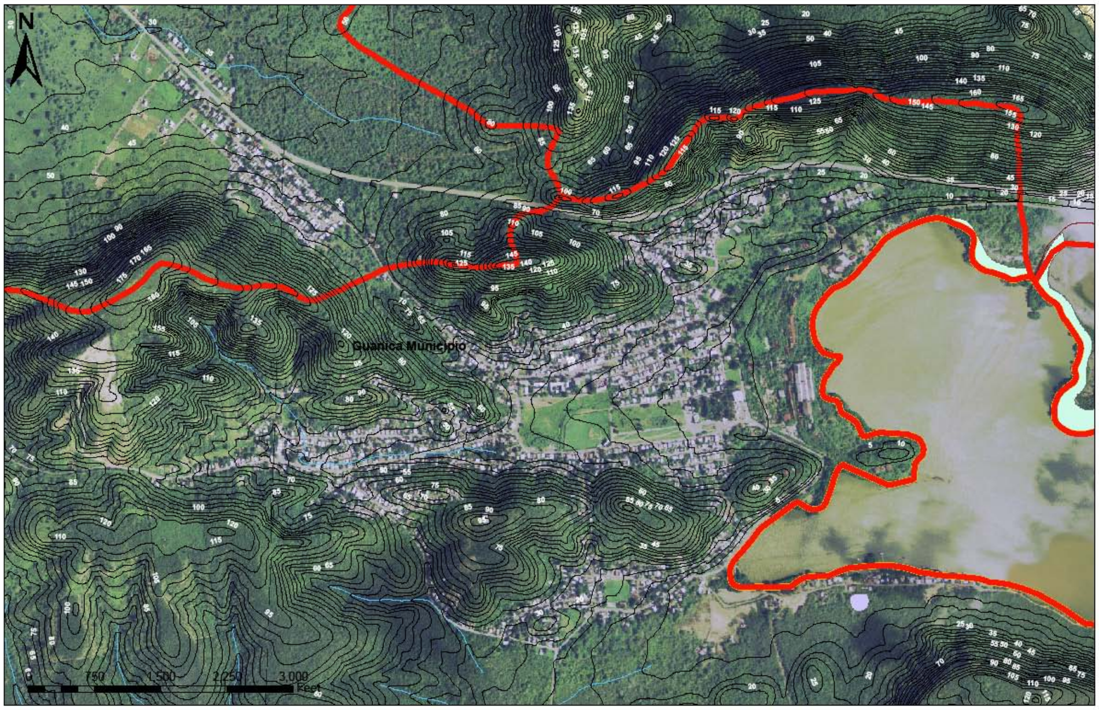
Guánica Bay Watershed Management Plan

A Pilot Project for Watershed Planning in Puerto Rico



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LIST OF ACRONYMS

BMP	Best Management Practice
CWP	Center for Watershed Protection
DRNA	Puerto Rico Department of Natural and Environmental Resources
EPA	United States Environmental Protection Agency
GIS	Geographic Information System
GSF	Guánica State Forest
GB/RL	Guánica Bay/Rio Loco Watershed
TMDL	Total Maximum Daily Load
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resource Conservation Service, USDA
PR	Puerto Rico
PRASA	Puerto Rico Aqueduct and Sewage Authority
PREPA	Puerto Rico Electric Power Authority
PREQB	Puerto Rico Environmental Quality Board
SWPR	Southwest Puerto Rico Project
UPR	University of Puerto Rico
UNESCO	United Nations Education, Scientific and Cultural Organization
USDA	United States Department of Agriculture
USGS	United States Geological Survey

PURPOSE

This report by the Center for Watershed Protection (CWP) for the Puerto Rico Department of Environmental and Natural Resources (DRNA) presents a framework for managing the Guánica Bay watershed in southwestern Puerto Rico, funded by the National Oceanic and Atmospheric Administration (NOAA) Coral Program, *NCND3000-6-00007*. CWP, various Divisions of DRNA and NOAA have worked together to identify priority management recommendations and implementation strategies for the Guánica Watershed based on a review of existing studies, input from local experts, and observations from on-the-ground assessments.

This report is the result of one week in the field, meeting with Federal government staff from NOAA, USGS, DRNA, USDA/NRCS, academicians from the University of Puerto Rico (UPR) and local farmers and residents, to better understand the historic and current land use, farming practices, water usage, waste water treatment, local political constraints, and condition of the Rio Loco and its contributing drainage area. Fieldwork included walking stream channels and visiting representative upland areas to evaluate restoration and conservation opportunities throughout the watershed.

The primary purpose of this report is to outline a comprehensive set of actions and an overall management strategy for improving and protecting the Guánica Bay watershed from nonpoint sources of pollution derived from land use alterations, and residential, commercial and agricultural uses. This watershed plan is intended to identify a set of key recommendations, specific partners and next steps towards implementation. This effort is not intended to provide hydrologic analyses, pollutant load reduction estimates, or engineering design concepts to address site-specific drainage issues. Rather, recommendations presented here address land-use and land-use change, nutrient and sediment runoff, sewage treatment, streambank stabilization, buffer improvements, and improved sediment and erosion control.

The secondary purpose of this project is to pilot a methodology for assessment and planning appropriate for local agencies to apply in other watersheds throughout Puerto Rico. NOAA and DRNA will use the project to evaluate the level of effort required to develop a relatively comprehensive watershed management plan based on existing studies, limited field observations, and informal meetings with local residents, scientists, farmers, developers, and agency staff.

THE GUANICA WATERSHED

The Guánica Bay/Rio Loco (GB/RL) watershed is located in the southwestern corner of Puerto Rico, approximately 20 miles west of the city of Ponce and 100 miles southwest of San Juan. Due to human alteration, the watershed is approximately 151 square miles and discharges to Guanica Bay near the town of Guanica. The Guanica Bay/Rio Loco watershed includes the urbanized areas of Yauco and a portion of the Lajas Valley agricultural region. The GB/RL is one of the major riverine discharge points in the southwest coast. Historically, the area was associated with some of the most pristine reefs on the island.

Figure 1. Major hydrologic components considered in the study

Figure 1: Shows the Guánica Bay watershed, which is drained to the north by the drainage basins of Lakes Yahuecas, Guayo, Prieto, Lucchetti, and Loco as a result of the Southwest Puerto Rico Project. To the south, the study area includes the drainage areas of Río Loco. Finally, the study area includes roughly half of the Lajas Valley, including historic Laguna de Guánica (Guánica Lagoon) and the Lajas Irrigation Canal within the Valle de Lajas (Lajas Valley) Agricultural Reserve. (Map from Ortiz-Zayas & Terrasa-Soler. 2001)

The Guánica Bay watershed is a highly manipulated watershed. It has been artificially increased in drainage area by a series of interbasin or inter-watershed water transfers, five reservoirs and two hydroelectric plants (Yauco 1 and 2) known as the Southwest Water Project (Figure 1). This project, operated by Puerto Rico Electric Power Authority (PREPA), was completed in order to increase and regulate potable water from the high elevation watersheds of the central cordillera (mountain region) for use by the local populations in Yauco, Guánica and the Lajas Valley for irrigation of crops and flood control. So while Guánica Bay receives water directly only by the Rio Loco ("Crazy River"), the actual total drainage area encompasses much more than just the Loco watershed. This includes the five smaller basins and associated reservoirs: Lago Yahuecas, Lago Guayo, Lago Prieto, Lago Lucchetti, and Lago Loco. Guanica Bay is essentially drained by both the Rio Loco which receives flow from the four reservoirs north and upstream of it as well as by historic Guánica lagoon, all of which we refer to here as the Guánica Bay/ Rio Loco (GB/RL) watershed. (Ortiz-Zayas & Terrasa-Soler, 2001).

Ironically, despite the large increase in contributing drainage area, the Rio Loco is usually without any base flow with the exception of intentional release of water from the Loco reservoir once every month or so (pers. comm. from local residents and farmers) and during the rainy season from August through October.

GUANICA BAY HISTORY

Juan Ponce de León landed in the Guánica harbor on August 12, 1508 and founded a town called Guaynía, a word derived from the Taíno indigenous culture that possibly meant "Here is a place with water". The town, considered the capital of the island of Puerto Rico (which was at that time named *Isla de San Juan Bautista*), was destroyed during the indigenous uprising of 1511, and the area was abandoned by Europeans for some years, during which time San Juan (itself at first called Puerto Rico) became the capital of the island. In 1898, during the Spanish-American War US Marines landed on the beach at Guanica and seized control of Puerto Rico from the Spanish. The re-founded town of Guánica was at first a part of the municipality of Yauco until Guánica was established as a separate municipality on March 13, 1914.

Guánica is often recognized for the Guánica State Forest (*Bosque Estatal de Guánica*), the 9500 acre^2 dry forest reserve east and west of the town. It is the largest remaining tract of tropical dry coastal forest in the world, and was designated an international Biosphere Reserve in 1981 by UNESCO. The reserve also acts to buffer a significant portion of the watershed from additional development and impacts of land use alteration.

Land Use and Hydrology

The Guánica watershed deviates from typical island land use due to its extensive mountainous forest cover in the north and the extensive Guánica Dry Forest in the southeast portion of the watershed. The current land use in GB/RL watershed specifically (based on natural hydrology) is 48% forested, 43% agriculture and 9% urban totaling approximately 57,000 acres as CWP delineated the watershed study area based topography and on 2004 orthophotography. The watershed area however increases by 39,883 acres with the increases from the Southwest Water Project are considered (Ortiz-Zayas & Terrasa-Soler, 2001).

Soils are over 90% Class C&D by hydrologic classification. Class C soils are defined by slow infiltration rates due to layers impeding downward movement of water, or soils with moderately fine or fine textures. Class D soils are defined by very slow infiltration rates. They are clayey, have a high water table, or are shallow to an impervious layer. These soil types contribute to high amounts of runoff being generated (STATSGO USDA, 2008).

Mean annual rainfall for Puerto Rico is 63 inches (Diaz et al., 2001), but in this watershed, the rainfall regime varies significantly with elevation from 35 inches at sea-level in Guánica Bay to 80 inches at roughly 3000 feet at the highest point in the watershed in the cordillera (Warne et al., 2005). The near shore region is urban suburban with substantial agriculture on the Lajas plateau, also known as the Lajas Valley Agricultural Reserve. The Reserve, delineated above in Figure 1, encompasses 99,656 acres, 19,665 acres of which receive water from Lago Loco via the Lajas Canal for irrigation. This makes agriculture viable during the dry season (> 4 inches of rain per month), which lasts from December to June.

The watershed historically experienced high levels of deforestation during sugar cane cultivation on the majority of arable land in the watershed. In the 1950s, the Southwest Water Project greatly increased the headwater land area draining to the Rio Loco including significant amounts of highly erodible soils where the majority of coffee growing areas are located. The ditching and draining of Guánica Lagoon, a large historical lagoon and adjacent wetland system, in the 1950s had a profound effect on the filtering capacity in the watershed because the lagoon acted as a huge sponge / filter before Rio Loco passed into the Guánica Bay. Sediment transport in the watershed is exacerbated by the steep slopes, high mean annual rainfall, regular hurricanes and tropical storms every 10-20 years (Scatena and Larsen. 1991). A high proportion of labile minerals in the Cretaceous volcaniclastic and intrusive rocks of the Cordillera Central result in landslides and debris flows especially in areas which have been disturbed by human activity (Warne et al., 2005).

Historic land clearing, agriculture, poor erosion practices and attenuation of that sediment in the valley behind the historic Guanica Lagoon have resulted in large amounts of sediment deposition (20ft thick in some areas as seen in Figure 5) in the Rio Loco valley between Yauco and Ciénaga just above Guánica. This area currently serves as a location for fruit and vegetable agriculture. Further detail on agriculture in Puerto Rico and in RL/GB watershed in particular can be found in Appendix I. Clark and Wilcock 2000 found that between 1830 and 1950 runoff increased by approximately 50% and sediment supply to the river channels increased by more than an order of magnitude after much of northeastern Puerto Rico was cleared for agriculture. A similar historical process also occurred in southwest Puerto Rico since the end of the 19th century (Warne et al., 2005).

Warne et al. (2005) in their comprehensive study of rivers and their potential influence on coral reefs in Puerto Rico added that the irrigation project managed by Puerto Rico Aqueduct and Sewer Authority (PRASA) has greatly expanded the total watershed area of Guánica Bay and the Rio Loco and likely increased the supply of fine clay sediment and nutrients to the Guánica Bay and neighboring coral reefs. The reservoir impoundment on the Rio Loco has greatly reduced base flow in the Rio Loco watershed, while ditching of stream channels and the Guánica lagoon has resulted in a significant loss of attenuation/filtering ability of the watershed. The cumulative effect of these issues over the last 40–50 years is a steady decline in near shore reef quality (Warne et. al., 2005). Warne et al., 2005 classified the coral reefs of Guánica as currently in "poor" condition with exceptional vulnerability to river discharge, industry, resuspension, agriculture and dredging. Further detail on the status of reefs in Puerto Rico have been summarized in Appendix II.

Literature Reviewed on Guanica Bay/Rio Loco watershed

A number of key documents specific to the Guanica Bay/ Rio Loco watershed were reviewed and served as important resources in our analysis. A brief description is provided in Table 1 for each of the studies and how the documents were incorporated into the analysis for the watershed plan.

Table 1. Primary Literature on GB/RL Reviewed

Study	Description	How Incorporated
Ortiz-Zayas & Terrasa-Soler 2001. Allocating water resources for public supply within a complex hydroelectric system: the case study of Yauco, Puerto Rico. Weftec Latin America.	In this study, the complex arrangement for water management for irrigation, drinking, fish habitat, recreation, electricity generation and aquifer regeneration in Southwest PR is overviewed. The average (Q50) and safe yields (Q99) of the Southwest Project were determined based on empirical operational data. The computed water yields were compared with existing and future consumptive and non-consumptive water demands. A water allocation proposal, consistent with the current water use public policy in Puerto Rico is presented to improve the Yauco potable water system. A water allocation study was conducted for Yauco, Puerto Rico.	This document helps summarize the complex water use regime in effect in Southwest PR.
Soler-Lopez, 2000 US Geological Survey. 2000. Preliminary bathymetric study of Lago Lucchetti and Lago Loco in Yauco Puerto Rico during March 2000.	This study helps confirm the loss of storage capacity of the reservoirs in the study area.	Added technical data on the losses in storage capacity in the reservoirs and drainage areas to the reservoirs
Greg L. Morris and Associates. 1999. Guánica Lagoon Hydrology and Restoration Alternatives.	This report was funded by US EPA and in tandem with the report mentioned below, also by Greg L. Morris and Associates. Its analyzes technical issues related to restoration of water levels in Guánica lagoon including water levels, water budget and quality, groundwater, sedimentation, vegetation, water control	This document and its sister document provide technical analysis which supports recreation of Guánica lagoon and helps demonstrate political precedent for recreation

Table 1. Primary Literature on GB/RL Reviewed		
Study	Description	How Incorporated
	structures, and recommendations for project design, implementation and management for both the lagoon itself and the freshwater marsh known as "El Anegado". Both reports were prepared based on previously published reports and data and unpublished hydrologic data, field visits and interviews as well as modeling, surveying and by DRNA in 1998.	of this natural system.
Greg L. Morris and Associates. 1999. Hydrologic and Hydraulic Analysis: Guánica Lagoon Restoration Impacts on Regulatory [Controlled] Flood Levels	This study analyzes controlled flooding conditions in the Laguna Guánica area to determine the impact of changed lagoon water levels and of flood control structures on controlled flood levels in Lajas Valley and along Rio Loco into which the Laguna Guánica drains.	This document and its sister document provide technical analysis which supports recreation of Guánica lagoon and helps demonstrate political precedent for recreation of this natural system.

CRITICAL ISSUES AND PRIORITY POLLUTANTS IN GUÁNICA BAY / RIO LOCO WATERSHED

A list of priority pollutants, their impacts and the potential sources within the GB/RL watershed were identified and presented in Table 2.

Table 2. Priority Pollutants in the Guánica Bay / Rio Loco Watershed		
Pollutant	Impacts	Sources
Nitrogen	Eutrophication, algae growth, enrichment beyond tolerance of coral reefs.	Wastewater, fertilizers, stormwater runoff, atmospheric deposition (Ortiz-Zayas, 2001; Lapointe 1997)
Sediment	Deposition on reefs, effects on sediment intolerant reef organisms, sediment particles leading to water temperature warming, pollutants attached to sediment particles.	Soil erosion, channel erosion, poor erosion and sediment control practices, African dust (Warne et. al., 2005)
Bacteria	Health related illnesses due to water contact, swimming, beach closures, source of pathogens that effect coral reefs	Untreated wastewater, sewage overflows, stormwater runoff, pet waste, animal waste, wildlife (Schueler, 1999) (Centers for Disease control, 2008) (Henrickson et al., 2001)
PAHs	Toxicity to coral reefs	Stormwater runoff of automobile related contaminants, boat engine discharge particularly 2-stroke engines (NOAA, 2007)
DDT, PCBs	Toxicity to coral reefs	Legacy contaminants, erosion of legacy sediments (NOAA, 2007)

A number of critical issues were identified in the GB/RL watershed related to the impact of land based sources of pollutants on the near shore coral reefs in the areas surrounding the Guanica Bay. These include:

1. Upland erosion in the coffee growing regions;
2. Reservoir sedimentation and transport;
3. In-stream channel erosion;
4. Loss of Historic Guánica Lagoon;
5. Legacy contaminants;
6. Sewage treatment.

Each of these issues is expanded upon below.

1. Upland erosion in the coffee growing regions;

Loss of highly erodible soils on steep slopes is clearly a major issue in the Guánica Bay / Rio Loco watershed based on GIS analysis, field investigations and data on sediment accumulation in the reservoirs. GIS analysis was used to target the locations of Highly Erodible Lands (HEL) and agriculture, particularly sun grown coffee and other crops being grown at high elevations, and roads and homes on or adjacent to steep slopes. These areas were visited during the field investigations which are summarized in the following description. Based on the soil layer, these highly erodible lands were estimated to compose the majority of the high mountain land areas being used for agriculture in the Lago Lucchetti and Lago Loco drainage areas.

Field investigations in the high elevation agricultural areas near reservoir ("Lago") Lucchetti and the Rio Loco watersheds revealed clearing for coffee and other agricultural crops, including bananas, with very little evidence of conservation practices. Mass clearing, poor soils (Humatas Clay) and runoff associated with roads has resulted in numerous areas with completely exposed soils with very limited natural re-vegetation due to the high clay content and low fertility of the soils. Promotion of sun grown coffee over historically grown shade grown coffee at the very least accelerates sediment transport during the crop establishment phase. There is an estimated 3.5 times more erosion associated with sun grown coffee than shade grown coffee over the first several years after establishment (Hartemink, 2006).

Figure 2. Typical clearing associated with sun grown coffee plantations

As far as back as 1955, H.G. Wilm in a publication by the United Nations Food and Agriculture Organization noted the role of coffee cultivation in soil loss; "… the most serious erosion per acre came from clean-cultivated lands." At the time of the Wilm's survey these occupied only 3 percent of the watershed, but produced 23 percent of the soil loss. Coffee lands, occupying 26 percent of the area, produced 40 percent of the loss. Noll [1953] suggests that this erosion can be greatly reduced by maintaining the vegetative cover underneath the coffee trees." In the Guanica Bay /RioLoco watershed, we identified many small plots of clean cleared cultivated lands as well as many areas where sun grown coffee was grown without any ground cover. Warne et al., 2005 estimate mean annual suspended sediment discharge to coastal waters (from period of 1990-2000) to be 1000 to 4300 metric tons per square kilometer for the southern region of the island which includes Rio Loco. The export of suspended sediment discharge are some of the highest in Puerto Rico and reflect the upland exposed sediments in areas receiving very high rainfall over 80 inches (200cm) a year and channel erosion based on our field analysis occurring primarily in the Rio Loco between Yauco (just above Rt. 2) and Cienega.

2. Reservoir sedimentation and transport

A review of orthophotography with DRNA biologists at Guanica forest reserve clearly showed that sediment was passing through the Rio Loco Reservoir (Figure 3) through the watershed and into Guánica Bay. Even closer inspection revealed at least some of the sediment laden water was being discharged from the pump/flow house draining from Lucchetti Reservoir into Loco (Figure 4). The reddish clay colored water was clearly visible in the Rio Loco below the dam and extending down to the Guánica Bay and out to the near shore coral reefs.

Figure 3. Snapshot of sediment accumulation and flow through Loco Reservoir.

Sediment accumulation of fine clay soils in Lago Lucchetti and Lago Loco were observed in the field and verified in the literature in studies made by USGS and CSA Group in coordination with University of Puerto Rico (Soler-Lopez, 2000; Ortiz-Zayas & Terrasa-Soler, 2001). Clearing for coffee, tree crops and construction as well as exposed soils associated with historical road cuts were observed during a visual tour of the Loco and Lucchetti watersheds in April of 2008. This small area of the largely forested watershed represents the majority of land disturbance in the watershed, as verified in GIS, the accelerated transport of these highly erodible soils is due to the steep slopes and the high annual rainfall.

Hurricanes in combination with current and historic crop production, particularly the cultivation of sun-grown coffee using poor soil stabilization practices have resulted in significant sediment transport. These soils are particularly vulnerable after forest clearing and during coffee crop establishment where significant soil exposure and loss and resulting premature sedimentation of the Lucchetti and Loco reservoirs as indicated by a 2000 study by CSA Group (Ortiz-Zayas & Terrasa-Soler, 2001). Note that Lucchetti and Loco reservoirs have lost 42% and 64% of their original capacity, respectively due to sedimentation (USGS 2000).

Lucchetti also appears to be discharging fine sediment from its intake pipe to Loco Reservoir because the pipe invert is estimated to be at the same elevation or below the estimated current reservoir bottom due to sedimentation as was predicted by Ortiz-Zayas & Terrasa-Soler (2001).

GIS orthophotography zoomed in on the pump house into Loco Reservoir confirms the likelihood of this occurrence (Figure 4). Table 3 shows the extent of storage volume losses in the reservoirs in the RL/GB watershed and Appendix III reviews aerial photos of the sediment accumulation in the five reservoirs and presents the photos in order of upstream to downstream.

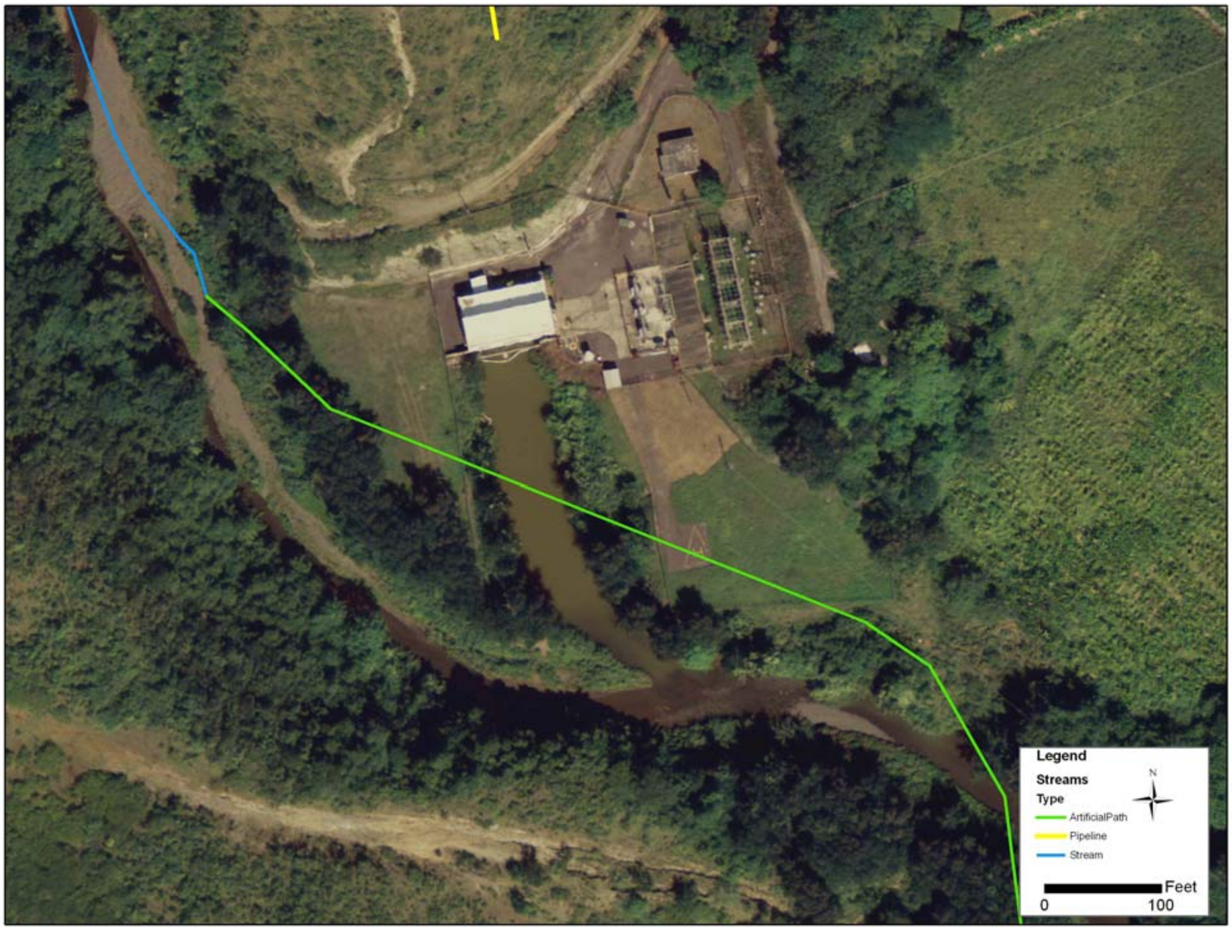


Figure 4. Fine sediment flow from the pumphouse from the Lucchetti Reservoir into the Loco Reservoir.

Table 3. Reservoir Sedimentation history in RL/GB watershed (from Soler-Lopez,2001)

Reservoir	Original capacity, in Mm3	Const. year	Study year	Storage capacity, in Mm3	Total vol. loss,Mm3	Long-term volume loss, in m3/yr	Loss in percent	Drainage area, in km2	Surface area, in km2	Deposition rate, in cm/yr	Sediment yield, in m3/km2/yr
Guayo	19.2	1956	1997	16.57	2.63	64,146	14	24.86	1.09	5.9	532
Loco	2.4	1951	2000	0.87	1.53	31,224	**64**	21.76	0.29	10.8	1,774
Lucchetti	20.35	1952	2000	11.88	8.47	176,458	**42**	44.81	1.11	15.9	4,102
Prieto	0.76	1955	1997	0.22	0.54	12,857	**71**	24.8	0.06	21.4	900
Yahuecas	1.76	1956	1997	0.33	1.43	34,878	**81**	45.17	0.22	15.8	1,430

3. In-stream channel erosion

Figure 5. Channel erosion in the Rio Loco due in part to old irrigation infrastructure, invasive species and the loss of Guánica Lagoon. The picture on the lower right shows the potential role of trees in this ecosystem to help to fortify streambanks and reduce erosion

Channel erosion on the mainstem of Rio Loco was clearly another major issue in the watershed as documented in the stream channel assessments. Severe erosion was associated with areas that lacked mature riparian trees, particularly those areas that contained non-native species that seemed to exacerbate erosion as well as areas with historic irrigation infrastructure which created downstream scour (Figure 5). These low head dams, concrete footers, and other structures continue to act as strainers and constrictions in the channel causing debris to become lodged and changes in erosive forces to destabilize banks, increasing channel erosion, bed scour and sediment transport. Both Warne et. al. (2004) and Clark and Wilcox (2000) noted the continued importance of transport of historically deposited valley sediments and its likely impact on coral reef systems.

Projects working with individual farms to remove old irrigation infrastructure and re-grade streambanks while planting native species of trees to promote bank stability are key components of a restoration strategy for this area of the Rio Loco between Yauco and the Ciénaga.

Demonstration projects with willing farmers have a high probability for implementation and are critical first steps to demonstrate the benefits to other farmers. These shorter term demonstration projects can lead to a more comprehensive program to improve stream stability and buffers in this area of the watershed. Farmers that participated in the field tour were interested in restoration of these areas because they were losing farmland due to the excessive erosion.

Stream channels investigated in the upper portions of the watershed and within Yauco were evaluated as being relatively stable and appeared in many instances to be transport reaches rather than sediment supply reaches. The primary reason for this is that the land use having been returned to a large degree to forest from farming has reduced water supply and runoff coefficients in these areas. Many streams appeared to be "healing" after past land use abuses.

Figure 6. Left: Rio Loco river culvert, completely dry in April 2008; Right: Example of typical land clearing in upper watershed for coffee cultivation, without soil stabilization.

Figure 7. Lajas Valley Canal irrigation channel. Note: canal surface water immediately around outfall draining agricultural and pasture fields is replete with aquatic vegetation.

4. Loss of Historic Guánica Lagoon

The Guánica lagoon was a natural freshwater wetland and lagoon system drained in 1955 as part of an agricultural development project in the Valle de Lajas. Figure 7 shows some of the ditching efforts that were used to drain the lagoon. Prior to its drainage, the lagoon consisted of Laguna Guánica (a shallow coastal lagoon) and Ciénaga (marsh) El Anegado, a freshwater herbaceous marsh dominated by *Typha dominguensis.* Ciénaga El Anegado was located about 2.7 km west of the western shoreline of Guánica lagoon. (Ortiz-Zayas & Terrasa-Soler, 2001)

Historically, Guánica Lagoon served as a sink for nutrients sediment and other contaminants (Warne et. al., 2005). Its detention time, a key factor in water quality benefits of wetland systems, was estimated at over 1 year, providing ample time for attenuation, settling and processing of nutrients sediment and other contaminants. Even with almost complete historical deforestation of the watershed and heavy production of sugar cane and tobacco – the near shore reefs remained in excellent condition until the loss of Guánica Lagoon in the 1950's which marked a steady decline in the near shore reefs (Morelock, 2001). The effect of land based pollution and sedimentation on reefs is well documented in the literature as mentioned above and the loss of the Lagoon greatly reduced the detention time and water quality benefit of the Lagoon likely resulting in accelerated reef decline.

There is a proposed plan to restore historic Guánica Lagoon in Barrio Arenas of Guánica. The DRNA commissioned a study to evaluate the feasibility of restoring the Lagoon to reclaim its value as a wildlife refuge and ecological resource. Figure 8 shows the adjacent Lajas valley and some of the area that was originally part of the lagoon, the majority of which is actively being used for agriculture anymore. Greg L. Morris & Associates was contracted by DRNA to conduct a hydrologic and hydraulic study of the lagoon. The resulting reports are entitled: "*Hydrologic and Hydraulic Analysis: Guánica Lagoon Restoration Impacts on Regulatory Flood Levels*" and "*Guánica Lagoon Hydrology & Restoration Alternatives*" were both prepared in 1999. Three alternative scenarios were evaluated and from the perspective of the authors and the scenario that reconnects the historical Rio Loco watershed and floodplain with Guanica Lagoon is estimated to have the greatest benefit to water quality and habitat improvement and therefore is most critical to future improvements in the reefs.

Figure 8. Section of the Lajas valley (left); Historic Guánica lagoon in the distance (right).

5. Legacy Contaminants

NOAA has studied several points within Guánica Bay and the nearby coral reefs as part of its Assessment of Chemical Contaminants in the Marine Sediments of Southwestern Puerto Rico, National Status and Trends Program for Marine Environmental Quality (Pait et al., 2007). Relatively high concentrations of PAHs were found in the sediment samples in Guánica Bay in particular. According to a fingerprinting analysis, PAHs were linked primarily to automobile related sources. This tracks with the findings on significant urban areas of Yauco and Guánica that represent a significant amount of impervious surfaces that convey untreated stormwater to the Rio Loco and Guánica Bay respectively. Particularly of concern are roads and parking lots where PAHs are deposited and runoff during rain events. These pollutants have very little chance for attenuation or remediation due to the flashy nature of the Rio Loco and the loss of Guánica Lagoon which would have attenuated and remediated a great deal of the runoff from Yauco, but not from downtown Guánica which is adjacent to and drains into Guánica Bay.

Also found during the NOAA assessment were elevated levels of PCBs and DDT, likely legacy contaminants from historic industrial and agricultural land uses. Both pollutants could also be deposited in legacy sediments of the Rio Loco – specifically in the reach between Yauco and Guánica. This area is undergoing severe bank erosion in many areas and may be continuing to export historically deposited sediments contaminated with PCB and DDT. Further investigation and streambank soil sampling and aging is suggested to confirm or deny this hypothesis in the Rio Loco.

6. Sewage Treatment/ Urbanization

The historic aerial photographs of near shore Guánica Bay in Figure 9 demonstrate increases in near-bay urbanization, particularly after 1950. This urbanization has two primary effects on the near shore coastal system; an increase in population and an increase in impervious cover and generation of stormwater. The increase in population results in more sewage being generated and discharged to the near shore coastal environment and increases in impervious cover result in increases in loading of nutrients, bacteria and sediments as well as PAHs, heavy metals and other pollutants associated with vehicle travel.

Sewage treatment in Puerto Rico has historically consisted of primary treatment discharged to the ocean and secondary treatment discharged to rivers and other smaller water bodies (Ortiz-Zayas, 2006). Much of rural population in Puerto Rico has relied upon septic systems or other on-site practices. More recently in the last ten years or so with changes to EPA regulations, there has been a move toward connecting rural communities to central sewer and upgrading sewage treatment plants to secondary treatment.

Unfortunately, secondary treatment only provides for minimal nutrient reduction and tropical coastal systems, particularly coral reefs are more sensitive to nutrient enrichment than other coastal systems. Past research by Lapointe (1997) suggests that a critical threshold for nitrogen may be 14 parts per billion (ppb) whereas primary and secondary treated sewage is between

30,000 and 40,000 ppb comparison, or approximately 20,000 times the safe limit for coral systems. Pristine ocean waters are typically around 1 ppb.

Figure 9: Aerial photographs of Guánica Bay and the near shore area taken in 1936 (top left), in 1950 (top right) in 1987 (bottom left) and again in 1996 (bottom right). Notice the significant increase in urbanization along northeastern shore nearer to mouth of the Bay sometime after 1950.

Two treatment plants (shown in Figure 10) are located in tidal areas in the watershed. A summary of their capacity and return flow are located in Table 4. Guánica Sewage Treatment Plant (STP) which currently receives 460,000 gallons per day from Guánica proper and but is capable of accepting 750,000 gallons per day for secondary treatment (Guanica STP operators personal communication, 2007). This same treatment plant has been recently upgraded with three additional treatment tanks with a total additional capacity of 2 million gallon per day of secondary-advanced treatment as part of additional proposed development in Guánica. The second much smaller treatment plant is located at Cana Gorda Beach and handles about 3000 gallons per day but has a treatment regime dictated by use of the public beach and associated facilities which is of course seasonal.


Figure 10. Small 3000 gpd sewage treatment plant at Cana Gorda Beach (left), one750,000 gallon treatment tank within Guánica waste water treatment plant.

Table 4. Sewage treatment plants (STPs) in Guanica Bay tidal areas (USGS, 2005 and Guanica STP operators CWP personal communication, 2007)		
Facility Name	**Maximum Capacity**	**Average Return Flow**
Guanica STP	0.8 mgd (being upgraded to 2 mgd)	0.58 mgd (460,000 gal/day)
Cana Gorda Beach STP	0.5 mgd	0.04 mgd (3,000 gal/day)
(parenthesis represents information gathered in meeting with Guanica STP operators)		

Many smaller existing developments located directly in coastal tidal areas utilize septic systems including development near the Guánica Forest and Cana Gorda Beach. These parcels represent a limited number but are likely almost a direct input of nutrients into coastal waters due to discharging to groundwater that is likely hydrologically connected to adjacent tidal water. Upgrading these systems to denitrifying systems may help reduce nutrient inputs in these sensitive areas close to coral reefs and important recreational areas.

Ironically, efforts to connect rural areas often far away from tidal waters with wastewater treatment, in lieu of local septic systems may actually increase the nitrogen transport/yield to near shore coastal waters rather than attenuate the nitrogen load. This is due to the efficient transport of sewage in pipes to treatment plants, often located on the coast, such as the Guanica STP where nitrogen is released much closer to sensitive coral systems. This phenomenon is particularly true in tropical climates where small streams affected by on-site septic systems are effective at processing nitrogen (Ortiz-Zayas, 2006).

Smaller package plants have been used in the Guánica Bay area watershed to treat sewage from resorts and beaches. However, there is likely very little treatment / reduction of nitrogen in these systems as they are akin to secondary treatment. They also discharge to groundwater in most cases and in the case of Cana Gorda discharge to groundwater within 30 feet of the tidal shoreline.

In order to reduce nitrogen concentrations, biological conditions for denitrification have to be created and fostered. Evaporation used in some of the sewage treatment efforts in Puerto Rico does not result in denitrification. Constructed wetlands and "living machine" wetland systems where anoxic denitrification processes can take place in the organic matter are effective at reducing nitrogen (Kangas, 2004). Wetlands or "living machines", in series, can be used to provide greater levels of denitrification and nitrogen uptake in each successive treatment cell (Todd and Todd, 1994). Such a system would be relatively easy to maintain in a tropical environment where temperature and climate are optimal for denitrifying systems. The lack of rainfall in Guánica and on the coast the majority of the year should assist with making the construction, maintenance and operations of these systems easier and more cost effective. Great growing conditions year round for wetlands and the lack of rainfall ensure good residence time in the wetlands, critical for nitrogen, sediment and pathogen removal.

MANAGEMENT RECOMMENDATIONS

A series of recommendations have been made to reduce the impact of land based sources of pollution on the near shore coastal environmental to Guánica Bay and the Rio Loco. The recommendations are intended to reduce the flow of nutrients, sediment and other contaminants. Appendix IV provides some of the output of a run using the Watershed Treatment Model (WTM) to determine existing sources of pollutants. For each recommendation we have provided a rationale, expected costs, potential partners and the location in the watershed.

Table 5. Implementation Recommendations for Guánica Bay/ Rio Loco watershed

Recommendation	Rationale	Cost	Partners	Location
#1Rio Loco streambank riparian plantings and removal of historical irrigation infrastructure (likely have a willing farmer and existing USDA programs for funding)	Farmers are losing land and excess nutrient rich sediment and topsoil is being exported to the Guánica Bay and reefs	$50k-100k depending on length	USDA, NOAA, DRNA	Demo area that was visited on farm tour just downstream of Yauco before Rio Loco crosses under Rt. 116
#2 Demonstration project where sewage effluent is treated in a series of treatment wetlands or living machine to reduce nitrogen export (2nd most important recommendation after Restoration of the Guánica Lagoon)	Nutrients particularly nitrogen are not significantly removed in a primary or secondary treatment system – a treatment wetland would result in increased denitrification of sewage effluent	$50-100k	UPR, PRASA, NOAA	Guánica STP, Cana Gorda STP
#3 Hydroseeding of areas with bare soil associated with roads or clearing of home sites in high elevation erodible soil areas	Sediment loss of highly erodible clay is filling reservoirs and remaining in suspension and reaching Guánica Bay	$20-30k	USFWS, USDA, Ag Consultants	High elevation areas in Loco and Lucchetti

Table 5. Implementation Recommendations for Guánica Bay/ Rio Loco watershed				
Recommendation	**Rationale**	**Cost**	**Partners**	**Location**
	and reefs			
#4 Cover crop outreach and cost share to high elevation coffee farms	Sediment loss of highly erodible clay is filling reservoirs and remaining in suspension and reaching Guánica Bay and reefs	$30k	USFWS, USDA, Ag Consultants	High elevation areas in Loco and Lucchetti
#5 Restoration of Guánica Lagoon to restore sediment and nutrient assimilative capacity and wildlife habitat (single most important recommendation – but perhaps most challenging)	Guánica lagoon historically served as a large treatment wetland for upland pollution and sediment – sediment transport has likely declined from upland areas due to reforestation but there is no attenuation due to the loss of the lagoon	$1 mil+	NOAA, USDA, DRNA, USFWS	Lower Loco
#6. Reef education/ experiential learning – taking youth and their parents to experience and learn about the coral reefs and their importance to fisheries, ecological health and the economy	According to statistics from most coral reef areas - very few members of the local community have actually experienced the near shore coral reef system	$50,000	DRNA, local dive and snorkel operators, Local school system	Guánica, Yauco and upper watershed
#7. Hold meeting to discuss and explore possibility of slower releases for a longer duration from Rio Loco and other methods of reducing sediment transport through Lagos Loco and Lucchetti reservoirs	Current short duration / high intensity releases appear to re-suspend sediments and create channel erosion	No cost	DRNA, PRASA	Upper Watershed
#8. Work with DRNA and PRASA to explore sustained release from Lago Loco for minimum baseflow to sustain aquatic habitat to help process nutrients in Rio Loco.	Rio Loco is currently devoid of any benthic or aquatic biota which could help process nutrients both because there is no baseflow and because of severe channel erosion during periodic high flow events.	Minimal Cost	USFWS, PRASA, DRNA, USDA, PREPA	Rio Loco
#9. Evaluate phasing out	Sun grown coffee and	Minimal Cost	USDA-	Upper

Table 5. Implementation Recommendations for Guánica Bay/ Rio Loco watershed				
Recommendation	**Rationale**	**Cost**	**Partners**	**Location**
subsidy for sun grown coffee or providing an equal subsidy for shade grown coffee	associated clearing on steep, highly erodible clay soils creates excessive amounts of erosion that fill the reservoirs and then are transported to Guánica Bay and the near shore coral reefs		NRCS, USFWS, NOAA	Watershed / Puerto Rico
#10. Discuss with PRASA* plans for dredging of reservoirs that are filled beyond their capacity **	Most of the reservoirs – particularly the ones critical for sediment transport are filled to functional capacity	Expensive	PRASA, DRNA, PREPA	Upper Watershed
#11. Pet waste cleanup education and ordinance in coastal cities such as Guanica to reduce transport of nutrients and pathogens in stormwater runoff	Widespread problem which includes a large population of stray dogs in the coastal town of Guanica – the highly impervious nature of the City and the frequency of fecal matter	Inexpensive	DRNA, Guanica, NOAA	Guanica,
#12. Rainwater collection systems in Guánica and Yauco particularly in new development	Reduce the pressure on a finite resource that is water	Policy change / Homeowner Cost (Maybe a cost per system)	Town of Yauco and Guánica, DRNA	Developed areas
*PRASA Puerto Rico Aqueduct and Sewer Authority, UPR- University of Puerto Rico ** Dredging the reservoirs should be conditional on adequate upstream controls to control erosion sources				

Recommendations for Further Information Gathering and Monitoring

- Monitoring of nutrient concentrations flowing into the Guánica Lagoon 3-6 months during the dry season to establish typical loads transported to historic Lagoon area. Monitoring during the rainy season (August – October), when the majority of sediment transport takes place. This will help to determine discharge – sediment transport relationships.
- Sediment movement in streams in the upper Loco watershed : This would involve physical observation and deployment of rising stage samplers during storm events during the wet season to identify key catchments serving as sediment sources.
- Water release schedule from Lago Loco – Determine the existing schedule of releases and flow rates. The CSA paper identifies flow rates that would be sustainable for the various end users. Scenarios evaluated included ample flow for Guanica Lagoon that would be sustainable 99% of the time even under drought conditions (Ortiz-Zayas & Terrasa-Soler, 2001).

- Determine if there is an option to take water from Lucchetti closer to the surface of the lake to minimize sediment movement; and/or to evaluate options to sediment transport though the reservoirs such as drawing down Loco and Lucchetti before the rainy season.
- Sample analysis of nighttime flows in the town of Guánica where residents have reported flows that might contain significant amounts of nutrients from either stormwater or sewage. Also, any flow or outfalls from the fertilizer plant in Guanica should also be evaluated.
- Evaluate the concentration of contaminants like PCBs and DDT in valley legacy sediment areas to determine if channel erosion is continuing to liberate these pollutants into the Guanica Bay. This would involve sampling bank sediment for PCB and DDT and age-dating sediments in bank soil horizons within the deposited valley sediments between Rt. 2 and Cienaga.
- Determine if erosion and sediment control (ESC) regulations are enforced in the watershed particularly in new construction around Yauco. Yauco should have an EPA Phase II NPDES ESC mandate and population appears to be increasing. In general any future development that may occur near Guanica should require erosion and sediment control to limit impacts on the reefs. In most areas of Puerto Rico, we found very little evidence of erosion and sediment control practices being implemented and corresponding very poor enforcement.
- Calculation of the percentage of highly erodible soils particularly humatas clay in the five reservoir areas that are part of the Southwest Project and identification where the majority of the soil exposure and coffee plantations leading to high sediment transport rates are located – so that outreach efforts for cover crops and other erosion control methods can be better targeted.
- Determine feasibility of providing treatment for stormwater runoff from the town of Guanica particularly the outfalls that discharge directly into the Bay.

REFERENCES

Acevedo, Roberto, Morelock, Jack, and Olivieri, R.A., 1989, Modification of coral reef zonation by terrigenous sediment stress: Palaios, v. 4, p. 92-100.

Centers for Disease Control, 2008. Website accessed 8/30/08. http://www.cdc.gov/ncidod/dbmd/diseaseinfo/etec_g.htm

Clark, J.J., and Wilcock, P.R., 2000, Effects of land use change on channel morphology in northeastern Puerto Rico: Geological Society of America Bulletin, v. 112, p. 1763-1777.

CWP, 2007. Personal communication with Guanica STP operators. Visit August 2007.

Díaz, P.L., Aquino, Zaida, Figueroa-Alamo, Carlos, Vachier, R.J., and Sánchez, A.V., 2001, Water resources data Puerto Rico and the U.S. Virgin Islands water year 2000: U.S. Geological Survey Water-Data Report PR-00-1, 678 p.

Goenaga, Carlos, and Cintrón, G., 1979, Inventory of the Puerto Rican Coral Reefs: Puerto Rico Department of Natural Resources (prepared for the Office of Coastal Zone Management, National Oceanic and Atmospheric Administration), 190 p.

Hartemink, A.E. 2006. Assessing soil fertility decline in the tropics using soil chemical data. Advances in Agronomy 89: 179-225.

Henrickson et al., 2001. Marine Swimming-Related Illness: Implications for Monitoring and Environmental Policy. Environmental Health Perspectives.

Hourigan et al;, 2007. State of deep coral ecosystems of the united states: introduction and national overview. NOAA Technical Memorandum Crcp – 3. Silver Spring MD.

Kangas, P. 2004. Ecological Engineering: Principles and Practices. CRC Press. Boca Raton, FL.

Lapointe, B.E. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. Limnology and Oceanography, 42:119-1131.

Larsen, M.C., 2000, Analysis of 20th century rainfall and streamflow to characterize drought and water resources in Puerto Rico: Physical Geography, v. 21, no. 6, p. 494-521.

Larsen, M.C., and Santiago-Román, Abigail, 2001, Mass wasting and sediment storage in a small montane watershed: an extreme case of anthropogenic disturbance in the humid tropics, in Dorava, J.M., Fitzpatrick, F., Palcsak, B.B., and Montgomery, D.R., eds, Geomorphic processes and riverine habitat: American Geophysical Union Monograph, p. 142-170.

Lutz S.J & R.N. Ginsburg. 2007. State of Deep Coral Ecosystems in the Caribbean Region: Puerto Rico and The U.S. Virgin Islands. NOAA Technical Memorandum Crcp – 3. Silver Spring MD.

Morelock, Jack, Grove, K.A., and Schwartz, M.L., 1983, Oceanography and patterns of shelf sediments Mayagüez, Puerto Rico: Journal of Sedimentary Petrology, v. 53, no. 2, p. 371-381.

Morelock, Jack, Grove, K.A., and Trumbell, J.V.A., 1980, Sediments and recent geological history of the Guayanilla submarine canyon system, Puerto Rico: 9o Conferencia Geologica del Caribe, Santo Domingo, Dominican Republic, v. 1, p. 129-138.

Morelock, Jack, Hernández-Avila, Manuel, Schwartz, M.L., and Hatfield, D.M., 1985, Net shore-drift on the north coast of Puerto Rico: Shore and Beach, v. 53, p. 16-21.

NOAA. 200). An Assessment of Chemical Contaminants in the Marine Sediments of Southwest Puerto Rico.

NOAA. 2007. Benthic Habitat Characterization and Bathymetry of Mid-water Habitats in the USVI and Puerto Rico (2007). Project on-line prospectus, accessed July 2007. Silver Spring, MD.

NOAA. 2008. Coral Reef Conservation Program, Roadmap for the Future. A Plan for Developing CRCP Direction Through 2015. Silver Spring, MD.

Noll, John J. 1953. The silting of Caonillas Reservoir, Puerto Rico. Soil Conservation Service, U. S. Dept. of Agric. Tech. Paper 119, pp. mimeo, illus.

Ortiz-Zayas & Terrasa-Soler. 2001. Allocating water resources for public supply within a complex hydroelectric system: the case study of Yauco, Puerto Rico. WEFTEC Latin America.

Pait, A.S., D.R. Whitall, C.F.G. Jeffrey, C. Caldow, A.L. Mason, J.D. Christensen, Mark E. Monaco, and J. Ramirez. 2007. An Assessment of Chemical Contaminants in the Marine Sediments of Southwest Puerto Rico. NOS NCCOS 52. Silver Spring, MD. NOAA/NOS/Center for Coastal Monitoring and Assessment. 116pp. National Status and Trends Program for Marine Environmental Quality

Scatena, F.N., & Larsen, M.C., 1991, Physical aspects of Hurricane Hugo in Puerto Rico: Biotropica, v. 23(4a), p. 317-323.

Schueler, T. 1999. Managing Watersheds for Pure Drinking Water. Center for Watershed Protection. Ellicott City, MD.

Soler-López, L.R., 2000 Sedimentation Survey of Lago Loco, Puerto Rico, March 2000. US Geological Survey In cooperation with the Puerto Rico Electric Power Authority.

Soler-López, L.R., 2001, Sedimentation survey results of the principal water supply reservoirs of Puerto Rico; in W.F. Sylva (ed.), Proceedings of the Sixth Caribbean Islands Water Resources Congress, Mayagüez, Puerto Rico, February 22 and 23, 2001, unpaginated CD

Todd, N.J. & J. Todd. 1994. From Eco-Cities to Living Machines: Principles of Ecological Design. North Atlantic Books, Berkeley, California.

Torres, J.L., and Morelock, Jack, 2002, Effect of terrigenous sediment influx on coral cover and linear extension rates of three Caribbean massive coral species: Caribbean Journal of Science, v. 38, no. 3-4, p. 222-229.

US Department of Agriculture. 2004. Puerto Rico Census of Agriculture, 2002. Volume 1. Geographic Area Series; Part 52. National Agricultural Statistics Service.

US Geological Survey. 2000. Preliminary bathymetric study of Lago Lucchetti and Lago Loco in Yauco Puerto Rico during March 2000. Data included in Appendix 1 of the Current Yield Study.

US Geological Survey. 2005. Estimated Water Use in Puerto Rico, 2000. Open-File Report 2005-1201.

Warne, A.G., Webb, R.M.T., and Larsen, M.C., 2005, Water, Sediment, and Nutrient Discharge Characteristics of Rivers in Puerto Rico, and their Potential Influence on Coral Reefs: U.S. Geological Survey Scientific Investigations Report 2005-5206, 58 p.their Potential Influence on Coral Reefs.

Weil, Ernesto, 2004, Coral reef diseases in the wider Caribbean: in Rosemberg, E., and Loya, Y., eds., Coral Health and Disease, Springer-Verlag., p. 35-68.

Wilm, H.G. 1955. The influence of forest vegetation on water and soils. Unasylva Vol.11., No.4.

Appendix I. Background on the Influence of Agriculture and Coffee

Agriculture plays an important role for various reasons, including the draining of Guánica lagoon specifically to make way for agriculture, the resultant soil loss and chemical runoff from agriculture and the tremendous influence of the Southwest Water Project whose purpose is irrigating the Lajas valley, among others.

Sugar cane was the main crop in the Lajas Valley until the 1950s but the main product is now hay or pasture, followed by sugar cane, fruits and vegetables. Note that not all of the Lajas Valley connects with the Rio Loco, as per Figure 1. Municipalities relevant to the Rio Loco and Guánica lagoon include, Guánica, Yauco, Lajas and Sabana Grande. Figure I-1 below shows municipality boundaries for the Island.

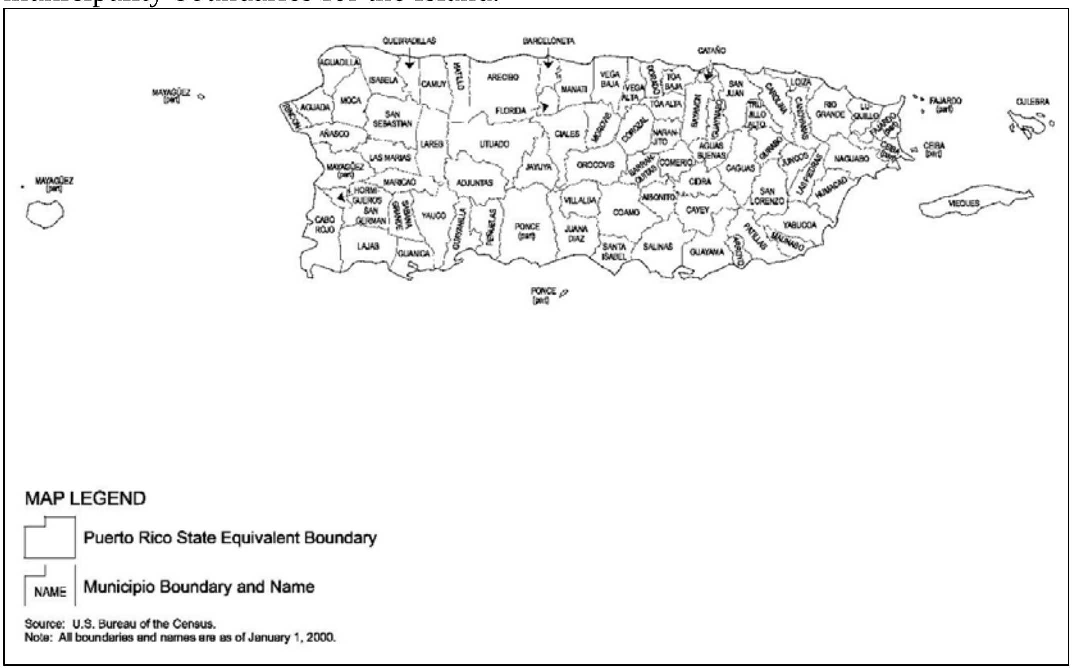


Figure I-1: Map of the municipalities of Puerto Rico (USDA 2004).

In terms of the entire GB/RL watershed, total land dedicated to farming has decreased in the Municipality of Guánica from 1998 to 2002 from 7998 to 6049 cuerdas (1 acre = 0.97 cuerdas), as well as in the Municipality of Yauco from 17703 to 15568 cuerdas and also slightly in Lajas from 24,727 to 24511 cuerdas. (USDA 2004) Table I.1 below summarizes this change.

In Guánica valley proper, fruits and vegetables are the primary products (making up 2000 acres), in addition to about 400 acres of hay, 600 acres of pasture (pers comm. Louis G. Meyer, local farmer). The Agriculture Extension Service of the UPR Mayagüez estimated in 1990 that 16,853 acres of the Lajas Valley were actually being used for farming. Of those farms, 61% were located in the Municipality of Lajas; 14% in Sabana Grande; 13% in Cabo Rojo, and 11% in Guánica. (Ortiz-Zayas & Terrasa-Soler, 2001)

Table I-1: Changes in Farm "Cuerdas" from 1998 to 2002. US Agricultural Census Data (USDA 2004). [1 acre = 0.97 cuerdas]				
Municipality	1998 (cuerdas)	2002 (cuerdas)	Percent Change	Absolute Change (cuerdas)
Guánica	7,998	6,049	-24.4%	-1,949
Yauco	17,703	15,568	-12.1%	-2,135
Lajas	24,727	24,511	-0.9%	-213
Sabana Grande	9,296	6,138	-34.0%	-3,158
TOTAL	**61,722**	**54,268**	**-12.1%**	**-7,455**

Coffee in fact is the largest user of arable land on the Island, using 57,549 cuerdas or 55,892 acres as indicated in Figure I-2 generated by the most recent US Census of Agriculture of 2002. (USDA 2004) Although it is important to note that total land dedicated to coffee has decreased island wide from 77,472 cuerdas in 1998. (USDA 2004)

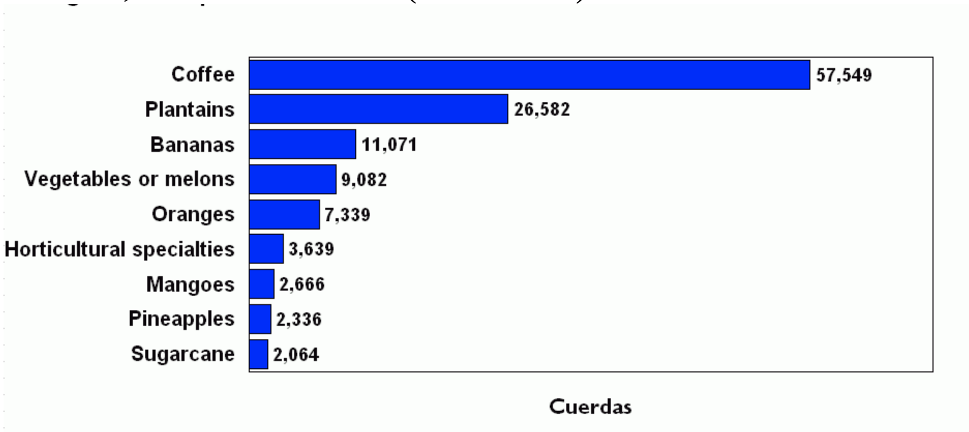


Figure I-2. Land allocation for major crops harvested 2002. USDA Census of Agriculture for Puerto Rico (USDA 2004).

Note that Yauco is the only municipality in the watershed growing a substantial amount of coffee. (USDA 2004) The upper watershed (in Yauco) is heavily farmed for coffee, primarily monocrop sun-grown coffee as well as bananas and other tree crops. In the 1950s the entire region produced approximately 400,000 pounds of coffee (pers. comm. Louis Meyer, local farmer). Today's coffee yields are 14,476,000 pounds for Yauco in 2002 down from 21,527,000 pounds in 1998, most of which is grown in full sun grown. In total, 220,523,000 pounds of coffee were produced on the entire Island in 2002. (USDA 2004)

The Census also indicates a decrease in land dedicated to shade-grown coffee island-wide between 1998 and 2002 from 34,071 to 23,625 cuerdas as well as a decrease in full sun grown coffee from 43,401 to 33,924 during the same period. (USDA 2004)

Despite any fluctuations in coffee crop cover over the past decade, the influence on the watershed by high elevation coffee, particularly the full-sun variety, is important because of the resultant soil exposure, on steep slopes, under an intense precipitation regime. Bulldozer and land clearing techniques on steep slopes evident during our field visit, for coffee cultivation, are a significant source of concern. Resultant soil loss is evident in downstream reservoirs.

Appendix II. The Coral Reefs of Puerto Rico and Threats to Guánica Bay

The National Oceanic and Atmospheric Administration recognizes land-based pollution sources, on coral as one of 3 key priority threats, along with fishing and climate change. The 2008 Coral Reef Conservation Program (CRCP), Roadmap for the Future, NOAA states;

"Pollution from land-based sources such as coastal runoff, agriculture, coastal development, road construction, and oil and chemical spills affects coral reef ecosystems through increased sedimentation, eutrophication, toxins, and pathogen introduction. These pollutants and related synergist effects can cause disease and mortality in sensitive species, disrupt critical ecological functions, cause trophic structure and dynamics changes, and impede settlement, growth, and reproduction. Land-based sources of pollution and poor water quality are recognized as one of the most important factors driving coral reef decline and as such will be addressed by the CRCP.

Improving the health and function of coral reefs will occur through the management of human activity and behavior within coastal watersheds."

In the first systematic report on coral reefs of Puerto Rico in twenty-five years, Warne et al., 2005 state that although living coral reefs are present around Puerto Rico, they are degraded in many locations. This is largely the result of increased sediment and nutrient discharge resulting from anthropogenic modifications to watersheds, eutrophication caused by sewage and agrochemical discharges, dredging, increased water temperatures and global warming.

These modifications are associated with intensive land clearing, agricultural and industrial development, and a steady increase in the standard of living. (Goenaga and Cintrón, 1979; Morelock et al., 1980, 1983, 1985; Rogers, 1990; Acevedo and Morelock, 1988; Acevedo et al., 1989; Clark and Wilcock, 2000; Larsen, 2000; Larsen and Santiago-Román, 2001; Torres and Morelock, 2002; Weil 2004) Coral reef degradation is widespread in waters surrounding the island, but generally greatest offshore of watersheds where population is high and terrestrial discharge of water and sediment are high. (Warne et al., 2005)

Coral reefs are among the most spectacular ecosystems on the planet, supporting such rich biodiversity and high density of marine life that they have been referred to as the "rainforests of the sea." (Hourigan et al., 2007). Warne et al., 2005 state succinctly the value of coral reef systems generally and in Puerto Rico specifically; "Coral reefs are the foundation and primary structure of many highly productive and diverse tropical marine ecosystems. The coast and shelf of Puerto Rico support numerous coral reefs and these living carbonate structures accommodate a number of ecosystem and socioeconomic functions including protection and feeding areas for fish, tourism, recreation, dampening of potentially erosive waves, and creation of sand material for beaches."

Figure II-1 demonstrates the current location and condition of major coral reefs on the island. As indicated, Guánica, our area of study, currently suffers from degraded coral reefs.

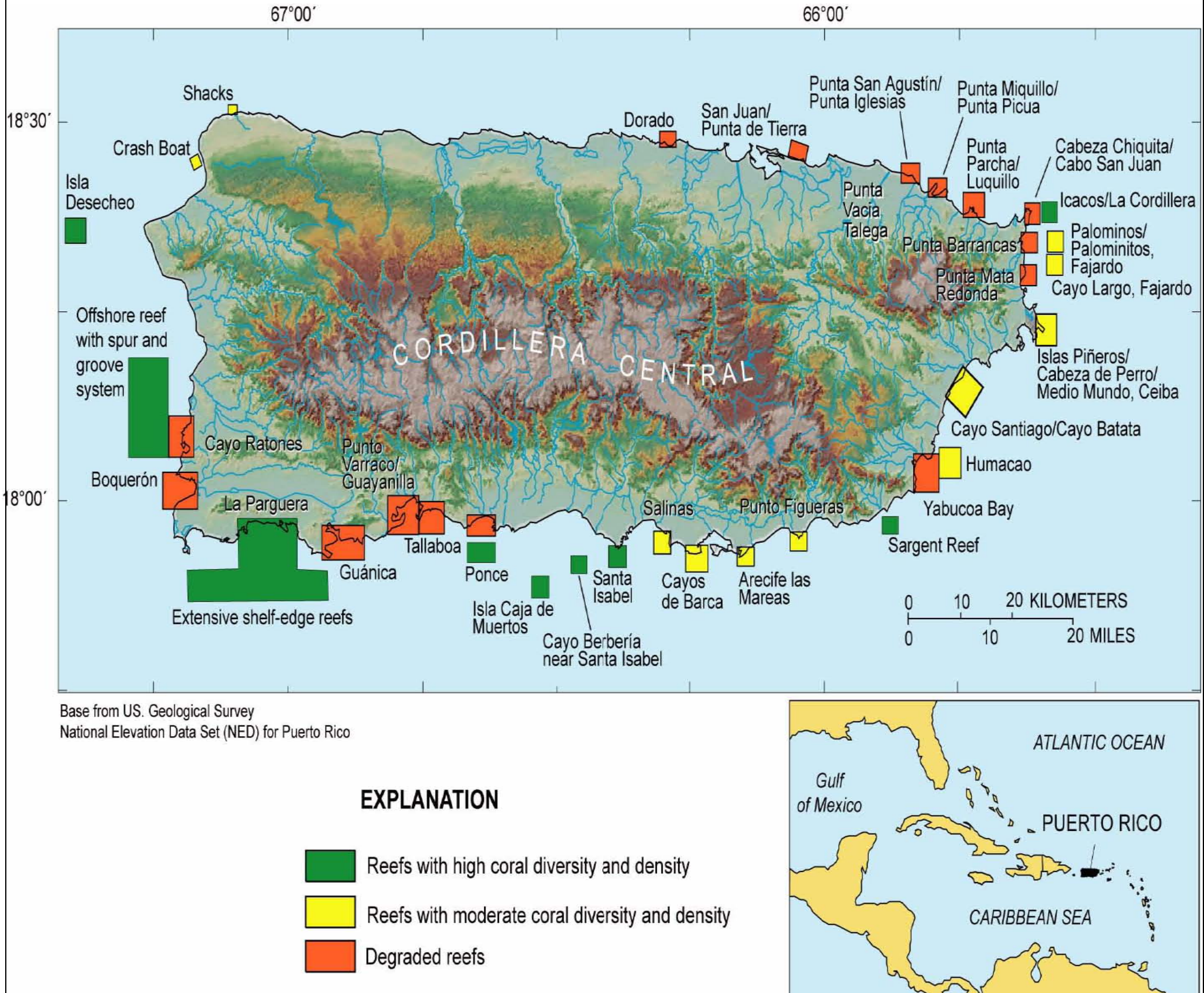


Figure II-1. Location and condition of major coral reefs around Puerto Rico from Warne et al., 2005.

As can be seen from Fig II-1 below the southwestern shores of the island are a significant location not only for shallow, stony corals which are found at depths of up to 100 meters, but also for structure forming and potential habit-forming deep sea corals found at depths of up to 3000 meters. A wide variety of deep-sea corals occur within the wider Caribbean region. These include stony corals, gorgonians, soft corals, stylasterids, black corals, lithotelestid coral and sea pens. The knowledge about the distribution of these corals is generally considered poor, but greater for some groups than others. (Lutz and Ginsburg, 2007).

Ongoing deep water research in the U.S. Caribbean includes the exploration and characterization of seafloor habitats, with ROVs, down to 1,000 meters within the U.S. Virgin Islands and Puerto

Rico by NOAA (NOAA 2007). This effort aims to characterize and map moderate to deep water coral reef ecosystem habitats within targeted study areas. Priority areas include the La Parguera region along the southwestern coast of Puerto Rico (Lutz and Ginsburg 2007) just 10 miles west of Guánica Bay.

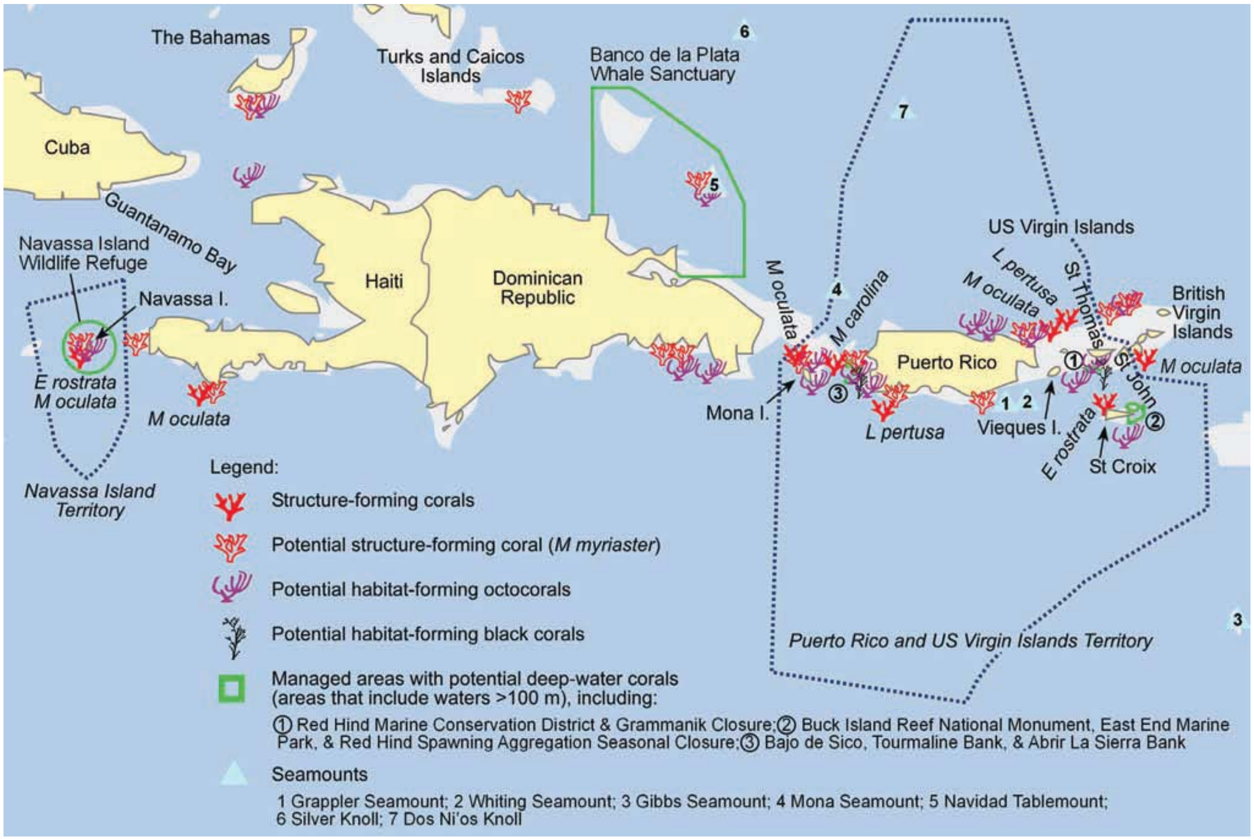


Figure II-2. Taken from Lutz and Ginsburg 2007. Distribution of deep water features and corals found in the U.S. Caribbean and adjacent area.

Appendix III. Lakes of the Southwest Puerto Rico Project

Table III-1. Reservoir Sedimentation history in RL/GB watershed (from Soler-Lopez,2001)											
Reservoir	Original capacity, in Mm3	Const. year	Study year	Storage capacity, in Mm3	Total vol. loss,Mm3	Long-term volume loss, in m3/yr	Loss in percent	Drainage area, in km2	Surface area, in km2	Deposition rate, in cm/yr	Sediment yield, in m3/km2/yr
Guayo	19.2	1956	1997	16.57	2.63	64,146	14	24.86	1.09	5.9	532
Loco	2.4	1951	2000	0.87	1.53	31,224	**64**	21.76	0.29	10.8	1,774
Lucchetti	20.35	1952	2000	11.88	8.47	176,458	**42**	44.81	1.11	15.9	4,102
Prieto	0.76	1955	1997	0.22	0.54	12,857	**71**	24.8	0.06	21.4	900
Yahuecas	1.76	1956	1997	0.33	1.43	34,878	**81**	45.17	0.22	15.8	1,430

Figure III-1. Lago Yahuecas

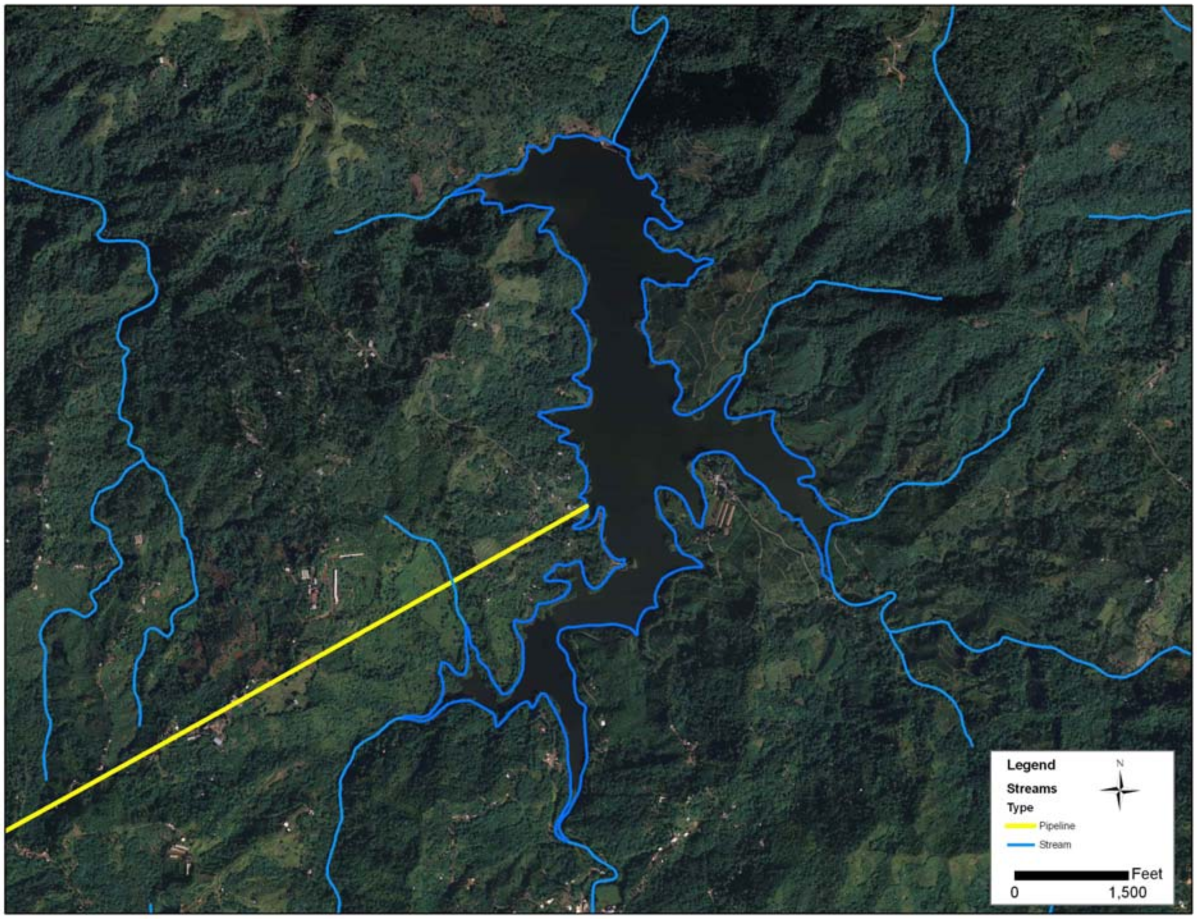


Figure III-2. Lago Guayo

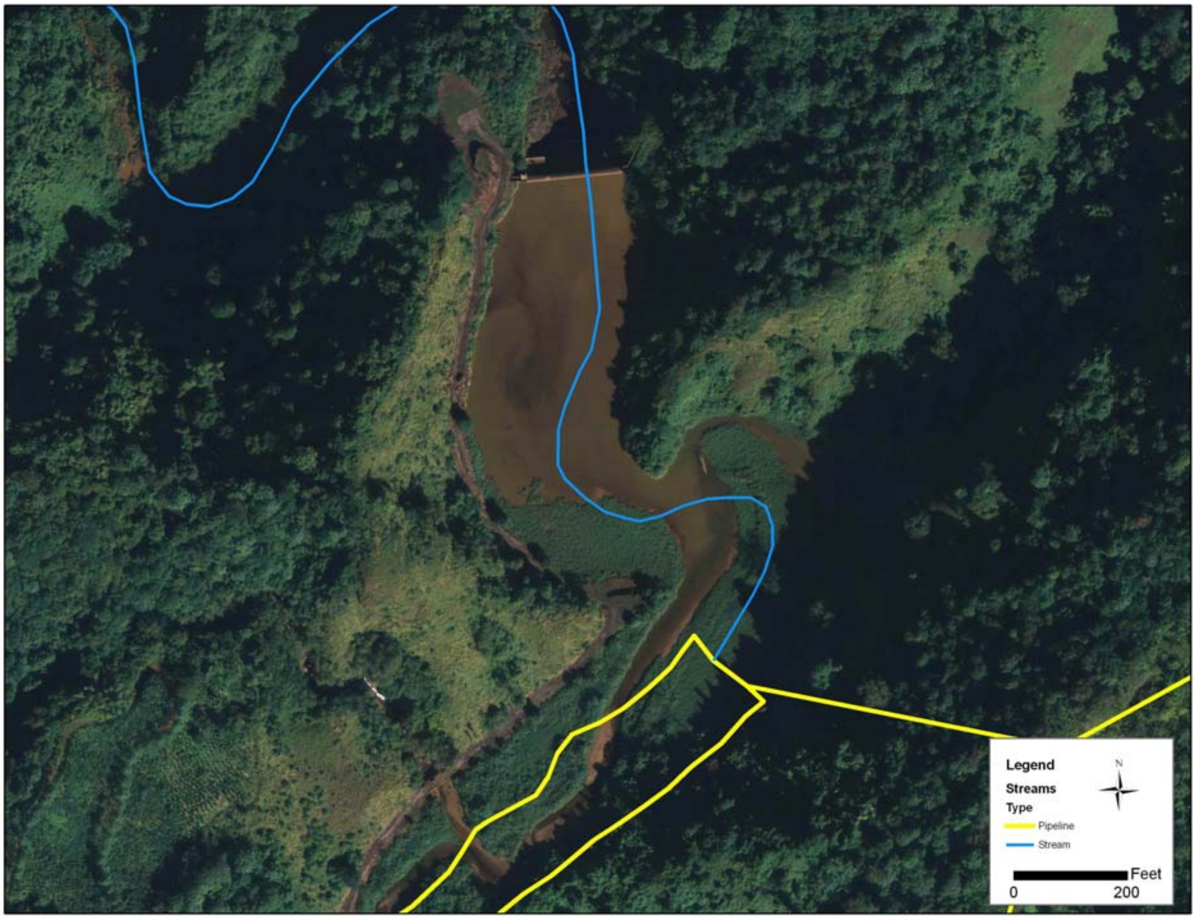


Figure III-3 Lago Prieto

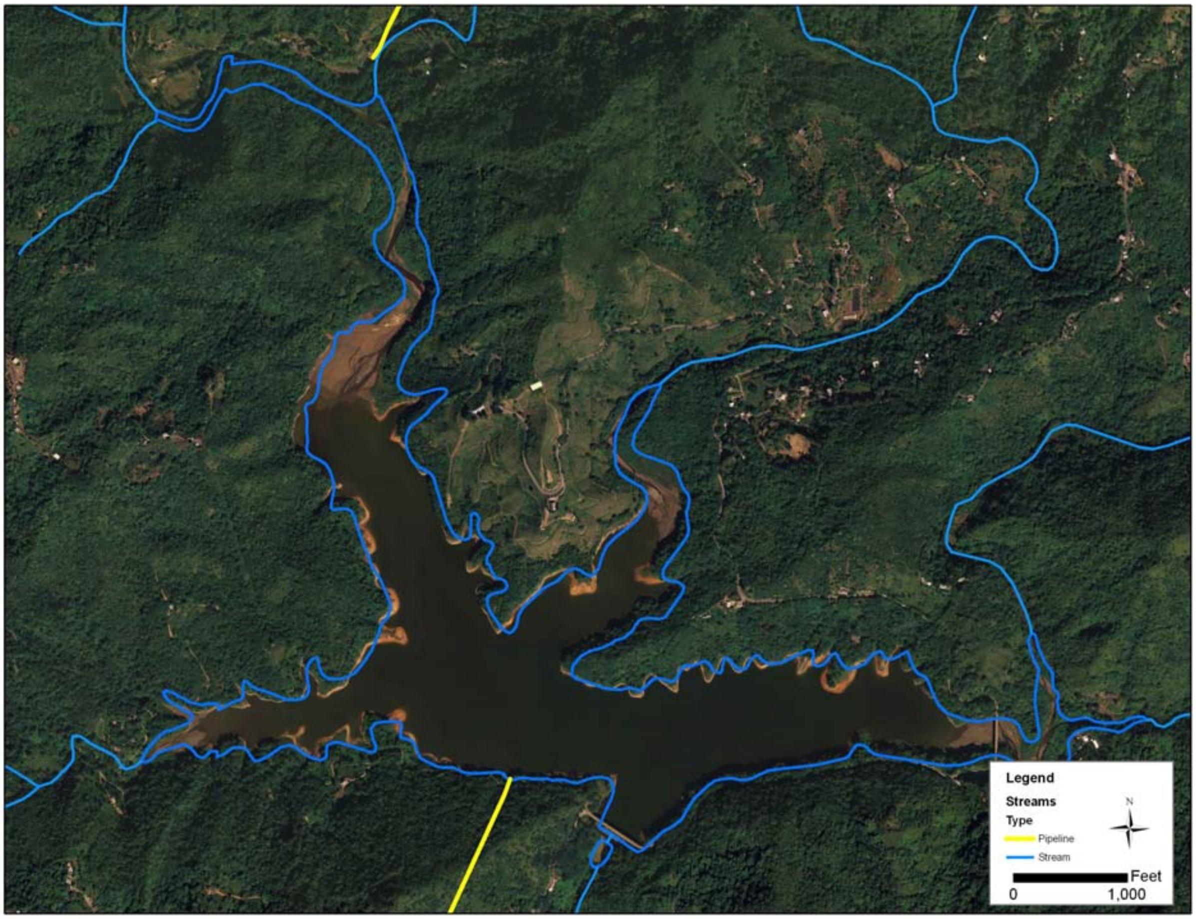


Figure III-4. Lago Luchetti

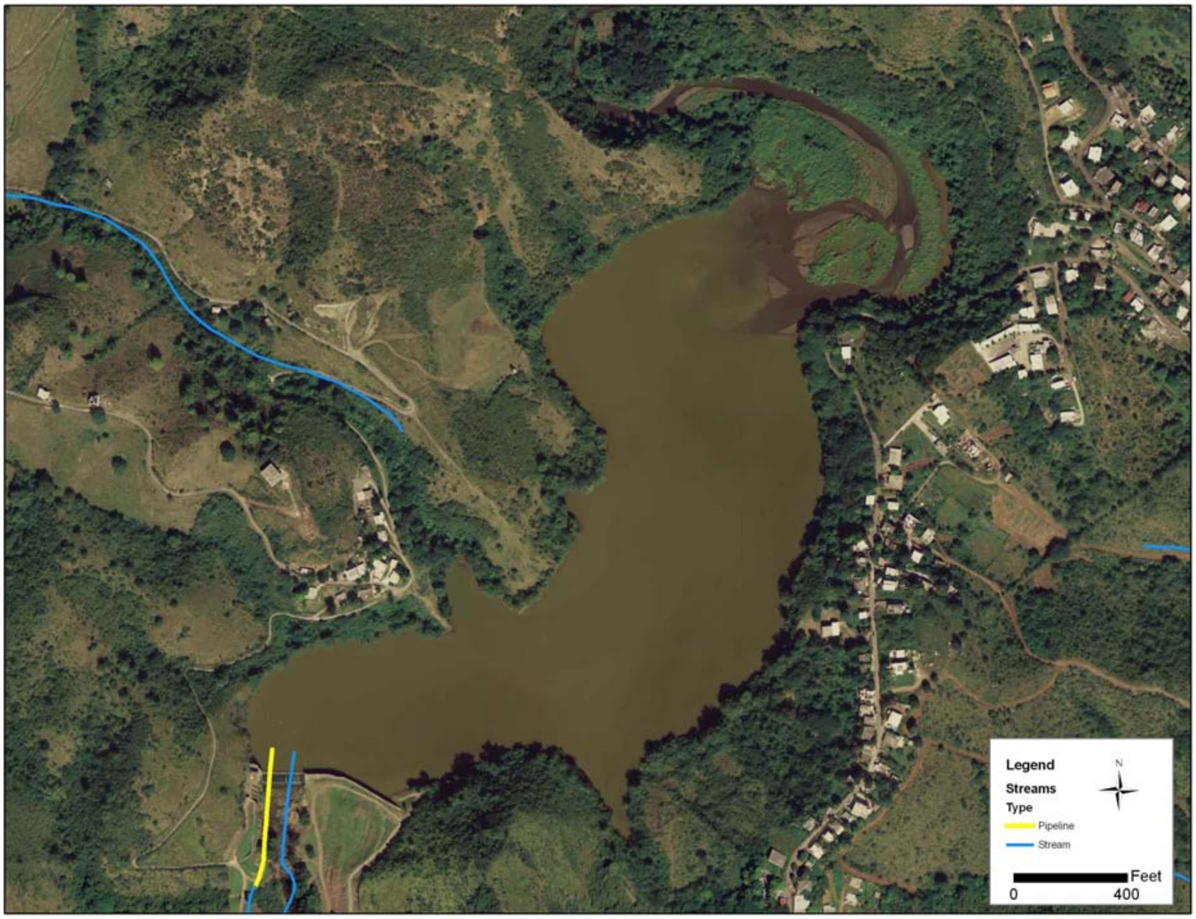
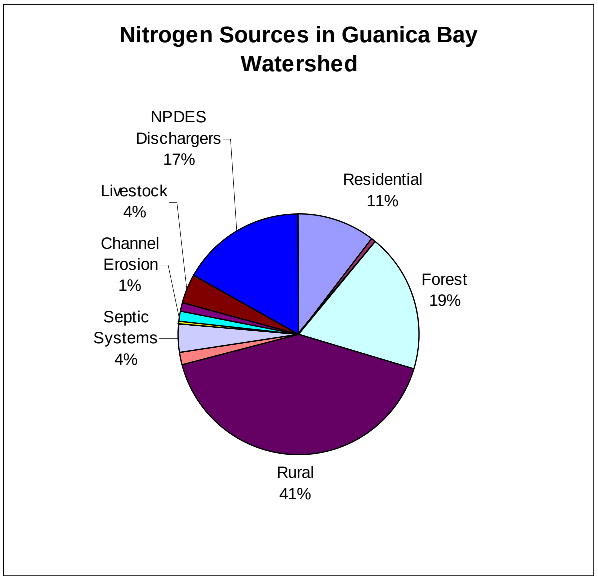


Figure III-5. Lago Loco

Appendix IV. Summary of Watershed Treatment Model (WTM) Load Estimations and the Implications for Restoration Recommendations



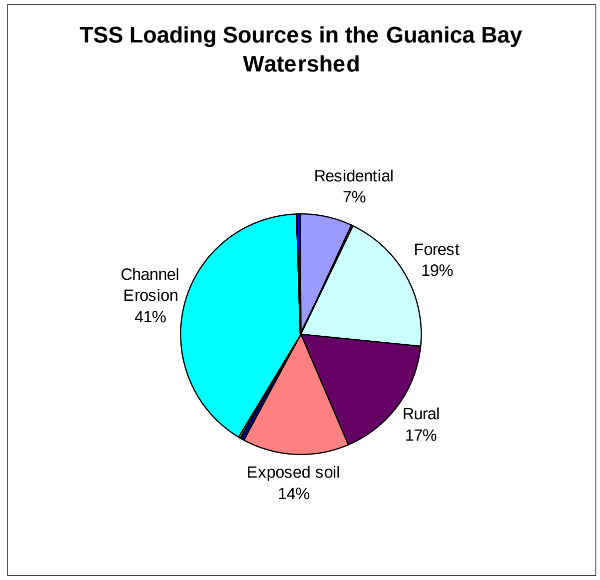


Figure IV-1. Nitrogen and Sediment Sources in the Guanica Bay/ Rio Loco Watershed

The restoration implications of the nitrogen and sediment budgets include:

- the importance of addressing sewage treatment plants for nitrogen removal particularly since they discharge (17% of the nitrogen load) directly or in close proximity to tidal waters.
- the remaining sources of nitrogen loads rural land (41%) and forest land (19%) generally have to travel some distance within the streams and Rio Loco itself – this humid tropical system is effective at processing nitrogen particularly during baseflow conditions (Ortiz-Zayas, 2006). So a portion of the loads from these sources are likely reduced through in-stream denitrification before reaching the coastal waters.
- the majority of land in the watershed including over 75% of the agricultural land and over 60% of the urban land are located above the location of the historical Guanica lagoon which if restored would provide treatment for a significant portion of the watershed and the major sources of loads for both sediment and nitrogen
- the major sediment sources in the watershed; channel erosion, exposed soil and the majority or rural land are all located upstream of the of the proposed lagoon restoration project – the calculation also points to the importance of addressing some of the existing channel erosion so that the restored Guanica lagoon is not inundated with sediment.