst case scenario (presence of litter, high turbidity, crowds and less dense vegetation). The resulting images which are the foundation of the Choice Experiment scenarios, are presented here:




- Our main emphasis during year two will be to conduct interviews at each of the designated sampling sites. Once we obtain an appropriate sample size, we can proceed to analyze results using Choice Experiment methodology and obtain preliminary estimates for the previously identified environmental attributes. We will also explore respondents' connectedness to nature by means of in-person interviews. Our intent is to associate user profiles with various connectedness to nature attitudes.

**Next steps (Year 2)**

1. Obtain land cover classification for the river watershed using OLI Landsat 8 images (2014/2015).
2. Reclassify land cover/land use categories according to SWAT model categories
3. Execute SWAT model for the watershed study site (1977 and 2010).
4. Monitor coral cover and quality for the site (Tómbolo Beach).
5. Continue monitoring beach profile and beach sediment data from both beaches.
6. Continue defining key watershed attributes for subsequent economic valuation (Choice Experiment).
7. Execute Choice Experiment.
8. Integrate LCLUC, hydrological (field and SWAT model), coastal component, and economic valuation data to understand possible relationships between LCLUC and coastal component distributions.
9. Integrate stakeholders in monitoring and training activities in this project.

**Acknowledgements**
Thanks to all research students for their support in this project, special thanks to Nahir Cabrera, Luis Adorno, Arian Torres (Planning School); Orlando Santaella (Geography); Irma Caraballo and Joel Melendez (Environmental Sciences).

# Human Impacts to Coastal Ecosystems in Puerto Rico (HICE-PR): the Río Loco Watershed (southwest coast PR)

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**Abstract:**

Since the 1940's, Puerto Rico's coastal and marine ecosystems (CMEs), like beaches, coral reefs, mangroves and seagrasses, have suffered the effects of anthropogenic stresses associated with population growth, land use changes and direct extraction of resources. The main goal of the HICE-PR project is to evaluate the impacts of land use/land cover changes on the quality and extent of CMEs in two priority watersheds in Puerto Rico (Manatí and Guánica). Here, we present a summary of our first year of efforts within the Río Loco Watershed (Guánica). We have established collaboration with local agencies in the Guánica watershed and through the Watershed Coordinator now have additional site access and data collection coordination with established projects. The first field campaign (November 2014) focused on the collection of benthic data within the La Parguera-Guánica reef platform and the establishment of sediment traps in Guánica Bay and in the watershed that augment existing sediment sampling stations. Coral cover ranged within and between reefs from 0.2-30%. Cover of additional benthic components (i.e., macroalgae and the encrusting sponge *Cliona*) dominate in most of the reefs sampled, which creates concern about the resilience of these degraded sites to support biodiversity and fisheries and maintain coastal protection. A preliminary assessment of runoff and sediment production from coffee farms located near the headwaters of the watershed was conducted in 2014 through rainfall simulation experiments. Historic and current imagery is being collected for land cover/land use change analysis and cover change of CMEs, and a database of inputs for hydrological modeling is underway. Second year field activities include: 1) characterization of additional reef sites to increase our temporal dataset, for continuity and to compare with biodiversity estimates from an earlier NASA-funded IDS project (2006-2009), 2) characterizing water optical properties and their possible correlation to the benthic data, 3) bi-weekly collection and analysis of sediment data, 4) development and implementation of surveys for user attribute valuation and environmental concern, 5) further empirical quantification of runoff and sediment yields at spatial scales ranging from hillslopes to the entire watershed, and 6) calibrate the SWAT hydrological model for the watershed.

**Project goals:**

- To conduct an interdisciplinary study using sound mapping technologies and hydrological modeling to infer how anthropogenic activities related to land cover/land use changes have modified riverine inputs into the coastal and marine ecosystems (CMEs) associated with two priority watersheds in the north and south coasts of PR.
- A secondary goal combines outputs from field measurements within CMEs, ecological modeling and economic valuation methods to assess degradation of CMEs associated with the selected watersheds.
- Additionally, we will demonstrate the use of these remote sensing and modeling tools to stakeholders (local agencies, managers, community) via workshops allowing for technology transfer and future collaboration with the PI's.

## Image analysis Land Cover/Land Use (LC/LU)

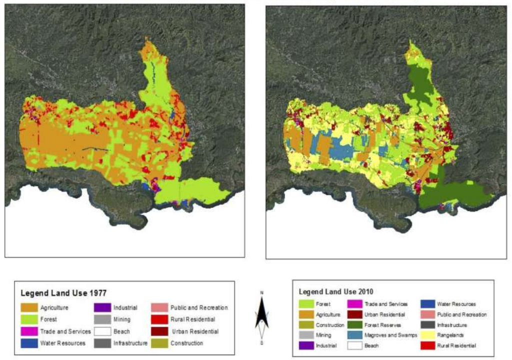
**Main objective:**

•To account for changes in LC/LU within the Río Loco and Parguera watersheds during the past five decades.

**This year:**

•Acquisition of available aerial and satellite imagery for LC/LU change analysis.
•Land use change maps have been develop for the watershed.
•Results show that agriculture and forest are the major land use categories identified in the watershed for 2010 period. Agriculture areas shift to forest reserve (40%), forest (32%) and rangeland (7%) at Río Loco watershed.

**Land Use Change at Rio Loco Watershed (1977 and 2010)**





Changes in LC/LU within the La Parguera watershed from a relatively unpopulated fishing village in the 1930's to one of the main fully developed tourist areas in the southwest coast of PR.

**Next steps:**

•Delineation of CMEs within the Río Loco and Parguera watersheds.
•Analysis of mangrove forests cover changes in the past 50 years and evaluation of how LC/LU change has affected these.

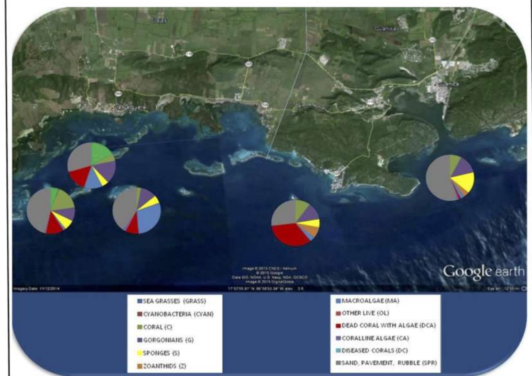
## Reef benthic composition

**Main objective:**

•Provide an updated benthic characterization of selected reefs within the La Parguera-Guánica platform and produce a time series analysis by adding data collected during past NASA-funded efforts. These data will be correlated with bio-optical properties measured in the area (water quality).

**This year:**

•Conducted phototransects for reef benthic characterization at multiple reefs in La Parguera and Guánica.
•Generated and analyzed 9,000 random points within each reef with Coral Point Count with Excel extensions (CPCe) for presence of benthic live taxa (identified to the lowest taxonomic level possible) as well as other nonliving benthic components such as sand and dead rubble.
•Conducted reef rugosity analysis at each transect.
•Established a series of sediment traps at each study site and inside Guánica Bay to analyze (yrs 2 and 3) resuspended sediment composition and grain size.




**Next steps:**

•Characterization of additional reef zones (fore-reef) at the study sites.
•Conduct video transects with a Delta Vision HD Pro drop video camera, additional benthic analysis of selected video frames with CPCe, and produce an Ecological Niche Factor Analysis (ENFA) modeling for habitat suitability.
•Collect bio-optical data (Chl *a*, $Kd_{(490nm)}$, total suspended sediments, remote sensing reflectance, etc.) for water quality analysis along several transects perpendicular to the coastline to correlate with upstream sediment and pluvial data.

## Watershed hydrology

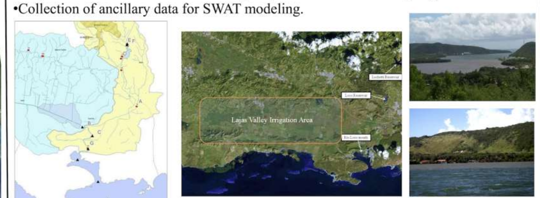
**Main objective:**

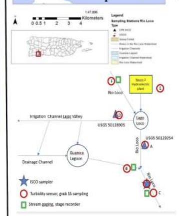
•To assess the effects of intensive historical anthropogenic water and land management in the water and sediment fluxes to Guánica Bay, and quantify runoff, nutrient, sediment yields at scales ranging from the hillslope and headwater stream to the watershed scale.

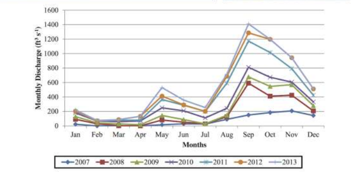

Analysis of upstream activities within the Parguera and Río Loco Watersheds and collection of sediment and water loads data to conduct a hydrological analysis and model future impacts to CMEs within Puerto Rico's watersheds.

**This year:**

•*Hillslope- & headwater scale*: Rainfall simulation experiments (n = 40; Jun-Jul 2014) were conducted within coffee farms. Results highlight the importance of vegetation cover in maintaining low soil erosion rates and suggests unpaved access roads can be important sources of sediment. These roads are generally ignored by erosion mitigation strategies that only emphasize reforestation practices.
•Established sediment monitoring stations through the watershed and started collecting grab samples for suspended sediment analyses while permanent sampling equipment arrives.
  •Obtained permits from PR Electric Power Authority (PREPA) to sample at hydroelectric plant and irrigation channel, and requested historical data.
•Acquisition of streamflow and water quality data from USGS sampling stations.
•Collection of ancillary data for SWAT modeling.






Monthly sediment discharge at the USGS gaging station (shown as **A** in map and sampling stations diagram on the left) showing the peaks during the rainy seasons (May and Sept-Nov) and how it has varied during the past 7 years.

**Next steps:**

•Gathering continuous water flow and turbidity data at selected stations in the Rio Loco watershed for one year.
•Calibrate the SWAT model for the Rio Loco watershed.
•Assess the role of intensive agricultural activities in the Rio Loco and Lajas Valley on the flux of sediments and nutrients to the Guánica Bay.
•SWAT workshop to research team (June '15) and modeling of the Río Loco watershed.
•*Hillslope- and headwater scale*: Additional rainfall simulation experiments will be conducted in coffee and mixed-use farms, as well as on hydroseeded areas to evaluate its efficiency (Jun-Jul 2015).
•*Sub-watershed and watershed scale measurements*- Runoff and sediment monitoring will be conducted in at least two of the ephemeral streams draining towards the La Parguera. In combination with data collected by the USGS at other south coast draining streams, these data will serve to better describe watershed conditions matching the bio-optical data being collected by another component of this study.

## Socio-economic analysis

**Main objective:**

• Compute the environmental economic value of selected CMEs (e.g. mangroves, seagrasses, coral reefs and beaches).

**This year:**

•Conducted initial fieldwork based on site visits and informal interviews with residents, visitors and key informants in the Río Loco watershed and found large differences in human interactions between the Manatí and Río Loco watersheds. We did not expect to find such a marked difference between watersheds, and as a result we had to consider various methods, not just Choice Experiments, to assess respondent attribute valuation.
•Identified and valued ecosystem services (following the Millennium Ecosystem Assessment framework) and attributes that may be readily apparent to residents and visitors as a result of direct interaction with the watershed, for instance, recreation and cultural services.
•We found that interaction resulting from consumption or enjoyment of cultural ecosystem services, particularly recreation, was rather rare in the Río Loco watershed.
•Provisioning services were more predominant than cultural services in the Río Loco. A significant amount of water use is dedicated to agriculture and power generation. This finding led us to a possible reassessment of the methods used in this watershed for attribute valuation.


Compute the environmental economic value of selected CMEs using Choice Experiments or Direct Market Methods depending on the watershed. Meetings with A) local stakeholders, B) fishermen, and C) the Guánica watershed coordinator.

**Next steps:**

•We will continue to study Río Loco watershed services during year 2. One of the possible options is to increase the sample size of the Choice Experiment exercise in the Río Grande de Manatí watershed, and once we obtain reasonable estimates at that watershed, we can proceed to apply the Benefit Transfer method to provide estimates of added value if Río Loco locations were more intensively used for cultural ecosystem services such as recreation. The second option is to conduct Choice Experiments on a reduced basis at the Río Loco to compare results with Manatí, and make adjustments based on the diverse characteristics observed in both regions.

**Acknowledgements:**

This is a NASA ROSES12 IDS funded project (NNX14AJ23G). We would like to thank all our students/research assistants who have contributed to the successful completion of the first year of this project. Special thanks to Frank Müller-Karger, Dan Otis and Pablo Méndez-Lázaro for their support and collaboration.

NASA · Universidad de Puerto Rico Recinto de Río Piedras 1903 · FIU Florida International University Miami's public research university · Bay Area Environmental Research Institute · The University of Texas at Austin

# A comprehensive analysis of the Guánica Bay / Río Loco Watershed: linking historical land use changes, with water and sediments fluxes and human perspectives of their impact to coastal ecosystems

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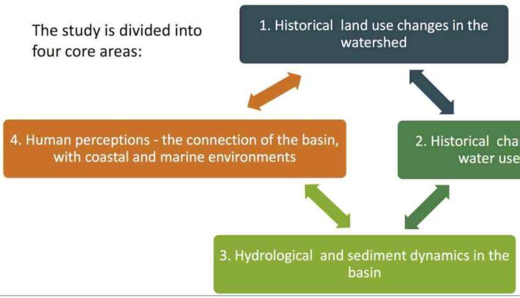
## Purpose

**The primary purpose of this project is to understand how population dynamics and land use changes on the Rio Loco watershed affect the fluvial input of sediments to the coastal and marine ecosystems associated with the Guánica Bay.**

The study is divided into four core areas:




## Objectives

- **Assess the net effects of land cover changes and dams on the flux of fluvial sediments to CMEs in Puerto Rico.**
- **Conduct a hydrological analysis of the sediment and water loads reaching the coastal ecosystems in Guánica Bay to model future impacts to CMEs in Puerto Rico watersheds.**
- **Develop a time series of land cover changes based on remotely-sensed data.**
- **Analyze the actual water uses of the Southwest Project.**
- **Analyze human perceptions of the connection of the basin with coastal and marine environments.**

## Study Area

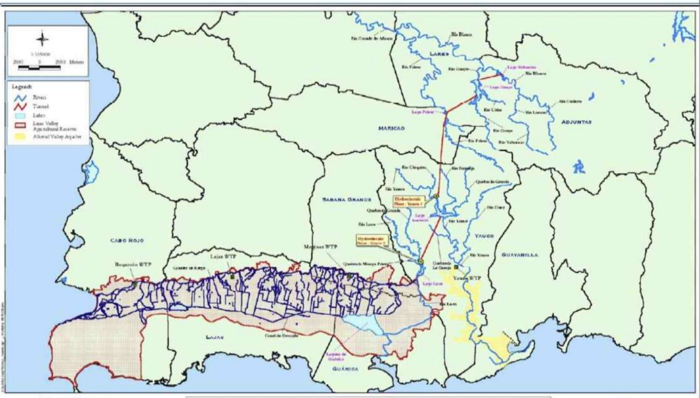


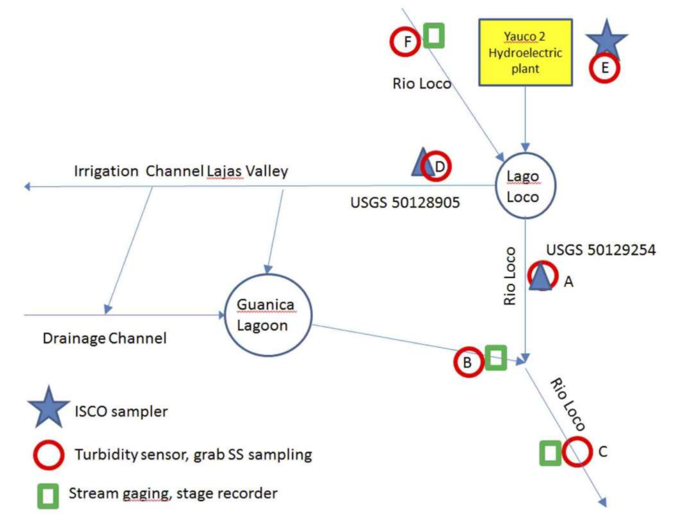
Figure 1. Major hydrologic components considered in the study

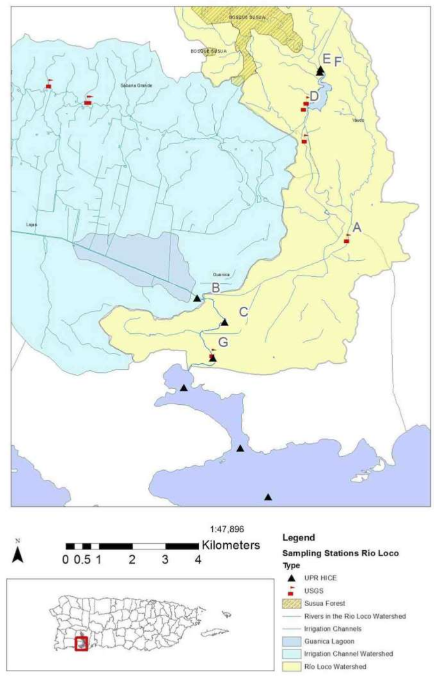
**The Guánica Bay/Río Loco watershed (Ortiz-Zayas, et al., 2001)**

| | |
|---|---|
| **Area** | 151 squares miles |
| **Discharge** | Guánica Bay |
| **Drainage area increase by water transfer of five reservoirs** | Lago Yahuecas , Lago Guayo, Lago Prieto Lago Lucchetti & Lago Loco |
| **Two hydroelectric plants** | Yauco 1 & Yauco 2 |
| **Land use** | 48% forested, 43% agriculture, 9% urban (2004 – Rio Loco watershed & Lajas Valley) |
| **Water use** | Public supply, agriculture, hydropower generation, flood control, maintenance of fisheries habitat at Lago Lucchetti, maintenance of minimum flows downstream of Luccheti and wastewater disposal |

## Survey design

**Sediment and water dynamics**




**Changes in land use**

Is the loss of highly erodible soils on steep slopes used for agriculture a major issue in the Guánica Bay / Río Loco watershed?

In what way creating buffer areas around the rivers and the reservoirs that feed the Yauco 2 system would help to reduce the sediments reaching the Guánica Bay?

**Changes in water use**

How does the demand for water in the basin has changed? How much water is consumed by PRASA? How much water is presently used by farmers?

**Hydrological and sediments dynamics in the basin**

What is the magnitude of fluvial sediment export to Guánica Bay in this highly regulated system? In what way has sedimentation contributed to the evolution of the coastal ecosystems?

**People perceptions**

Do stakeholders perceive a connection between the watershed, the coast and the marine environments?

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# Drainage Basin Delineation and Land Use Change at the Río Grande de Manatí and Río Loco Watersheds (1977 and 2010).


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Advisor: Maritza Barreto, Ph.D

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## Introduction

This presentation includes an evaluation of the drainage watersheds delimitations and land use changes at Río Grande de Manatí and Río Loco (1977 and 2010). This study includes mainly an evaluation of the feature class, metadata, criteria used in the watershed delimitation and land-use categories definition. This evaluation is so important to perform due to the diverse data sources available that may cause misunderstanding of the physical description of the real scenario of the study site. The using ArcMap 10.2 was helpful to identified the strength and limitations of these data.

## Objective and Question

- Identify and evaluate drainage basins delimitations.
- Identify and evaluate land use distribution based on the watershed delimitations.
- Identify land use changes in both river basin for 1977 and 2010 period.

How have land use changed in the Río Grande de Manatí and Río Loco Watersheds (1977 and 2010)?

## Study Area

This study is conducted at two important watershed on the north and south coasts of Puerto Rico, Río Grande de Manatí and Río Loco. The Río Grande de Manatí has an approximate area of 235 $mi^2$ and the Río Loco has an area 24.7 $mi^2$. The climate at Rio Grande de Manatí is mainly humid subtropical. The climate at Río Loco varies from abundant rainfall areas in the Cordillera Central to semiarid conditions in the coastal valley.

## Methodology

- ArcMap 10.2 was used to prepare, display and evaluate all features classes related with watershed delimitation.
- Land use categories (1977 and 2010) were evaluate for both watersheds delimitations.
- A reclassification procedure was conducted to identify land use changes for both source data (Xplorah and DRNA).
- Land use changes were identified for both watershed.

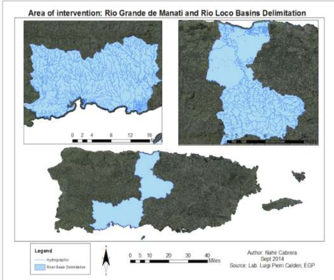
## Findings

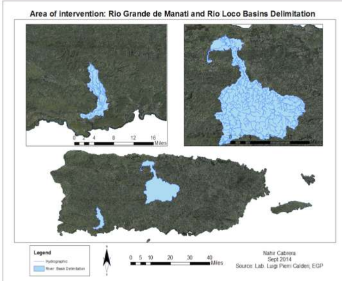
- Four different features classes of watershed delimitations was found it. These are prepared by: United State Geological Survey (USGS) and Puerto Rico Department of Natural and Environmental Resources.
- Major land use distributions are Agriculture and Forest for both watersheds during 1977.
- Major land use distributions are Forest and Rangeland for Río Grande de Manatí watershed during 2010.
- Major land use distribution for Río Loco watershed are Forest Reserve and Forest during 2010.

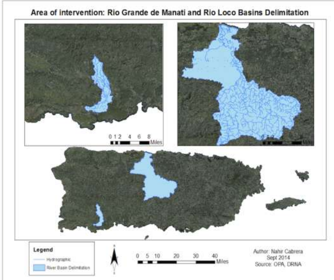
Comments:

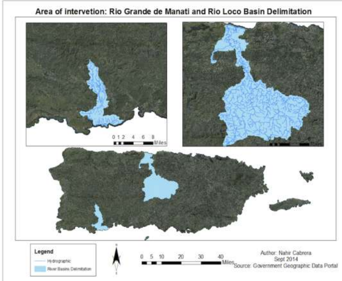
- Reevaluation of pasture category definition(Land Use Classification) will be conducted.
- Field trips will be conducted to recheck land use categories as pastures.

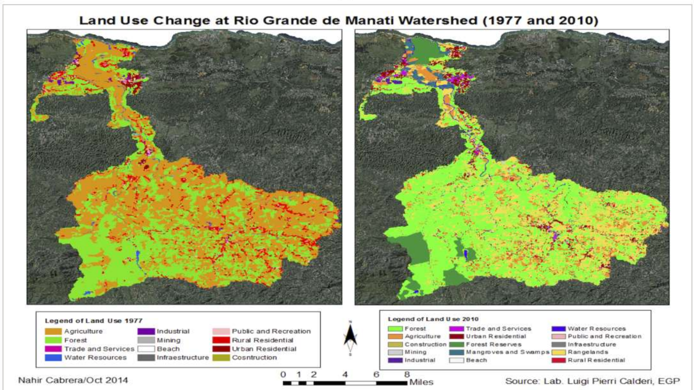
## Results

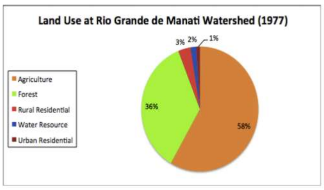


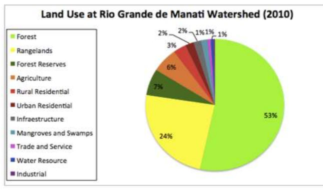



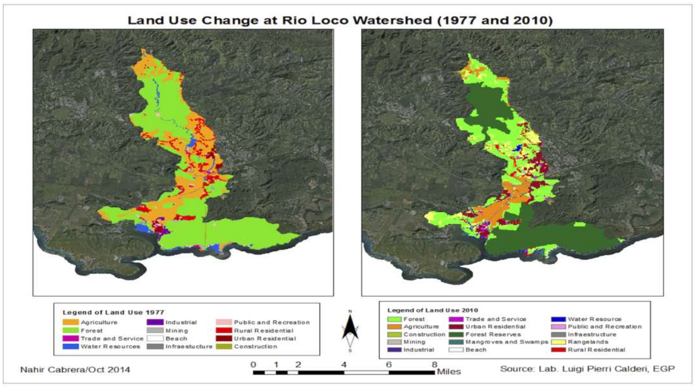



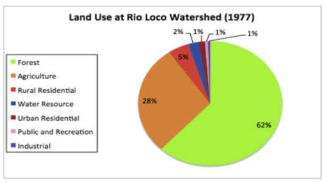



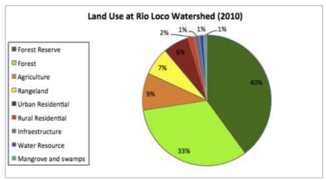





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# Choice Experiments: a stated preference method to attribute economic value to the Rio Grande de Manatí Watershed

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## Introduction

The valuation of environmental changes has become an important area of specialization within economics, motivated largely by the need to give a monetary value to the damage or effects associated with the consumption and production of human beings. In the basin of the Río Grande de Manatí this has a great importance; six key locations have been identified to estimate the human impact on the Manatí basin. We will implement Choice Experiment methodology for the estimation of key watershed attributes. Neoclassical theory points out that the market prices usually refer to the value that society imposes on goods and services, but prices associated with environmental services may be distorted, since there are not bought or sold in markets. Choice Experiment methodology will allow us to estimate a user assigned value for particular attributes.

## Objective and Hypothesis

In our experiment, the objective is to attribute an economic value to key "Rio Grande de Manatí" watershed attributes through Choice Experiments. This declared preference method is suitable for estimating the economic value associated with attributes that may be altered by human impacts.

## Literature Review

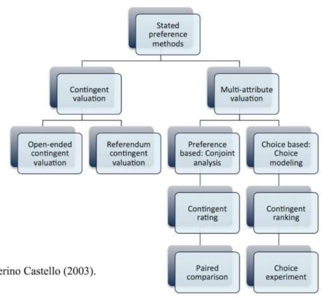
The use of the CVM in the non-market valuation literature began in the 1960s. CVM remains a widely used and accepted method for estimating visitor willingness to pay (which is an economist's definition of benefits; see Loomis and Walsh 1997; Freeman 2003). The use of CE in environmental attribute valuation began in the 1990s, and its use is becoming increasingly prevalent (Adamowicz, Boxall, Williams, and Louviere 1998; Boxall et al. 1996). Both CVM and CE are Stated Preference (SP) methods designed to elicit economic responses to hypothetical scenarios that allow the estimation of economic values of attributes of environmental quality. Wetlands and the ecosystem services they provide are hugely valuable to people worldwide: this has been a key finding of the Millennium Ecosystem Assessment (MA), in its report to the Ramsar Convention (De Groot, R.S., Stuip, M.A.M., Finlayson, C.M. & Davidson, N. 2006). The value of these wetlands and their associated ecosystem services has been estimated at US$14 trillion annually. Values have a worth to people, which can be measured in various ways. Most understandable is the concept that the values have an economic worth that can be expressed as an amount of money, for instance a market price. Values can also be given a worth in nonmonetary ways such as by estimating importance to a way of life or community (Stuip, M.A.M., Baker, C.J. and Oosterberg, W. 2002. The Socio-economics of Wetlands, Wetlands International and RIZA, The Netherlands). Only in very few cases have decisions been informed by the total economic value and benefits of both marketed and non-marketed services provided by wetlands. This lack of understanding and recognition leads to ill-informed decisions on management and development, which contribute to the continued rapid loss, conversion and degradation of wetlands - despite the total economic value of unconverted wetlands often being greater than that of converted wetlands. Economic valuation of ecosystems is a rapidly developing discipline, and there are now many different methods available for undertaking different aspects and purposes of wetland valuation.

## Methodology

Choice Experiments (CE), a stated preference valuation method, are proposed as a tool to assign monetary values to environmental attributes during the ex-ante stages of environmental impact assessment. CE can create hypothetical but realistic scenarios for consumers and generate restoration alternatives for affected goods. Economic valuation methods provide monetary estimations of baseline changes caused by environmental, health and social impacts, so that they can be incorporated into cost-benefit analysis (Vega, D. And Alpízar, F. Choice Experiments in Environmental Impact Assessment).

Stated preference techniques are a series of approaches or methods to estimate the value of goods and services not commonly bought and sold in existing markets. In a CE, individuals are asked to choose their preferred alternative from several options in a choice set, and they are usually asked to respond to a sequence of such choices. Each alternative (e.g., roads A, B, and C) is described with a number of attributes or characteristics (e.g., several types of bridge), where the levels of the attribute change from one alternative to the other. A monetary value is included, as are other significant attributes, when presenting each alternative. There are four steps involved in the design of a CE: 1) Definition of attributes and attribute levels, 2) experiment design, 3) experiment context and preparation of questionnaire, and 4) choice of simple and sampling strategy (Vega, D. And Alpízar, F. Choice Experiments in Environmental Impact Assessment).

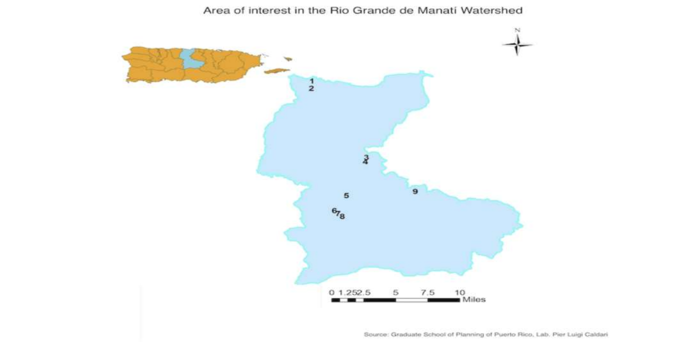
**Family of Stated Preference Methods**




Source: Merino Castello (2003).

## Preliminary Sampling Sites

We conducted several visits to the study area to identify sites where there were stronger links between human activities and the river. The following list includes sites where such activity is strong, making them appropriate locations for sampling using CE methodology.




1. Mouth of the Rio Grande de Manatí

2. Boat Ramp near to the river

3. Lookout point

4. Wilfredo Rodriguez Track

5. Ciales recreation area

6. Camping area

7. Toro Negro pool

8. Toro Negro Bridge

9. "La Playita" Morovis

## Ecosystem Services Provided at the Selected Sampling Sites

The following ecosystem services have been identified in the Rio Grande de Manatí potential sampling sites.

Ecological process and/or component providing the service (or influencing its availability)

| ***Provisioning*** | ***Regulating*** | ***Cultural & Amenity*** | ***Supporting*** |
|---|---|---|---|
| Food: production of fish,algae and invertebrates | Natural hazard mitigation: flood control, storm & coastal protection | Cultural heritage and identity: sense of place and belonging | Biodiversity & nursery: Habitats for resident or transient species |
| | Biological Regulation: e.g., control of pest species and pollination | Spiritual & artistic inspiration: nature as a source of inspiration for art and religion | |
| | Air quality regulation: e.g., capturing dust particles | Recreational: opportunities for tourism and recreational activities | |
| | Climate regulation: regulation of greenhouse gases, temperature, precipitation, and other climatic processes | Aesthetic: appreciation of natural scenery (other than through deliberate recreational activities) | |
| | Pollution control & detoxification: retention, recovery and removal of excess nutrients / pollutants | Educational: opportunities for formal and informal education & training | |

## Further Research

- Prepare a socio-economic and institutional profile of the study area.
- Conduct meetings with stakeholders to gather data on the current status of the watersheds.
- Design the sampling strategy and prepare CE survey.
- Administer CE questionnaires in the selected sampling sites.
- Analysis of the results of CE.

## Acknowledgements

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# Ecosystem Services Valuation: Trade-offs of the Rio Loco Watershed


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## INTRODUCTION

Only in very few cases have decisions been informed by the total economic value (TEV) and benefits of both marketed and non-marketed services provided by watersheds. Thus the importance of providing a more thorough valuation of ecosystem services. We will explore current ecosystem service provision and study possible trade-offs between conflicting uses at the Rio Loco watershed. We will use TEV techniques for use and non-use valuation, including the possibilities of using techniques for non-marketed services such as the Benefit Transfer method.

## OBJECTIVE

After preparing a socio-economic and institutional profile of the Río Loco basin by identifying stakeholders according to their type of influence and spatial distribution, this study pretends to use different types of valuation methods to determine the contribution of key ecosystem services and the tradeoffs that may arise as a result of changes in the future use of the watershed. We specifically aim to quantify key provision services (mainly associated with agriculture) and compare them to estimations of potential cultural services in the region (mainly associated with recreation).

## LITERATURE REVIEW

Since we pretend to determine the importance of key Rio Loco watershed ecosystem services, we will use several use and non-use valuation methods. The concept of Total Economic Value (TEV) has become a widely used framework for assessing the utilitarian value of ecosystems.

The basic value judgment underlying economic valuation is that 'preference count'. Preferences are revealed in many ways, but the context of interest is the market. In the market place, preferences show up through individuals' willingness to pay (WTP) for the good in question. *(Pearce, D. and Ozdemiroglu, E. et al. 2002).* Economic valuation also refers to the assignment of money values to non-markets assets, goods and services, where the money values have a particular and precise meaning.

Broadly, there are two ways of estimating economic values attached to non-marketed goods and services: using *revealed preferences* or *stated preferences*. Revealed preference approaches identify the ways in which a non-marketed good influences actual markets for some other good. Stated preference approaches on the other hand are based on constructed markets. A third approach to economic valuation relies on the build-up of case studies from revealed and stated preference studies and then seeks to 'borrow' the resulting economic values and apply them to a new context. This is Benefit Transfer. *(Pearce, D. and Ozdemiroglu, E.,et al. 2002).*

## METHODOLOGY

We will use a RAMSAR (2006) framework to assist in the process of conducting an integrated assessment of wetland ecosystem services, setting five key steps in undertaking a wetland valuation assessment. These are: 1) Analysis of policy processes and management objectives; 2) Stakeholder analysis and involvement; 3) Function analysis; 4) Valuation of services; and 5) Communicating wetland values.

The stakeholder analysis is particularly important for us because in almost all steps of the valuation procedure, stakeholder's involvement is essential in order to determine the main policy and management objectives, to identify the main relevant services and assess their value, and to discuss trade-offs involved in the Rio Loco watershed use.

Also, the economic value and importance of key Rio Loco watershed ecosystem services is central to this research. Given a preliminary overview of our study area, we can use direct market valuation methods for an accurate estimation of some of the key services provided, with a focus on those currently provided by agriculture. Furthermore, because minimal scenic or recreational activities were identified throughout the Rio Loco watershed, we would like to explore the contribution cultural ecosystem services can make to the region by applying Benefit Transfer, using results from the Río Grande de Manatí watershed study. The combination of direct market estimation and the benefit transfer estimation would allow for an interesting comparison between two seemingly conflicting uses in the region: agricultural use versus conservation.

## ACKNOWLEDGEMENTS


We would like to thank the Center for Watershed Protection for their collaboration.

This research is funded by the National Aeronautics and Space Administration (NASA).

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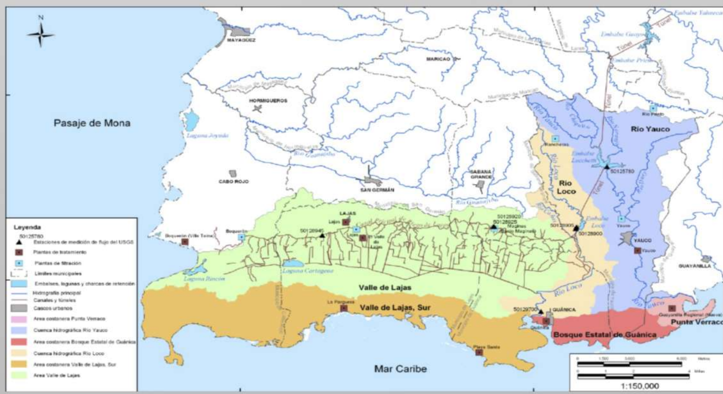
## BACKGROUND

The Rio Loco watershed is part of the Lajas District Irrigation System (LDIS), operated by the Electric Power Authority. The LDIS is the most important irrigation system in Puerto Rico since, in addition to water for agriculture, it is the main source of drinking water to the inhabitants of the municipalities of Guánica, Sábana Grande, San Germán, Lajas and some sectors in Cabo Rojo.




## ECOSYSTEM SERVICES PROVIDED BY THE RIO LOCO WATERSHED

The following ecosystem services have been identified thoughout the Rio Loco watershed

| Provisioning | Regulating | Cultural & Amenity | Supporting |
|---|---|---|---|
| **Food:** production of fish, algae and invertebrates | **Air quality regulation** | **Educational:** opportunities for formal and informal education & training | **Soil formation:** sediment retention and accumulation of organic matter |
| **Fresh water:** storage and retention of water; provision of water for irrigation and for drinking. | **Climate regulation** | | **Nutrient cycling:** storage, recycling, processing and acquisition of nutrients |
| | **Hydrological regimes** | | |
| | **Pollution control & detoxification** | | |
| | **Erosion protection** | | |
| | **Natural hazard mitigation** | | |

## FURTHER RESEARCH

- Finish the socio-economic and institutional profile of Rio Loco Watershed
- Establish criteria for identifying, prioritizing and involving stakeholders, and interview stakeholders
- Formulate the methodological process for the estimation of ecosystem services of the watershed
- Conduct relevant direct market and Benefit Transfer techniques and analysis
- Dissemination of results

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# Impact of land cover change on the frequency and magnitude of floods in the valley of the Río Grande de Manatí between 1977 and 2014

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## Introduction

A watershed is defined by the United States Geological Survey (USGS 2014), as the area in which water that falls in it or runs trough it is carried to the same location, usually to a river or stream (Department of Natural and Environmental Resources, nd). It is also known as catchment area or drainage basin (USGS, 2014; DNER, nd). Precipitation is the main factor controlling surface runoff through a basin, while not the only factor. Other factors include soil characteristics, slope and land use/land cover.

With population growth and the change in the economic activities of the past century, the demand for living spaces, trade, transportation and other human activities grew. As a result, soils have undergone profound changes. In Puerto Rico, the growth and development of pharmaceutical and other industries between 1960 and 1990 led to the urbanization of the coastal plains.

Several studies and models indicate that urbanization can change both the health and diversity of aquatic ecosystems and the hydrological processes in the basin (Ackerman and Stein, 2008 ;Goetz & Fiske, 2008; Goetz et al. 2011). Most studies conclude that more research and use of different technologies are necessary to establish a pattern of impacts and employ successful management strategies (Ackerman and Stein, 2008; Booth et al, 2002).

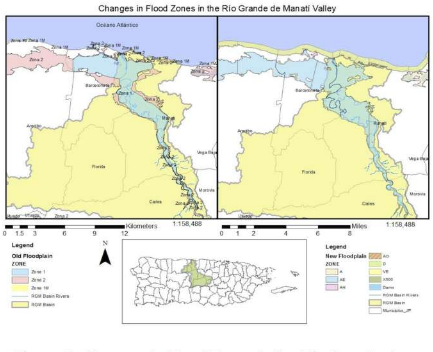
## Objective and Hypothesis

The main goal of this research is to establish a relationship between land use/land cover changes in the Manatí watershed and the historical flooding events in its valley. We hypothesize that the increase in impervious cover due to urban growth in the watershed will increase peak discharges and therefore floods in the valley.

## Methodology

- Register changes in land use/land cover and in flood plain hydrography between 1970 and 2010 combining maps and aerial photographs.
- Develop a flood-frequency analysis based on annual maximum discharge streamflow data (USGS station 50038100).
- Compare the previous and new flood zone maps in the Manatí valley (Figure 2).
- Evaluate the justification of flood-control interventions implemented in the watershed and assess their efficacy.

Changes in Flood Zones in the Rio Grande de Manati Valley



| Zone (FEMA) | Zone (Planning Board) | Characteristics |
|---|---|---|
| V | 1M | High velocity water flow due to wind wave action of 3 ft, or more, in height, propagating over the 100-year stillwater flood. |
| A Floodway Area in Zone A | 1 | 100-year high velocity water due to riverine flow. |
| A | 2 | Floodable by 100-year storm surge, river, or rainfall ponding, but with low velocity. |

| Zone | Characteristics |
|---|---|
| A | No base flood elevation determined |
| AE | Base flood elevation determined |
| AH | Flood depth of 0.3 to 0.9 meters (usually areas of ponding) |
| AO | Flood depth of 0.3 to 0.9 meters (usually sheet flow on sloping terrain) alluvial fan flooding |
| D | Areas in which flood hazard are undetermined, but possible |
| VE | Costal flood with velocity hazard (wave action) |
| X500 | Areas of 500-year flood; areas of 100-year flood with average depths of less than 0.3 meters or with drainage areas less than 2.6 square kilometers |

**Figure 2:** Changes in Flood Zones in the Río Grande de Manatí Valley. Source: USGS

## Study Area

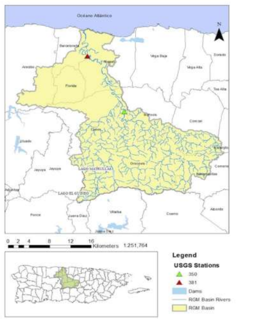


**Figure 1:** Manatí Watershed Study Area. Source: DNER

### Manatí Watershed

- Located at the north-central part of the island.
- Area of 608 km².
- Composed of a wide coastal plain confined laterally by karst topography.
- Urban growth and expansion along the northern coastline and in the mountains to the south.
- Population increase of 14% in Manatí city from 1990 to 2010.

## Findings and Observations

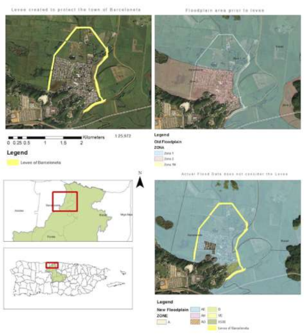


**Figure 3**: Floodplain area and levee constructed around the town of Barceloneta. Source: USGS

- Changes in zonification terminology between previous and actual maps.
- Town built and developed in an area already classified as flood zone.
- Alterations made to the stream course (Fig. 3).
- Intensity and type of human activity varies throughout years.
- Important to investigate activities in the upper part of the watershed to establish a relationship.

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# POTENTIAL IMPACTS OF SEDIMENTATION ON CORALS AND COASTAL EROSION IN GUÁNICA BAY, PUERTO RICO

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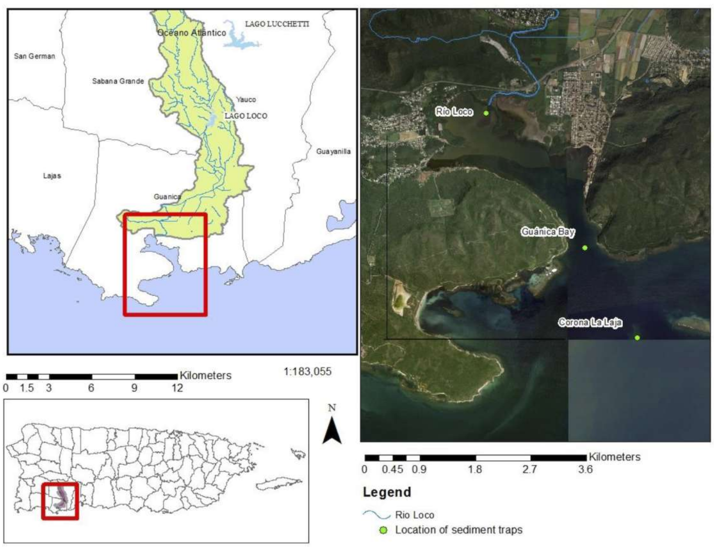
## Introduction

Coral reefs represent a large and complex ecosystem, which consists of a high and varied biodiversity. These structures are very important in terms of productivity and diversification of tropical marine ecosystems. Therefore, deterioration or loss of these ecosystems can have adverse effects on the entire marine ecosystem. A high flux of sediments composed, for example, of terrigenous contents, calcium carbonate or organic material, can compromise the health of coral reefs. Suspended sediments could be found throughout the water column, affecting water clarity. Consequently, the development of corals can be limited resulting in a collapse of the ecosystem. The loss of coral cover can result in accelerated coastal erosion by decreasing the effectiveness of the coral structure in attenuating erosive waves. The goal of this study is to measure the amount of sediments reaching Guánica Bay and Corona La Laja reef and examine whether the conditions caused by sediments on corals have contributed or could contribute to coastal erosion in this area.

## Study Area




The study will take place in the area of Gúanica Bay. Sediment traps will be placed in the mouth of Río Loco, the mouth of Guánica Bay and in the Corona La Laja reef.

## Methodology

- Make a light profile using a Secchi disc to see the light penetration into the Guánica Bay and Corona La Laja.
- Measure the amount of suspended sediment at different depths, both in Guánica Bay and Corona La Laja.
- Place sediment traps in the mouth of Río Loco, the mouth of Guánica Bay, and in Corona La Laja reef to measure how much sediment is being deposited.
- Compare aerial photographs over time to observe changes in the coast.

## Hypothesis and Objectives

If there is an increase in the rate of sedimentation in the Corona La Laja reef, coral coverage will decrease, resulting in an increase in coastal erosion. The goal of this study is to measure the amount of sediments reaching Guánica Bay and Corona La Laja reef and examine whether the conditions caused by sediments on corals have contributed or could contribute to coastal erosion in this area.

## Published Data

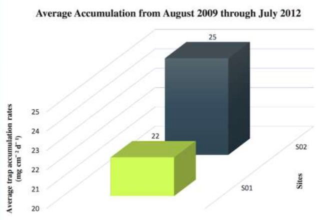



Figure 1

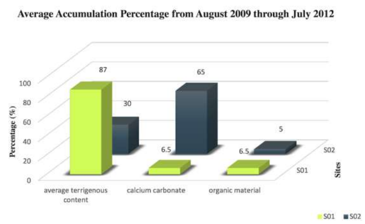



Figure 2

Figures 1 and 2 show sediments data reported from August 2009 through July 2012 of sites S01(mouth on Río Loco) and S02 (Guánica Bay) as published by Sherman et al. 2013. Figure 1 shows the average sediment accumulation rates and Figure 2 shows the average composition of sediments reported for each site.

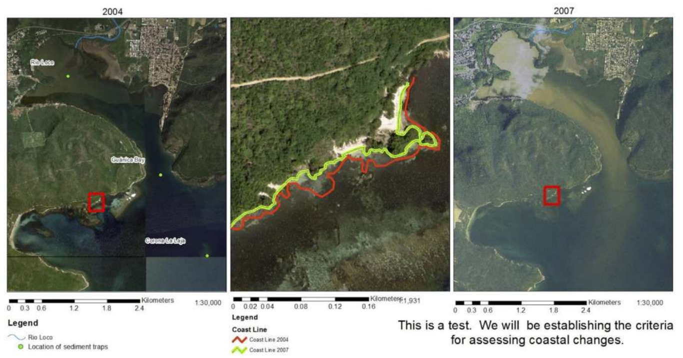



Figure 3

Figure 3 presents a test of a comparison between aerial photographs from 2004 and 2007 showing changes in Guánica Bay's coastline.

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