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21A Watershed Management and Reef Pollution

Addressing land based sources of pollution in Guánica, Puerto Rico

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Abstract. 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. Due to human alteration, the watershed area was increased by 50% to approximately 151 square miles and discharges to Guánica Bay near the town of Guánica. The Guánica Bay/Rio Loco watershed includes the urbanized areas of Yauco, a portion of the Lajas Valley agricultural region, and the upper watershed where coffee farming and subsistence agriculture is practiced on steep often highly erodible slopes. 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 extensive and healthy reef complexes in Puerto Rico. Coral reefs have experienced an unprecedented decline over the past 30-40 years in the Caribbean by some estimates have lost greater than 50% of live coral and over 90% of sensitive and federally listed *Acropora palmata* (elkhorn) and *Acropora cervicornus* (staghorn) species. Meanwhile studies by scientists in Puerto Rico have suggested that important nutrient and sediment contaminants have increased by 5-10 times pre-colonial levels and several times in the last 40-50 years. The Guánica project represents an effort to marry local efforts with an interagency and interdisciplinary approach to watershed management for improved coral reef health.

Key words: Land based sources of pollution, water quality, wetlands, green infrastructure

Introduction

Historic land clearing, agriculture, hydrologic alteration and poor erosion practices in the watershed have resulted in increased sediment deposition in the Rio Loco valley and transport through the Lajas valley. Alluvial deposits in the Guánica valley create high quality farmland and serve as a location for fruit and vegetable agriculture but also result in sediment transport from the erosion of legacy sediment exported from the riverbanks. Close to 90% deforestation followed by sugar cane cultivation from the end of the 19th century into the 1970s had significant impacts on the watershed (Warne et al., 2005). Between 1830 and 1950 (the period of peak deforestation and sugar cane agriculture), runoff increased by approximately 50% and sediment supply to the river channels increased by more than an order of magnitude (Clark and Wilcock, 2000).

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 created to bring freshwater to the arid southwest greatly expanded the total watershed area by the construction of a series of five reservoirs (only one was naturally part of the original watershed area; Fig. 1). These reservoirs were connected by tunnels drilled through the mountains in the upper watershed. This 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 also greatly reduced base flow in the Rio Loco watershed, while ditching of wetlands in the Lajas Valley including the largest natural freshwater body in Puerto Rico the 1200 acre Guánica Lagoon and over 2000 acres of wetlands has resulted in a significant loss of attenuation/filtering capacity of the watershed (GME, 1999). The cumulative effect of increased urbanization over the past 40 years has resulted in a steady decline in the near shore water and reef quality (Warne et. al., 2005). Warne et al. (2005) classified the coral reefs of Guánica as in “poor” condition with exceptional vulnerability to river discharge, industry, re-suspension, agriculture and dredging.

The watershed was chosen by Puerto Rico Department of Natural and Environmental Resources. (DNER) as the site for the creation of a model watershed plan for Puerto Rico due to its historic importance for coral reefs and the local capacity composed of the staff of the Guánica Dry Forest and the community which surrounds this beautiful area. This paper provides a case study of the activities associated with the development and implementation of that watershed management plan.

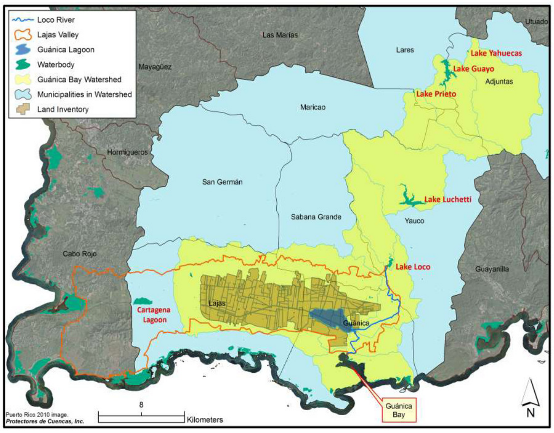

Figure 1. The Guánica Bay/Rio Loco watershed (yellow), including the footprint of the historic Guánica Lagoon

Material and Methods

In order to construct a watershed plan with a limited budget, several assessment methods were chosen including research into historical watershed conditions, water quality and GIS analysis methods, modeling and field assessments. Research into the natural history of the watershed was conducted in order to understand the nature and extent of land use disturbance that included almost complete deforestation to the majority of land being used for agriculture during its peak in the 1950s.

Field assessments based on the Unified Stream Assessment (Kitchell and Schueler, 2004) and upland assessments methods developed by the Center for Watershed Protection (Wright, 2004) were conducted in a relatively rapid fashion by technical staff. These efforts were aided by local stakeholders including farmers and resource managers from Guánica Dry Forest UNESCO Heritage site whose familiarity significantly reduced the amount of time needed to assess the watershed and determine key sources of pollution.

Extensive contacts and community trust of local partners helped gain access to important lands in the watershed and key into locations of potential key stressors. This information was used in conjunction with GIS analysis of exposed soils, cropland as well as the scientific literature for the area. In addition, the Watershed Treatment Model (WTM) was used to construct a rough nutrient and sediment budget for the watershed and to estimate water quality benefits of identified implementation measures (Caraco, 2001). Modeling in this system is hindered by the lack of land use-loading coefficients available in the Caribbean and rainfall variability in this watershed.

Results

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 Guánica Bay. These include upland erosion in high mountain regions; reservoir sedimentation and transport; in-stream channel erosion; loss of historic Guánica Lagoon; and sewage treatment and urbanization.

Upland erosion in high mountain regions

Field investigations illustrated legacy accumulations in the Guánica Valley along the lower Rio Loco and sediment transport through the Lajas Valley due to extensive channelization. Spatial analysis techniques have also shown that the loss of highly erodible soils on steep slopes is a major issue in the Guánica Bay / Rio Loco watershed. Highly erodible lands and agriculture, particularly sun grown coffee and other high-elevation crops, and roads and homes on or adjacent to steep slopes were identified through GIS analysis. 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 Lago Lucchetti and the Rio Loco watershed 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. 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). In addition, sun coffee trees need to be replaced more frequently as production wanes more quickly than coffee trees under shade. 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" (Wilm 1955). At the time of 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. Such erosion can be greatly reduced by maintaining the "vegetative cover underneath the coffee trees" (Noll 1953).

In the Guánica 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) estimated mean annual suspended sediment export 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 including Rio Loco. Suspended sediment exports are some of the highest in Puerto Rico and reflect the upland exposed sediments in areas receiving over 80-120 inches a year. Two restoration efforts are underway as a result of these findings. First, is farmers' conversion of sun grown coffee to shade grown coffee—with support from Natural Resources Conservation Service (NRCS) and US Fish and Wildlife, which provides outreach and assistance with planting of a shade tree mosaic amongst the existing coffee plantations. Over 1200 acres in the watershed have been contracted for conversion over the past 3 years. Second, Protectores de Cuencas (a local NGO) is leading the stabilization of bare soils associated with road cuts, construction and urban areas in the watershed. These are in the process of being stabilized using hydroseeding and hydomulching techniques developed using a technical roundtable approach. The mixes are being tailored to use local material and to local flora and soils. It is anticipated that over 16 acres of bare soils will be stabilized in the watershed.

Reservoir sedimentation and transport

A review of orthophotography with DNER biologists at Guánica Forest Reserve clearly showed that sediment was passing through the Rio Loco Reservoir 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 (Fig. 2). 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.

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, 2001; 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 inspection 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, due to the accelerated transport of these highly erodible soils from a combination of 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 (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 is also 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). Personal communication with USGS and GIS orthophotography zoomed in on the pump house into Loco Reservoir confirms this occurrence (Fig. 2). The extent of storage losses in the reservoirs in the watershed is documented in Soler-Lopez (2001). Extensive sedimentation is present in four of the five reservoirs in the watershed.

Figure 2: The pumphouse into Lago Loco reservoir from Lago Luchetti demonstrating interbasin transfer of sediment.

In-stream channel erosion

Channel erosion on the main stem of Rio Loco was another major issue in the watershed as documented using a qualitative Rapid Geomorphic Assessment (RGA) (MacRae and DeAndrea, 1999). Severe erosion was associated with areas that lacked mature riparian trees, the occurrence of non-native species that seemed to exacerbate erosion and areas with historic irrigation infrastructure which created downstream scour (Fig. 3). These low head dams, concrete footers, and other structures cause debris to become lodged in the channel, destabilize banks, and increase channel erosion, bed scour, and sediment transport. Clark and

Wilcock (2000) discussed the deposition of valley sediments during the period of deforestation and intense agriculture and the continued importance of these historically deposited valley sediments as significant contributors to the current and future sediment regime and Warne et. al. (2005) noted the resulting continued impact on nearshore coral reef ecosystems.

Projects have begun working with individual farms to remove old irrigation infrastructure and re-grade streambanks while planting native species of trees to promote bank stability. These are key components of a restoration strategy for this 2000 meter, relatively unstable area of the Rio Loco between Yauco and the La Laguna community. It is anticipated that demonstration projects showcasing the benefits of these practices with farmers can lead to a more comprehensive program to improve stream stability and buffers in this area of the watershed. 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 yield and runoff coefficients in these areas. Many streams appeared to be "healing" after past land use abuses.

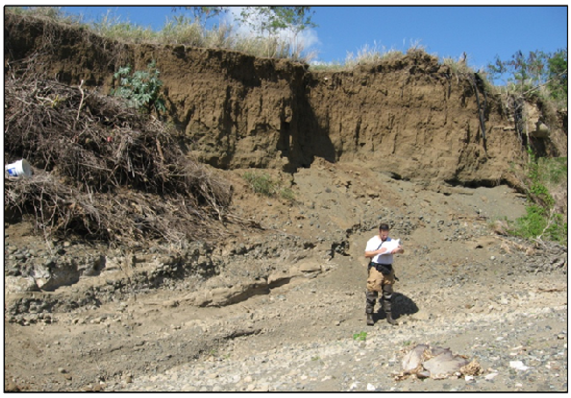

Figure 3: Unstable legacy sediments deposited in the Rio Loco/Guánica Valley.

Loss of historic Guánica Lagoon

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. The former Lagoon was extensively drained and ditched. 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 the southern cattail *Typha dominguensis*. Ciénaga El Anegado was located about 2.7 km west of the western shoreline of Guánica Lagoon (Ortiz-Zayas & Terrasa-Soler, 2001 and Soler-Lopez, 2001).

Historically, Guánica Lagoon served as a sink for nutrients, sediment and other contaminants including bacteria, herbicides and pesticides (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 reefs (Morelock et. al., 2001). The effect of land based pollution and sedimentation on reefs is well documented in the literature 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 DNER commissioned a study to evaluate the feasibility of restoring the Lagoon to reclaim its value as a wildlife refuge and ecological resource. The focus recently has been on addressing the concerns of the agricultural community that include additional flooding of agricultural lands, concerns about soil salinity and potential loss of agricultural production.

The potential impacts of restoring Guánica Lagoon have been studied and a restoration of a 950 acre lagoon versus the historic 1200 acres is estimated to minimize impacts to agricultural land and maximize both ecological and economic benefits (Amador, 2012).

Sewage treatment and urbanization

Historical urbanization, particularly after 1950 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 also results in additional sewage being generated and discharged to the near shore coastal environment. The increases in impervious cover result in increases in loading of nutrients, bacteria, sediments, Polycyclic Aromatic Hydrocarbons, heavy metals and other pollutants associated with automobiles.

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 et. al., 2006). Much of the rural population in Puerto Rico has relied upon septic systems or other on-site practices. With changes to EPA regulations over the past decade, there has been a move toward connecting rural communities to central sewer and upgrading sewage treatment plants to secondary treatment. In addition, sanitary sewers are inherently leaky systems and this is compounded by intense rainfall in the tropics, the lack of maintenance of the infrastructure system and the trunk of the system often being located at the lowest elevation where it can be inundated with seawater from high tides and coastal storm surges both exacerbated by climate change. The on-site septic systems are usually poorly sited in soils with high water tables or impermeable soils. Discharge from sewage and septic systems are key sources of contamination in the watershed particularly along the coast.

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. A constructed wetland is being designed and will be built at the 850,000 GPD Guánica sewage treatment plant to reduce nutrients from secondary effluent before being discharged into Guánica Bay.

Discussion

A complex assemblage of stressors exist in the Guánica Bay watershed – requiring a multi-agency and stakeholder approach to restoration that addresses sources of pollution from agricultural land, urban land and the river channels. Re-establishing wetlands and on-going efforts to identify sewage leaks and failing septic systems may also help restore ecosystem function. Restoration projects and strategies were identified (Table 1) with the goal of reducing nutrient, sediment and bacteria on a watershed basis to improve conditions for coral reefs. Many unanswered questions exist as to how much reduction is needed to see improvements in reef conditions and how long it will take to see reef improvements - this coupled with global stressors associated with climate change and ocean acidification -- make the prospects for improvement in reef condition even more complex.

Restoration Action	Lead Agency	Status
1. Restoration of Guánica Lagoon	NOAA, Ridge to Reefs, Protectores de Cuencas	Feasibility/impact analysis and outreach
2. Treatment wetlands at Guánica treatment plant	Ridge to Reefs, NOAA, National Fish and Wildlife Foundation	Funded (in design and permitting)
3. Conversion of sun coffee to shade coffee	NRCS, FWS	Funded – contracts for over 1 sq. mile of conversion
4. River restoration of the Rio Loco	NRCS, Soil Conservation District	Funded – in design and permitting
5. ID of other source areas of pollution	RTR, PC, Municipality of Guánica	Funded – number of sources identified but additional id on-going
6. Stabilization high mountain exposed soils (urban and roads)	PC, RTR, NOAA, NRCS, Forest Service, FWS	Funded – roundtable discussed stabilization and hydroseed mixes and test plots

Table 1: Table of restoration actions on-going in the Guánica Bay watershed.

Acknowledgements

Since the creation of the plan in 2008, the watershed has become a priority of the US Coral Reef Taskforce (USCRTF) and federal and local partners including NRCS, FWS, NOAA, EPA and local NGOs have taken active roles in implementation of the watershed plan. We would also like to recognize the input and support of many federal and local partners as well as the local community and farmers who have been generous with their time and efforts to help to restore the watershed.

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