CULEBRA

COMMUNITY WATERSHED ACTION PLAN FOR WATER QUALITY AND CORAL REEFS

PREPARED FOR

NOAA CORAL REEF CONSERVATION PROGRAM

PUERTO RICO DRNA

CULEBRA OFFICE OF THE MAYOR

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Glossary of Acronyms

ACDEC – Authority of Conservation and Development of Culebra

ADS – Solid Waste Authority of Puerto Rico

AEE/PREPA – Electrical Authority/ Puerto Rico Energy and Power Authority

CATEC -- Center for Applied Tropical Ecology and Conservation

CESAM – Student chapter of the Marine Environment Society (Capítulo Estudiantil Sociedad Ambiente Marino)

DNER/ DRNA – PR Department of Natural and Environmental Resources

EQB – Environmental Quality Board

NOAA CRCP – NOAA Coral Reef Conservation Program

NOAA RC – NOAA Restoration Center

PC - Protectores de Cuencas

PDV- Punta del Viento Estates

PRASA – Puerto Rico Aqueduct and Sewer Authority

PR Dept. of Ag – Puerto Rico Department of Agriculture

PR Tourism Company (PRTC) - Puerto Rico Tourism Company

RTR – Ridge to Reefs

SAM – Marine Environment Society (Sociedad Ambiente Marino)

UPR – University of Puerto Rico

USACE – US Army Corps of Engineers

USDA Rural Development – US Department of Agriculture

USEPA – US Environmental Protection Agency

USFWS – US Fish and Wildlife Service

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Section 1. Executive Summary

Purpose

This watershed plan represents the culmination of the initial watershed planning process in Culebra– the goal of the watershed plan is to help chart a course for the improvement of water quality and coral reefs and to serve the goals of the citizens of Culebra. The process to complete the Plan has included: 1) a baseline study that summarizes existing scientific information and background on the study area (integrated into this report); 2) a stakeholder process that has included meetings with individuals, agencies and a series of meetings with the public to establish goals and objectives for the watershed plan; 3) fieldwork to establish water quality and coral reef conditions as well as the sources of pollution coming from the land; 4) identification and prioritization of restoration opportunities including policy changes, implementation projects and enforcement issues; and 5) completion of a draft and final watershed plan.

Synopsis

Culebra is a small island off the northeast coast of Puerto Rico. It is home to 1,900 residents and is approximately 11.6 square miles including the small adjacent uninhabited islands of Culebrita and Cayo Norte to the east and Luis Peña to the west. Culebra is a tourism destination due to its beautiful white sandy beaches, scenic vistas, and coral reefs with marine life that are reachable from shore. Culebra is home to some of the healthiest coral reefs in Puerto Rico, as well as a significant population of resident and breeding sea turtles (Figure 1). In spite of global and local stressors, many of the reefs remain in good condition, bolstered by coral farming and restoration efforts. As a result, Culebra is one of the top priorities for coral reef protection and coastal management in Puerto Rico the watershed planning process is a key first step (DRNA, 2013) (NOAA, 2009).

Figure 1. Near shore coral reef (left) area and a Green turtle in Culebra (right) (Photo credits: CESAM)

In this plan, it is important to acknowledge global stressors as well as local stressors to marine and coral reef ecosystems. Global stressors such ocean acidification and increased sea surface temperatures caused by increasing CO2 from fossil fuel combustion. The impacts of more frequent high sea surface temperatures on coral bleaching can be minimized by reducing local nutrient and sediment stressors (Vega-Thurber et. al, 2013, Wooldridge et. al. 2012). Local stressors include historical overfishing, sediment, nutrients and bacteria from cleared land, stormwater runoff, and sewage contamination. Culebra's population, which is now at its highest level (Figure 2), is creating a peak in local stressors. Fortunately, these stressors are also reversible through direct action and most stressors can be kept at bay through effective protective measures and policies.

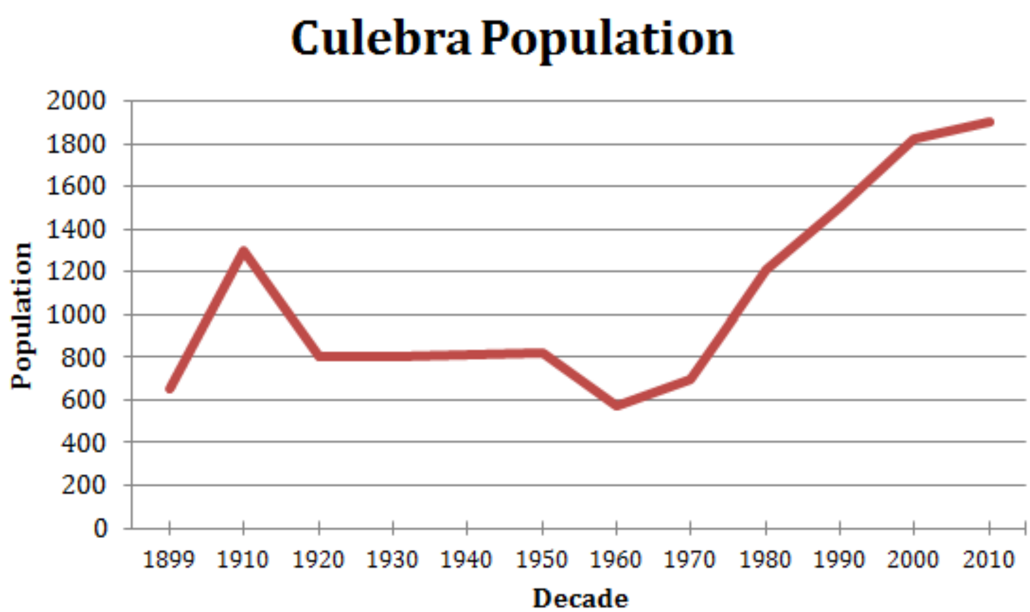


Figure 2. Culebra population 1899-2000 (Adapted from PR Sea Grant, 2008)

The two most critical local stressors in Culebra are sewage and sediment: sewage from failing septic systems, illegal discharges and (at least sometimes) a poorly functioning treatment plant; and sediment from unpaved roads, impervious surfaces and bare soils. Addressing these two stressors, sediment and sewage, through restoration and infrastructure improvements and preventing future impacts through improved policies are the critical steps to ensure a sustainable future for Culebra. A focus on these two parameters also helps to address other stressors including bacteria, heavy metals and PAHs (hydrocarbons) summarized in Table 1.

Table 1. Priority Pollutants in Culebra

Pollutant	Impacts	Sources
Nitrogen, Phosphorus	Eutrophication, algae growth, enrichment beyond tolerance of coral reefs.	Wastewater, fertilizers, stormwater runoff, atmospheric deposition, boat discharge
Sediment	Deposition on reefs, effects on sediment intolerant reef organisms, sediment particles leading to water temperature warming, pollutants attached to sediment particles.	Soil erosion, unpaved roads, channel erosion, poor erosion and sediment control practices, African dust
Bacteria	Health related illnesses due to water contact, swimming, beach closures, source of pathogens that effect coral reefs	Untreated wastewater, sewage overflows, stormwater runoff, animal waste (from pets, wildlife, and domestic animals), boat discharge
PAHs	Toxicity to coral reefs , potential for human health issues	Stormwater runoff from automobiles, boat engine discharge (2-stroke engines)
DDT, PCBs, Pesticides, Heavy Metals and Legacy military contaminants	Toxicity to coral reefs, potential for human health issues	Legacy contaminants, pesticides for control of insects and vegetation

The people of Culebra have helped chart a course to address local and global stressors and set an example for Puerto Rico and the Caribbean for reversing impacts through achieving the goals and actions recommended in the stakeholder process. In this plan, specific actions and costs have been identified to reduce the sediment and nutrient stressors by over 40%. It is possible to meet these goals with a reasonable budget and collective community action over the next 5-10 years.

Stressors

Culebra's history certainly impacts and reflects the condition of its natural and marine resources today. Historical activities have included extensive grazing and deforestation, military artillery training and bombing, overfishing, tourism and urbanization. These have all impacted current reef conditions as have more global stressors, including climate change (with bleaching associated with higher sea surface temperatures), hurricanes and ocean acidification. The establishment of protected areas such as Culebra National Wildlife Refuge, restrictive zoning and an active conservation populace, have acted to minimize most potential impacts and threats from large tourism developments and over commercialization. That said, the system is stressed and many reefs, including those at Flamenco Beach, have declined to very little live coral cover and currently lack the resiliency to recover from continued impacts.

The greatest stressors to coral reefs, seagrasses, mangrove forests and other coastal habitats are from existing and new development where impacts from stormwater runoff, dirt roads, land clearing, as well as inadequately treated sewage and septic systems are apparent. Illicit discharges are common and include washwater and direct sewage discharges to the Ensenada Honda and the Lobina channel. Even the centralized wastewater treatment plant (WWTP) appears to be underperforming based on our limited water quality data. Legacy impacts remain from military bombing in both terrestrial and aquatic habitats. Historic land use changes, including forest clearing and widespread grazing for much of the past century, has caused the loss of much of the older native dry forest and replacement by younger secondary forest often dominated by invasive plant species.

Other general challenges for the island reflected in stakeholder concerns include the lack of freshwater and food production, frequency and intensity of hurricanes and distance from mainland Puerto Rico (Figure 3). Rural areas on the island generally secure water using individual cisterns and the urbanized areas are served by a pipe from the mainland. During major hurricanes, tropical storms and times of very high demand, Culebra may lose power and water for durations of up to two weeks or longer. The island also has a very hot and dry climate with predominantly thin rocky soils with no perennial freshwater streams, only intermittent streams (quebradas), which carry runoff during rain events. The lack of food production also serves as a challenge to Culabrenses and poses a risk during major storms, work stoppages in major ports or other factors that limit transport of food to Culebra.

In general, Culebrenses are a very resilient, adaptive, strong-minded and independent people who used non-violent protests to force the military to leave Culebra in 1975. They have lived through major hurricanes, military dislocations and challenges associated with being relatively isolated from the mainland of Puerto Rico.

Process

The Plan is written to meet the Environmental Protection Agency's A-I Criteria for watershed planning in order to strengthen the competitiveness for funding sources (EPA, 2008). The criteria helps the plan process to: prioritize projects and actions, calculate costs and benefits, identify funding sources and present a monitoring strategy. The A-I Criteria for watershed planning are as follows:

a. Identification of the causes and sources that will need to be controlled to achieve the load reductions estimated in the watershed plan (Table 1);
b. Estimates of pollutant load reductions expected through implementation of proposed management and restoration measures (Section 5, Table 9);
c. A description of the management measures that will be to be implemented (Table 3 and Section 4);
d. An estimate of the amount of technical and financial assistance needed to implement the plan (Table 3);
e. An information/education component that will be used to enhance public understanding and encourage participation (p.7 and Table 1);
f. A schedule of NPS management measures (Section 5);
g. A description of interim, measureable milestones (Section 5, Table 9),

h. A set of criteria to determine load reductions and track progress (Section 5, Table 9); and
i. A monitoring component to determine whether the watershed plan is being implemented effectively (Section 5).

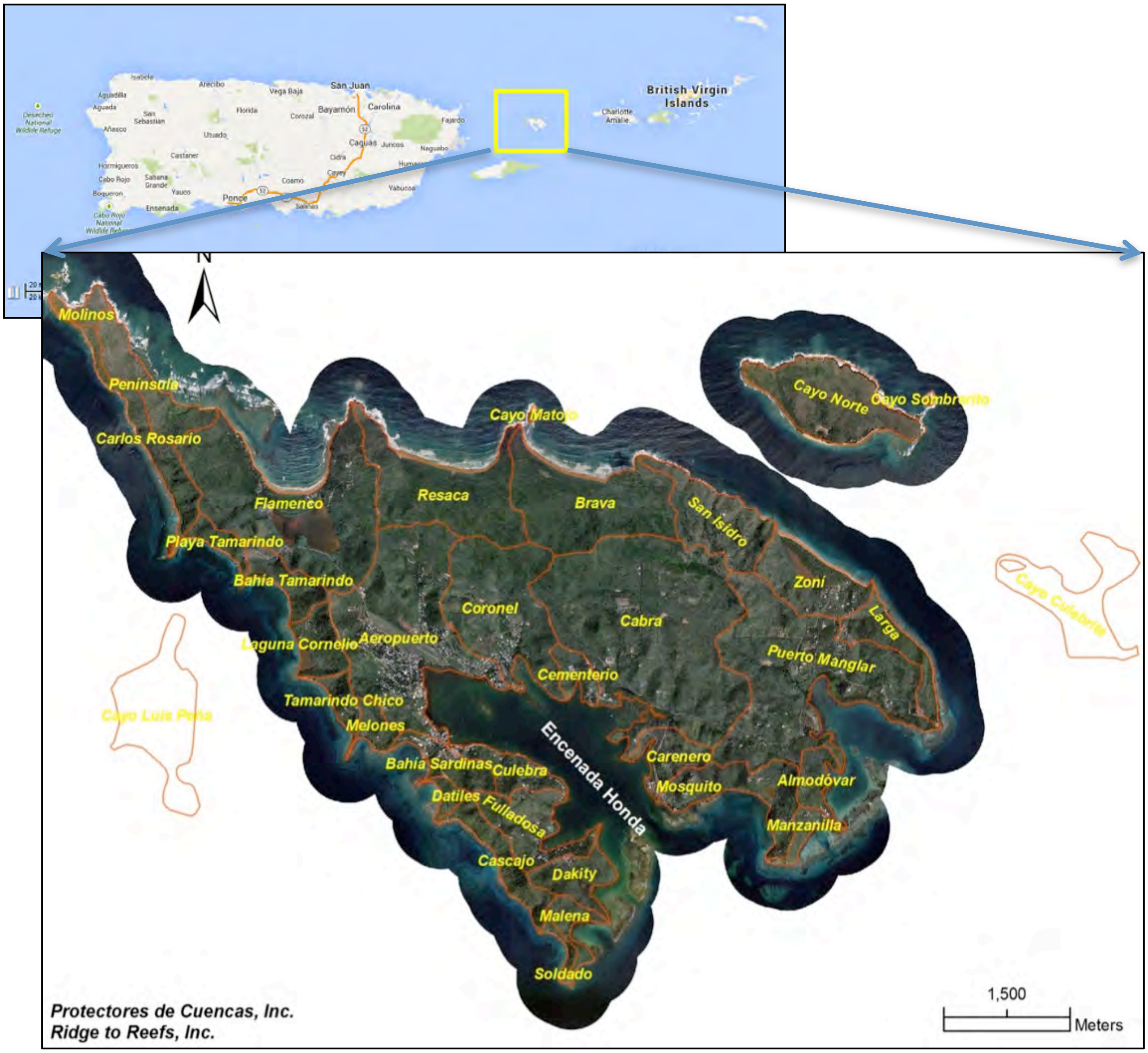


Figure 3. Map of Puerto and Culebra.

Pollution Source Estimates

A watershed pollutant model was constructed for some of the key priority pollutants in Culebra, with a focus on nitrogen, sediment and bacteria. The model was based on the Watershed Treatment Model (WTM), which uses typical pollutant estimates for the different land uses in Culebra, such as forest, cleared land, dirt roads, paved roads and developed areas including commercial, institutional and industrial land uses (modified from Caraco, 2002). Information from Ramos-Scharron 2009, and information collected during our fieldwork and water quality monitoring was used to help populate the model. Appendix A-4 summarizes land use input assumptions and land use coefficients derived from 2010 aerial orthophotos that were used as inputs to the model. Output from the model helps to prioritize and focus actions to reduce the pollution to coastal areas in Culebra.

Figures 4 and 5 illustrate the sources of nitrogen and sediment in the watershed based on the model output. Septic systems (including direct sewage discharges to Ensenada Honda and the Lobina channel) are the largest source of nitrogen in the watershed, followed by forested areas and the sewage treatment plant. Other sources of note are paved roads, dirt roads and very low-density development. For sediment the major sources include dirt roads, forested areas, channel erosion, paved roads and cleared roads. It is important to note that on a per acre basis forest/fields (63% of the land use of Culebra) produces the least pollution of any land use, so few strategies are available to achieve further reduction – though where coastal lagoons are located they often intercept water from diverse land uses and improve water quality.

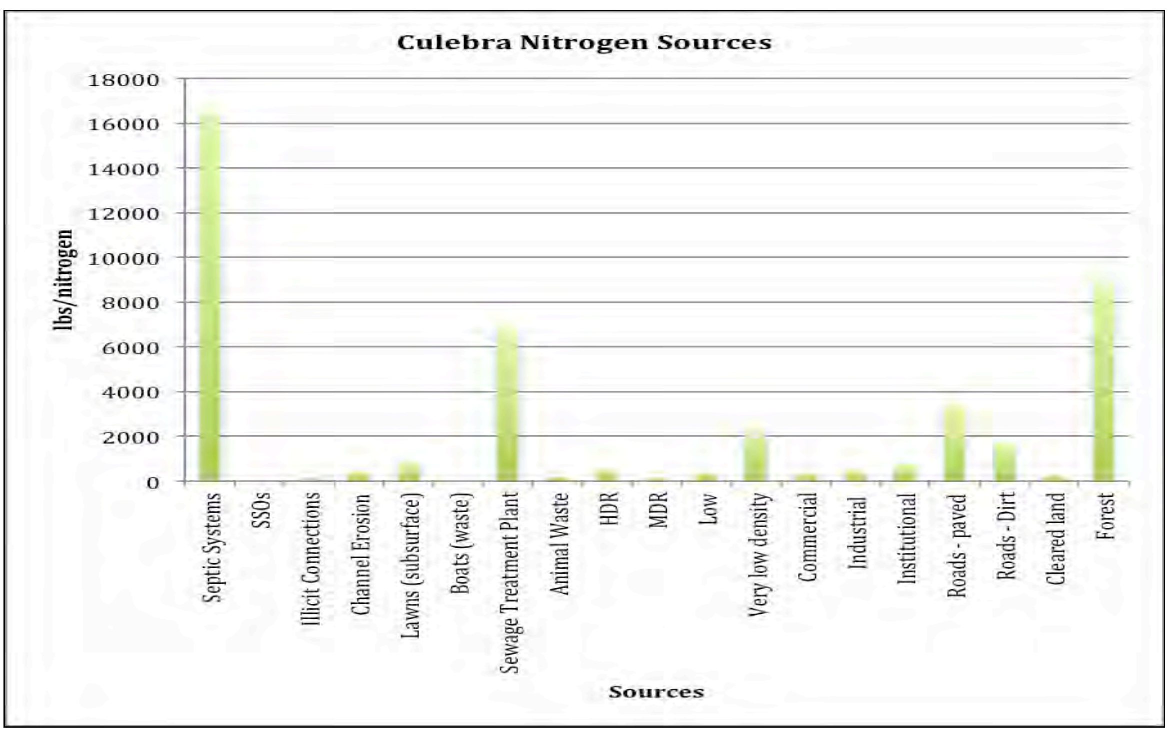


Figure 4. Nitrogen Source Estimates in Culebra using the WTM (HDR and MDR refer to High and Medium Density development) (Sturm et. al, 2014)

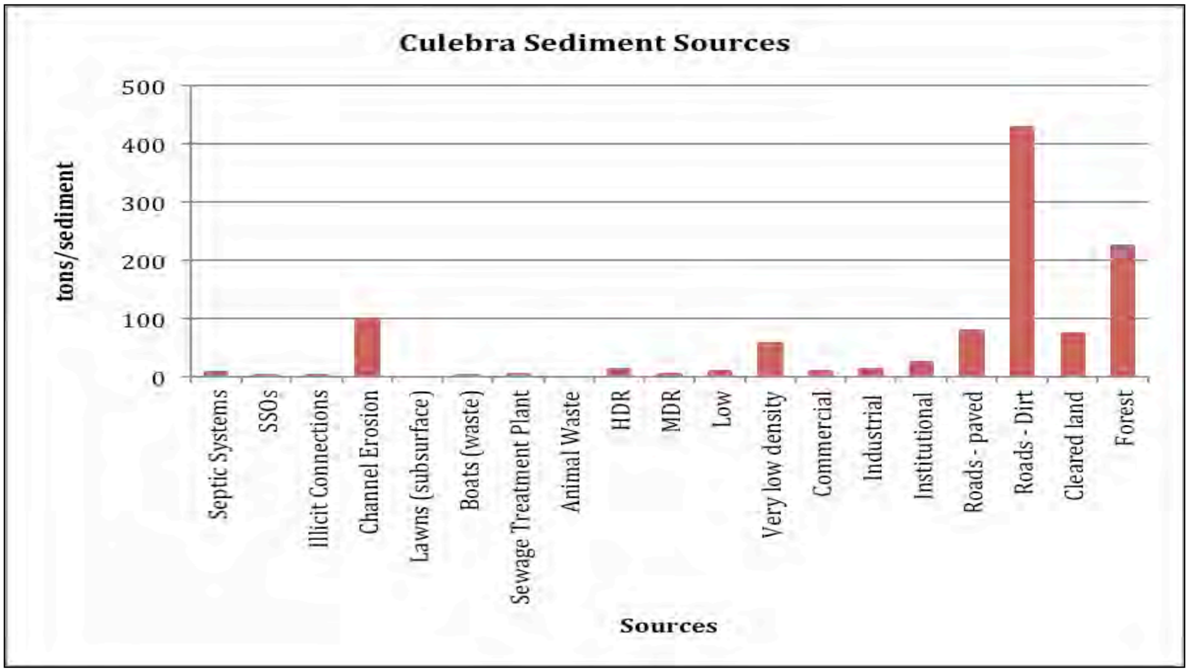


Figure 5. Sediment Source Estimates in Culebra using the Watershed Treatment Model (Sturm et. al, 2014)

Stakeholder Goals

A critical component of any watershed planning process is involving the local stakeholders in the development of a watershed plan. Ultimately it is the stakeholders who will determine if the plan is implemented and can help hold public officials and agencies accountable to ensure the watershed plan is implemented. As part of the stakeholder process (Figure 6), stakeholders including the Mayor, residents, community leaders, NGO's, municipal officials, and business owners were asked to discuss their goals for the watershed and vision of the future of Culebra.

The stakeholder goals from the four breakout groups are as follows and will be used to help focus the watershed recommendations:

1. Control erosion
2. Plan reforestation – urban, rural and new development
3. Communication – improve communication between sectors and teamwork
4. Reduce contamination of sewage and septic systems
5. Address contamination from the landfill
6. Increase natural history education in Culebra
7. Increase the use of renewable energy
8. Preserve more land for conservation
9. Culebra to be a model for implementation and restoration in Puerto Rico
10. Environmental practices and policies to safeguard the natural resources of Culebra
11. Self-sufficiency
12. Ensure streams and watersheds have natural filters
13. Foster sustainable agriculture

14. Identify funding sources
15. Training for machine operators and planning for erosion and sediment control
16. Maintenance sediment and erosion control measures and prevention of disturbance

Figure 6. Stakeholder Meeting; Small Groups Setting Goals and Priority Areas

Values / Priority Areas

Priority areas and values expressed by stakeholders during the goal discussions were recorded, as values can serve as a way to unify and clarify the vision of the community across political and social boundaries. Self-sufficiency, education, the natural legacy/heritage of Culebra and the idea that Culebra should be a model of sustainability and effective management for Puerto Rico and the Caribbean, were the core values expressed by stakeholders. These core values can serve as a focal point for decision-making and addressing future challenges.

Information on priority areas and areas in need of further assessment were also gathered from the stakeholders. Table 2 summarizes some of the priority areas identified for implementation by the stakeholders. These included dirt roads, waste disposal (homes, boats, businesses), recycling and education.

Table 2. Priority Areas for Implementation Identified by Stakeholders

Priority Areas	
Dirt Roads	Green Infrastructure(GI)/ GI Development
Boats and waste disposal	Solar energy
Residential connections to the sewer system	Education about contamination
Recycling / compost	Engage and involve students in activities
Nursery – Native Reforestation	

Recommendations

Prioritized implementation recommendations for the Culebra watershed are summarized in Table 3. Preliminary cost estimates and potential responsible parties have been identified so that financial resources can be allocated and roles in implementation can begin to be defined. It is important for the community to play as large a role as possible in the restoration/implementation plan. The long-term sustainability of Culebra requires stakeholder involvement, as well as a multi-faceted approach that includes improved management, communication, implementation, education and protection of watershed functions. The multi-faceted approach is estimated to reduce nitrogen to the coastal areas in Culebra by 45% and reduce sediment to the coastal waters by 41% plus help to minimize future increases in these pollutants. This approach strives for permanent protection and attempts to minimize long-term costs by implementing proactive, preventative solutions.

This method is not inexpensive, the estimate is $250,000 -$300,000 a year (a portion of which has been secured over the next two years) over 5 years and increases significantly when critical infrastructure projects are included (e.g., the landfill and connections to the WWTP) as well as significant investments in land acquisition or a conservation easement program. Long-term protection of water quality, fisheries, quality of life and biodiversity have quantifiable community benefits, creating jobs and helping to ensure the long-term economic and ecological prosperity of Culebra and its quality of life. The annual economic contribution of coral reefs is estimated at $500,000/per square kilometer per year in the middle Caribbean and coastal mangroves are valued at $200,000 -$900,000 per square kilometer (UNEP,2006). Therefore, the annual benefits of restoration and protection far outweigh the costs. Another key component of this watershed plan is measuring and monitoring the success. In Culebra, this consists of monitoring the effects of management measures on dirt roads, WWTPs, and on water quality and coastal resources (i.e., fisheries, coral reefs, sea grass beds). This will enable effective adaptive management and outcome-based implementation that achieves long-term protection and preservation of resources and a healthy economy.

Table 3. Culebra Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Sponsor/ Partners	Estimated
1. Reduce erosion and sediment runoff from roads	1,2,6, 9,10, 15,16	Approximately 5 miles of road are high priorities for stabilization and some dirt roads remain un-assessed due to access issues (Funds for 1.5 miles have been secured) (2-3 part-time jobs (PTE) for Culebrenses created) (Related projects shown in Figure 7)	EQB, DNER, NOAA, USEPA, PC/RTR	$150,000 +$20,000 yr maintenance
2. Improved sewage treatment and reduced discharge of effluent at the Culebra Sewage Treatment Plant	3,4,9, 10	Improve and make use of the treatment wetlands – recirculate and reuse effluent using a sprinkler irrigation system to create a zero discharge system (2-3 PT jobs or 1 full time (FTE) job)	PRASA, USEPA, NOAA, PC/RTR, EQB	$75,000 + $5000/ yr maintenance

Table 3. Culebra Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Sponsor/ Partners	Estimated
3. Improved treatment of sewage and washwater at Flamenco Beach and apartments	3,4,9, 10	Connection to sewer or the use of composting toilets and washwater gardens to minimize impacts to the marine environment at Flamenco Beach	ACDEC, PRASA, PR Tourism Company, PC/RTR, USDA RD, EQB, USEPA	$600,000 - $1M plus operational costs of pumps, service cost etc
4. Address runoff and erosion and sediment control from new development	1,2,6, 9,10, 15,16	Policies and training in place to limit clearing, preservation of buffers, require and enforce erosion and sediment control and stormwater management (requires institutional authority for fines) and training for the staff person (Restoration and Enforcement Coordinator) (Funding to assist in the creation of policies) (1 FT job)	ACDEC, PC/RTR, DNER. Legislative Commission of Culebra	$15,000 and 1 FTE at ACDEC for enforcement and training)
5. Treatment of stormwater runoff	6,9,10, 12	Implementation of 10-15 green infrastructure practices (One project complete funding secured for at least one additional project) (2-3 PTE for 5 yrs) (See Figure 7)	ACDEC, PC/RTR, Tourism Company	$350,000
6. Expansion of coral restoration efforts	3,6,10	Rapid expansion of restoration efforts to include other coral farming areas and out plantings areas in Culebra (possible to expand protected areas and also to further engage the community in restoring coral and to evaluate designating a restored area for Culebra fisherman) (1 FTE)	SAM, Coralations, CESAM, students and local community, DNER, NOAA	$100,000 annually
7. Development of long-term funding sources for restoration/ management and protection	8,11	Selling of conservation products to assist with a funding source, surcharge on ferry, flights, etc. to go back into conservation efforts (e.g., interpretation, education and communication to DNER for enforcement at Tamarindo and other high use areas)	CESAM, PC/RTR, SAM, DNER, ACDEC	$5,000
8. Connection of businesses and homes to sewer	4,9,10	Connect businesses and residences to the sewer line so that sewage is adequately conveyed to the treatment plant (1-2 PTE)	PRASA, USEPA, USDA RD, Businesses, PC/RTR, Coralations, Municipality, EQB	$200,000
9. Address sources of pollution including illicit discharges and failing septic systems	4,9,10	Continued monitoring and enforcement and working directly with businesses and homeowners on improvements	PC/RTR, USEPA, CESAM, SAM, DNER, Coralations, EQB	$20,000 + $5,000 annually for monitoring
10. Support small-scale renewable energy efforts/ support designation of green businesses, ecotourism, guest houses	7,11	Support implementation of small scale solar and wind at individual homes, airport, guest houses etc – train Culebrenses and others to help transition to these jobs, reduce use of fossil fuels impacting ocean acidification and reduce energy costs for residents and businesses (1-2 PT jobs potential for FTE)	USDA RD, PC/RTR, AEE/PREPA, local businesses and home owners, PR Tourism company	$100,000 initiation

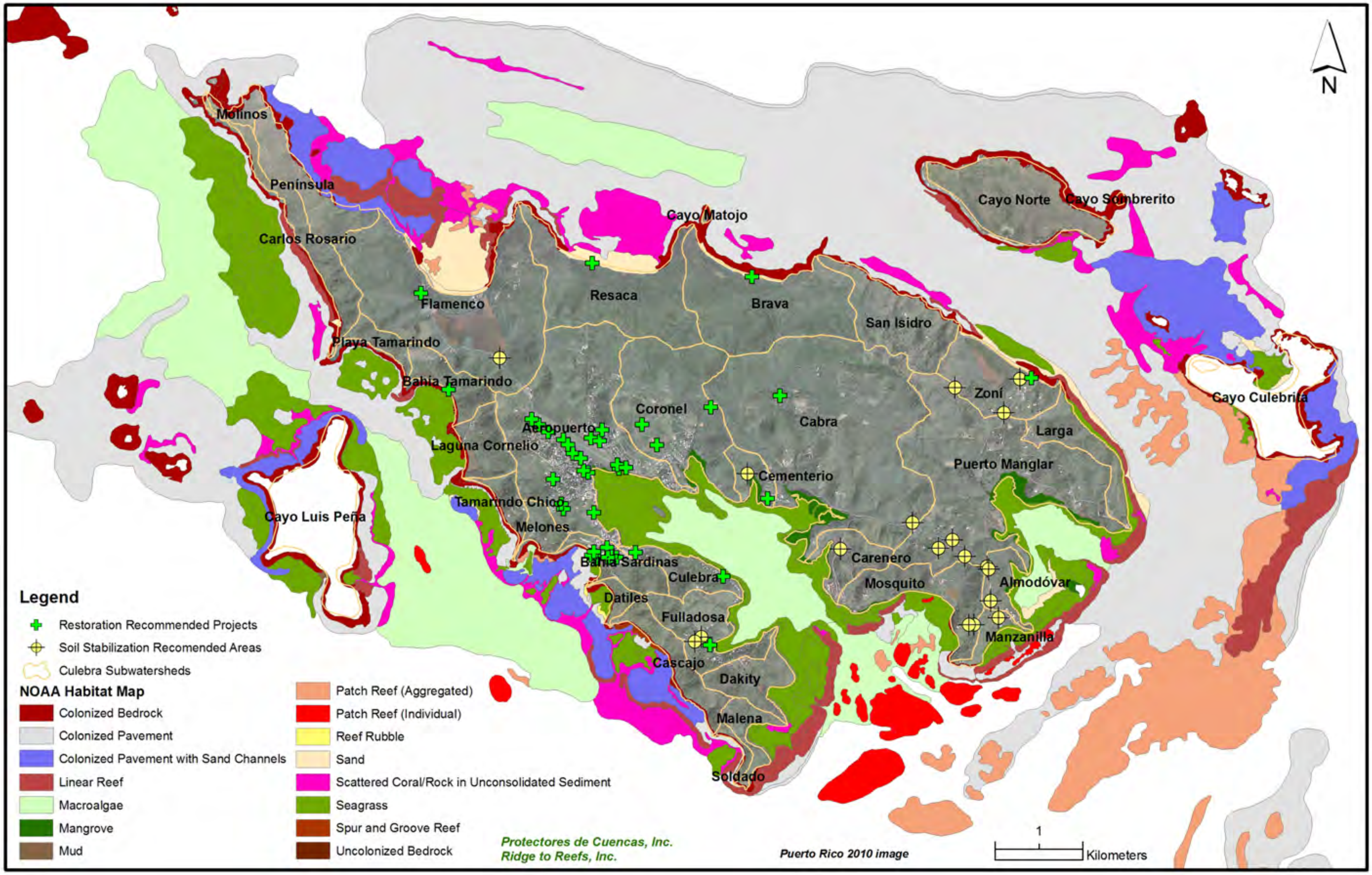
Table 3. Culebra Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Sponsor/ Partners	Estimated
11. Improved management and on-site personnel – restoration of fish and urchins species etc .	3,6,9, 11	Convene a taskforce to evaluate the current and needed level of enforcement/ management -- study and document improvements, evaluate the carrying capacity of various beaches and consider limits; evaluate / create a position for the restoration of grazer fish and urchin species (1 FTE)	PR Sea Grant, Board of Luis Peña Marine Reserve, UPR RP, SAM, CESAM, Coralations, DNER, Association de Pescadores de Isla de Culebra	$100,000 + $30,000 yr
12. Education and curriculum on the natural history of Culebra and educate tourists on the marine environment and their responsibilities	8,11	Development of curriculum on the natural resources and natural history of Culebra, adult and family led trips to different areas, provide education via gateways at airport and ferry terminal/ferries. Creation of an Ecological Education Center for Culebra.	Schools, teachers, Eco-school, Abby's school, USFWS, Coralations, NOAA, DNER, ACDEC	$15,000 (may include the commission of a field guide) , Ecological Center > $150,000
13. Address nutrient loss from large septic systems including Costa Bonita, large homes on fractured soils with year-round use, and Flamenco guest houses	3,4,9, 10	Implementation of nutrient reduction technologies to reduce loss of nutrients in these areas – monitoring can inform locations for implementation which may include Costa Bonita, Flamenco and Bahia Marina (2-3 PTE)	PC/RTR, USEPA, EQB, DNER	$100,000
14. Support small-scale community agriculture	13,14	Support the self-sufficiency and food security of Culebra	Isla Mujeres, PC, USDA/ NRCS, local restaurants, community, PR Dept of Ag., MaryAnn Lucking	$60,000 to initiate on-going efforts
15. Close and decommission landfill reducing its long term impact on the environment	10,14	Close, decommission and stabilize the landfill site, reducing potential for future leachate problems, recycle a portion of existing trash and look to create businesses that create products, set high standards and effective programs for recycling island wide; ensure local job creation	ADS (PR Solid Waste Authority), ACDEC, Municipality, DNER, USEPA, EQB	$8M (Money is supposed to be allocated by the current PR administration)
16. Reduce impact on coastal zone and properties in hazard areas (see #17)	3,4,9, 12	Identify areas likely to be most impacted by hurricanes, tsunamis, tropical storms and coastal flooding – phase out most vulnerable structures, hold roundtable in Culebra to address climate risk for health and water contamination (Consult NOAA Sea Level Rise Estimates and PR Tsunami maps)	Municipality, FEMA, DNER, UPR, PC/RTR, NOAA	$5,000 planning
17. Long-term protection of sensitive lands	8,9,12	Create a plan for conservation of lands that help ensure the long-term health of the marine environment in Culebra	DNER, Land Trust, PC, Municipality of Culebra, FWS, Sea Grant, NOAA CELP Program, Coralations	$5,000 planning $5M for implementation

Table 3. Culebra Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Sponsor/ Partners	Estimated
18. Accelerate the identification of unexploded/spent ordinances; protect impacted lands	8,10, 11	Raise awareness and a petition drive to accelerate the timeframe of the cleanup operations and advocate for the cleanup of federal lands which are currently excluded from cleanup efforts	Community groups, Army Corp of Engineers	$5,000 planning
19. Reduce impact of sewage from moored/ transient vessels (busy weekends)	3,4,6, 9,10	Institute a pump out program creating a local business and ensure there is adequate legislation and mechanism for enforcement (Harbor Master) (1 FTE)	DNER, PRASA, local businesses	$30,000
20. Environmentally sensitive growth and re-development to minimize the impacts of future growth	1,2,3, 4,10, 12, 15	Foster ecologically sensitive development and re-development which minimizes the impact of the ecosystems of Culebra and designs with nature and conservation in mind – (In general development should be focused on redevelopment and infill)	ACDEC, Legislative Commission of Culebra , Puerto Rico Planning Board	$5,000 planning
21. Monitoring program to ensure reduction in pollution	4,6,9	Tracking of coral conditions and biological communities at defined stations, water quality at key locations and effectiveness monitoring of implementation programs	DNER, Community, SAM, CESAM, CATEC, PC/RTR, NOAA, ACDEC, Coralations, EQB	$30,000/yr
Total	$1,150,000 plus large sewage and landfill infrastructure projects and land preservation ~ $150,000 in existing funding commitments With full implementation: >14-17 Part-time jobs, 4-5 Full-time jobs			
ACDEC – Authority of Conservation and Development of Culebra, ADS – Solid Waste Authority of Puerto Rico, AEE/PREPA – Electrical Authority/ Puerto Rico Energy and Power Authority, CATEC -- Center for Applied Tropical Ecology and Conservation, CESAM – Student chapter of the Marine Environment Society (Capítulo Estudiantil Sociedad Ambiente Marino), DNER/ DRNA – PR Department of Natural and Environmental Resources, EQB – Environmental Quality Board, NOAA CRCP – NOAA Coral Reef Conservation Program, NOAA RC – NOAA Restoration Center, PC - Protectores de Cuencas, PRASA – Puerto Rico Aqueduct and Sewer Authority, PR Dept. of Ag – Puerto Rico Department of Agriculture, PRTC -- Puerto Rico Tourism Company, RTR – Ridge to Reefs, SAM – Marine Environment Society (Sociedad Ambiente Marino), UPR – University of Puerto Rico, USACE – US Army Corps of Engineers, USDA Rural Development – US Department of Agriculture (USDA RD), USEPA – US Environmental Protection Agency, USFWS – US Fish and Wildlife Service				

Figure 7. Integrated map of habitats and recommended restoration projects in Culebra



Section 2. Scientific Imperative for Action in Culebra

Coral Reefs

Past coral studies have documented a declining trend in coral reef health in Culebra. In 1998, Hernández-Delgado reported that live coral cover at several sites in Tamarindo and Carlos Rosario was greater than 60% (Figure 8) even though at that time relatively high amounts of algae were present. Since that time, additional impacts have been documented and coral bleaching events have occurred to further degrade coral reefs in Culebra. For example, estimates of live coral cover in 2008 (just 10 years later in some of the same areas), ranged from 20-40% live coral cover (Figure 9 (left)). The best reef sites in Carlos Rosario in 1997 had 65% live coral cover but in 2008 had dropped to 30% coral cover – a decrease by 50% in just 10 years. At other sites, including Flamenco beach, there has been a catastrophic decline, particularly within the reefs close to shore and the beach area (Hernandez-Delgado pers. Comm). These declines are generally associated with mass bleaching events due to temporary conditions with high sea surface temperatures likely combined with chronic elevated nutrient levels. Recovery has been very slow in many areas, likely due to on-going anthropogenic impacts, lack of grazing fish and diadema, and elevated nutrients. High levels of algal cover are present on the reefs. Algae acts to stifle recovery from bleaching events, which can cause a phase shift from a coral-dominated to an algal-dominated system (Hernández-Delgado, 2010).

Even in 1997 with relatively healthy reefs from the perspective of live coral cover -- only 29% of the reef was considered healthy and 46% was overgrown with filamentous algae, 37% with macroalgae and 20% suffering from bioerosion. In just one year, 1997 to 1998 with a major bleaching event in Carlos Rosario (Figure 7) there was 33% coral mortality at CR1 and 28% at CR2. At that time another finding was that the biomass of fish, particularly in the Tamarindo area of the Luis Peña channel (prior to the establishment of the Marine Reserve), was very high with a biomass of 16007g vs. 4419g in Carlos Rosario. These studies in part served as the basis for the establishment of Luis Peña Marine reserve and the importance of Tamarindo as part of the Reserve due to its fish biomass (Hernández-Delgado, 2000).

A study by Norat, Mattei and Hernández-Delgado (2009) documented the transport of bacteria, nutrients and sediment via predominant currents from urbanized areas in Ensenada Honda and the Lobina Channel to coral reef areas along the Luis Peña Marine Reserve including Melones, Tamarindo and Carlos Rosario. This transport phenomenon was more pronounced in the summer (peak usage/ tourism population) and during the rainy season (fall) which highlights the importance of controlling sources of runoff and sewage discharges.

Studies by Ramos-Scharrón et al. (2009) have also documented high erosion rates on dirt roads and predicted sediment transport to nearshore waters, highlighting areas likely responsible for the greatest amount of sediment transport. Ramos-Scharrón estimated that export of sediment from dirt roads is 10 to 100 times higher than background levels.

A recent study by Vega-Thurber et al. (2013) from the Florida Keys, and past studies by Wooldridge et al. (2012) have documented the importance of reducing nutrients and bacteria (Sutherland et al. 2011) from nearshore coastal waters in order to reduce the prevalence of coral diseases and bleaching. The Vega-Thurber study illustrated that an increased input of nutrients to coral reef systems created conditions where much higher rates of coral bleaching took place, but once the nutrients were removed from the system, the coral recovered. These studies have helped to provide some of the basis for on-going and future restoration efforts to control both sediment sources and formed one of the starting points for fieldwork.

Despite challenges with land-based sources of pollution, Culebra plays an important role in leatherback turtle (*Dermochelys coriacea*) nesting and has some of the highest living coral cover when compared to other reefs in the region. It is considered to be very important in fish and larval dispersion in the Northeast Reserves. Culebra is home to hawksbill (*Eretmochelys imbricata*) and leatherback sea turtle nesting grounds (Diez et al., 2010). Leatherback nesting occurs at Playa Resaca, Brava and Zoni beaches. These sites are important, though nesting numbers have declined somewhat in the past 10-15 years to between 100 - 200 nests/yr (Figure 10). The leatherback is considered globally endangered and is the largest sea turtle in the world and feeds primarily on jellyfish. Its diet makes it vulnerable to climate change and changes in jellyfish distribution and populations. Green turtles and hawksbills are also year-round residents in the sea grass beds and coral reefs and are a draw for tourists.

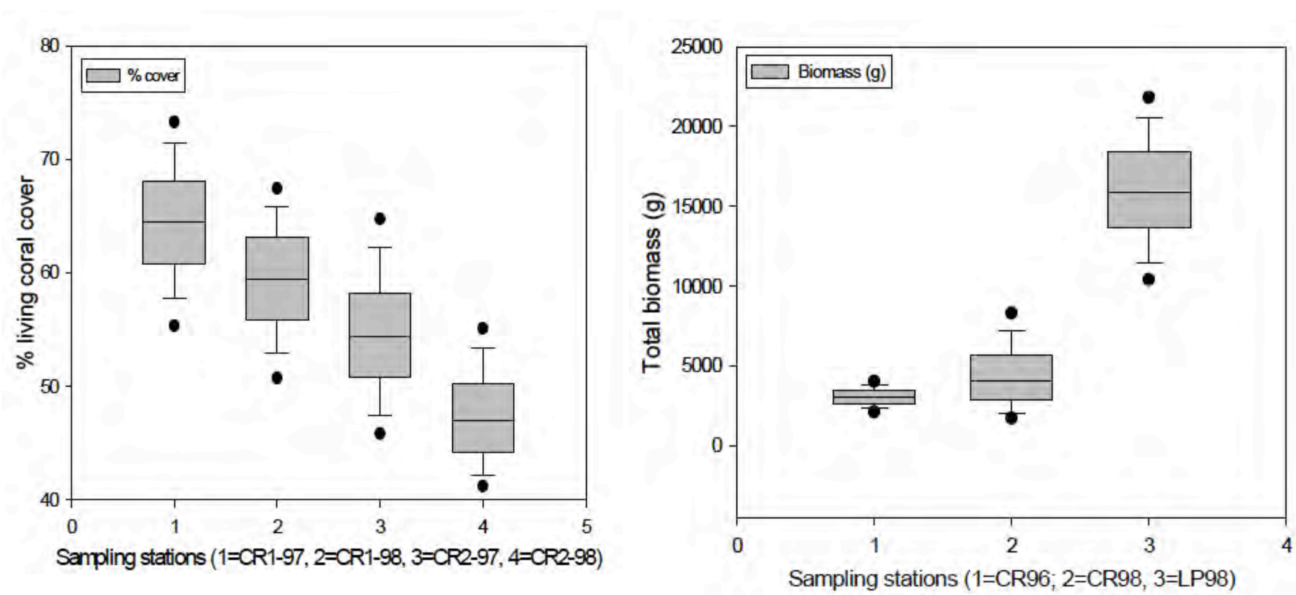


Figure 8. (Left) Shows % of living coral cover (45 - 65%) in 1997 and 1998 at two stations CR1 and CR2; (Right) show fish biomass at Carlos Rosario (CR) vs. a Luis Peña (LP) station (Hernández-Delgado 2000).

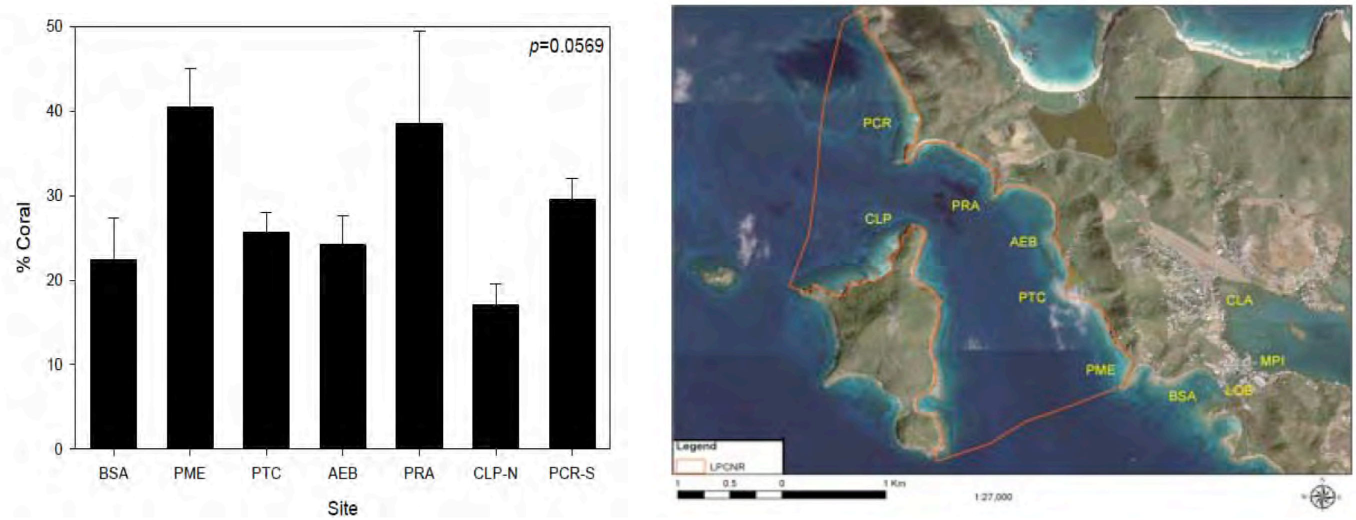


Figure 9. Shows live coral cover (20 to 40%) from 2008 for sites near Luis Peña Channel going from south to north (Norat, Mattei and Hernández-Delgado, 2009)

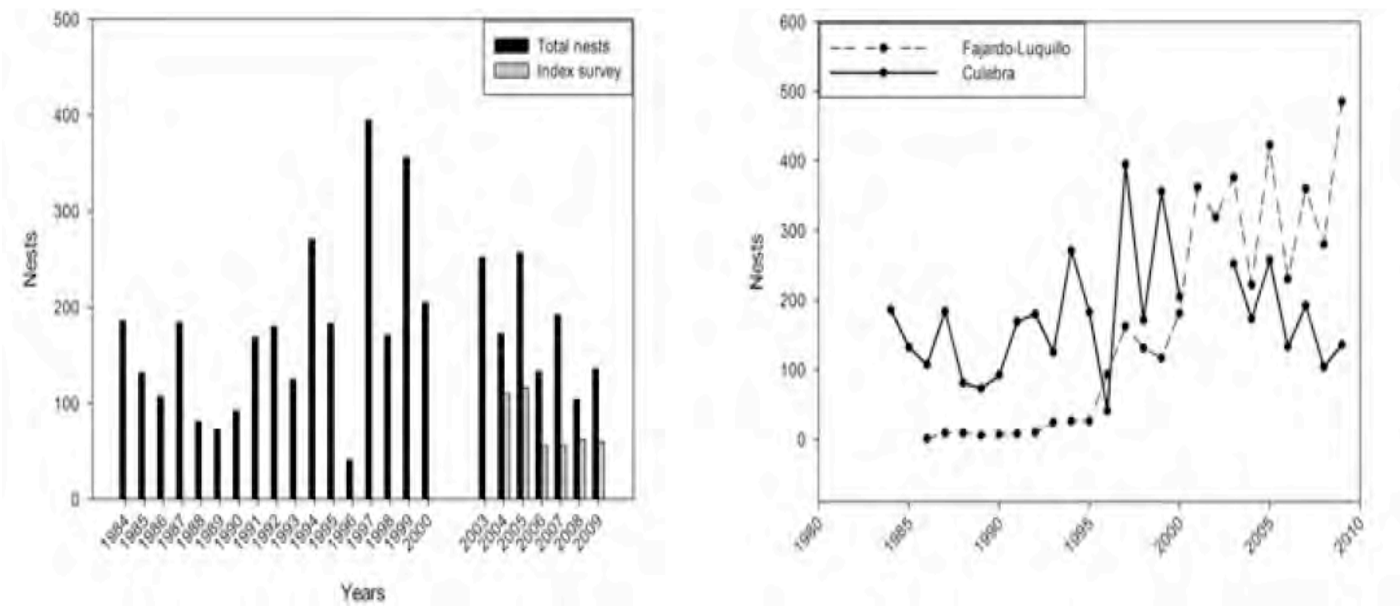


Figure 10. Nesting leatherback turtles in Culebra (1984-2009) (left); nesting leatherbacks in Culebra versus Fajardo-Luquillo area (Diez et. al., 2010)

Climate Change

Climate change poses an additional risk to island communities due to exacerbating existing challenges related to storms and hurricanes, food insecurity and coastal inundation. More frequent hurricanes cause physical damage to coral reefs, and increases in high sea surface temperature events (SSTs) are responsible for coral bleaching (Hernández-Delgado, 2009). Figure 11 (left) illustrates the above-normal SSTs at Bahia Tamarindo in Culebra from 2003-2008 where each of the years had periods when temperature levels exceeded those that threaten coral reefs. Figure 11 (right) shows recent high energy activity associated with hurricanes in the Atlantic/Caribbean (NOAA, 2013). Figure 12 shows the potential threat of ocean acidification as a result of CO2 loading into the world's oceans and them becoming increasingly acidic and less hospitable for coral reefs (Feeley et al. 2006). The impacts of high SST events can be mitigated by addressing the local sources of pollution in Culebra. However, increasing acidity of the oceans is an issue that can only be dealt with by reducing CO2 emissions globally.

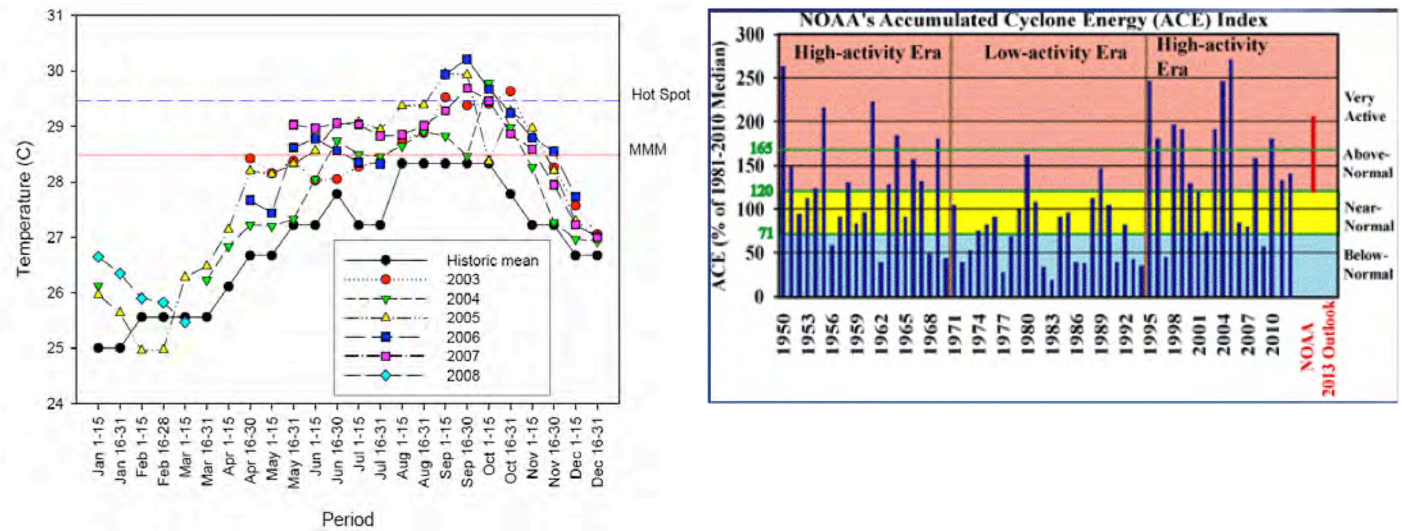


Figure 11. (left) SSTs at Bahia Tamarindo (2003-2008) vs. historic mean (Hernández-Delgado, 2009); (right) Atlantic NOAA Hurricane/Cyclone Intensity Index from 1950-2012 with 2013 predictions (NOAA, 2013)

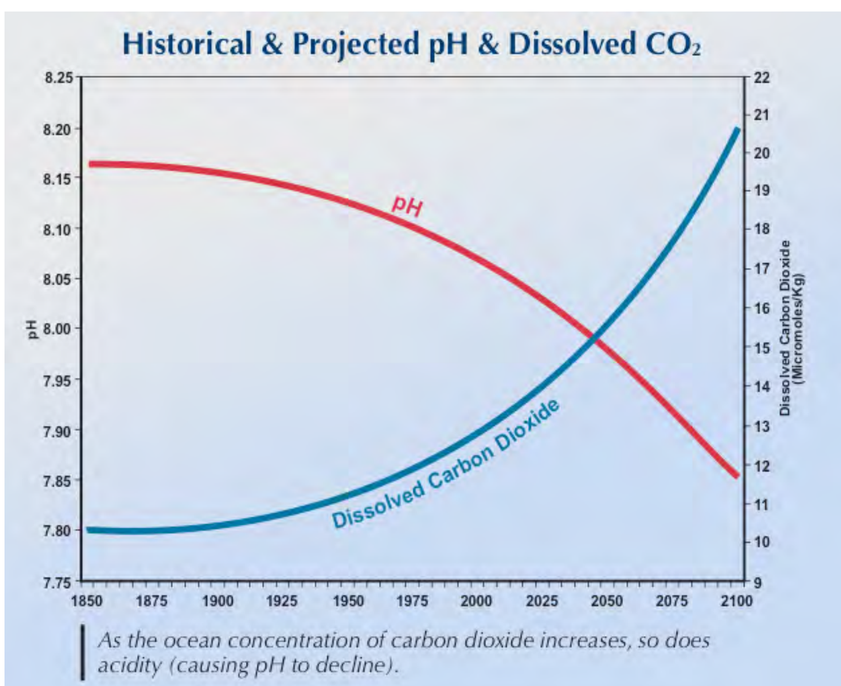


Figure 12. Current and Future Ocean Acidification Estimates (Feeley et al. 2006)

Section 3. Existing Conditions

History

Culebra is a small island off the northeast coast of PR, part of the Cordillera chain of islands and Cays. It is closer to St. Thomas, USVI than to mainland Puerto Rico, and was historically one of the Spanish Virgin islands. In pre-colonial times, there is evidence that that Culebra was settled by Caribe Indians native to South America who fished and traded throughout the Lesser Antilles. In the post-colonial period under Spanish rule in 1881, Ildelfonso was established as a small fishing and agricultural outpost -- lumber, charcoal, turtle shells, tobacco, salted fish, plantains, and livestock were some of the commodities produced. After US occupation of Puerto Rico in 1898, the US Navy began planning military training exercises in 1901, which included artillery training and various other maneuvers. There was an intensification of military exercises beginning in 1912-1914 and before and during WWI and WWII, which involved an intensification of bombing, the use of mines, air to land and sea bombing impacting coral reefs and coastal habitats (Romero-Sanes, 2011). This period of occupation and dislocation ended in 1975 when public protest resulted in the military leaving Culebra. Efforts to clean up the formerly bombed area were generally confined to the northern reaches of the island (now off limits to the public). The north side of Flamenco Beach and campgrounds continue to this day with very little actual cleanup having taken place. The authority for cleanup generally rests with the US Army Corps of Engineers (USACE) and on-going studies quantifying the need for removal of munitions have resulted in limited removal of surface munitions found in the public areas of the Flamenco campground. The timeline for removal is anticipated to last for 30-40 more years. Much of the potentially contaminated/dangerous lands are set aside as part of the Culebra National Wildlife Refuge administered by USFWS (not slated for cleanup) and a DNER reserve but many munitions are located in the public marine environment and pose risks to divers, snorkelers and wildlife. A small child recently received burns by unspent munitions (containing white phosphorus) picked up at Flamenco Beach; this underscores the need for a much more rapid and thorough cleanup than is currently underway.

According to the Army Corps of Engineers (USACE, 2012),

> *"Culebra's training ranges were used for naval bombardment, aerial bombing, rifle, mortar and machine gun practice, involving hundreds of thousands of rounds of munitions. Over the years, some of the munitions and debris may have deteriorated or have become covered by vegetation. Others can still be found on the surface, particularly in the area of the Flamenco (Northwest) Peninsula. Many munitions that the Navy used are now most likely below the ground surface."*

Since the Navy departed, Culebra has seen a growth in population and return of residents dislocated by the occupation, as well as new residents from mainland Puerto Rico and North America. Cuebra also has part-time residents including winter retirees, people with vacation homes from mainland Puerto Rico and North America. Much of the large-lot development has taken place in sensitive areas that are serviced by an extensive dirt road system, producing additional stress on the coastal ecosystems (i.e., dirt roads produce between 10 and 100 times the amount of sediment that a forested or field landscape does) (Ramos-Scharrón et al., 2009). Other development has occurred adjacent to existing dense development and has often resulted in poorly controlled site development where highly erodible soils are transported to the nearshore marine areas and Ensenada Honda Bay during construction. In addition, increases in tourism also provide an additional stressor to the Culebra ecosystem as much of the existing sewage infrastructure is not equipped to handle the crowds and less than half of the homes and businesses with access have been connected to sewer. The greatest crowds are generally seen in the summertime (from the mainland and North American) and the winter (tend to be from other countries).

Population and Land Use Plan (Planification)

Culebra's population has ranged from a low of 500 during military occupation and dislocation to 1900 in 2010. One can see a general trend in population increase from 1200 people in 1980 to 1900 people currently (PR Sea Grant, 2008)(Figure 2). According to the land use plan, around 50,000 visitors come to Culebra via the airport and some estimates have placed the annual visitors to Culebra at 500,000 to 1 million annually with most arriving by ferry. Resource-based tourism plays a huge role in Culebra's economy.

Zoning in Culebra (Figure A-1) has historically been relatively restrictive with much of the island being in conservation or zoned for either 5-acre or the more restrictive 20-acre residential/conservation zoning outside of the main developed areas. There are several exceptions to this: 1) in Zoni beach where two areas are zoned for 1-acre residential; and 2) the land above Melones beach, which is zoned for 1-acre residential and is a relatively dense development near an important coral reef snorkeling area at the beginning of the Luis Peña Marine Reserve. There is also pressure for both permitted and un-permitted growth near developed areas and potential annexations of higher density development. The land use plan was changed to reduce some of the minimum lots sizes at the end of 2012 but the legality of these changes are being challenged.

One of the greatest concerns with future new development and increased density is the lack of effective sediment and erosion controls and the lack of post-development stormwater controls -- in this fragile ecosystem the utmost care needs to be taken to minimize impacts to coastal waters and coral reefs. Other problems include the extensive dirt road network needed to service 5-acre zoning (sediment from dirt roads results in 10-100 times more sediment than paved roads) and the lack of standards and controls for the construction and maintenance of such roads. Lack of erosion and sediment control measures for sites under an acre of disturbance, the number of structures per parcel and the lack of controls for nitrogen in new septic systems are issues as well.

Soils and Geology

Upland soils in Culebra are dominated by Descalabrado Clay Loam (DeE2) and Rock land (Rs) (Figure A-2). Descalabrado Clay Loam soils are characterized by steep slopes, shallow bedrock, rapid runoff, low rainfall and hazard for erosion. DeE2 soils are also prone to erosion especially when associated with roads or clearing for development. Rock land (Rs) soils are dominated by rock outcroppings and very shallow soil material lying between the outcrops and stones. The Rock land (Rs) soil series makes up 10-15% of upland area soils and is predominant in the steep hillsides. For both DeE2 and Rs series, severe limitations are noted for development, roads and septic systems according to the Humacao USDA Soil Survey (USDA, 1969).

Given the existing scenario of soils and geology, it is not surprising that the failure of septic systems is common in both small-lot residential communities and in lower density, large-lot subdivisions where septic input into fractured bedrock can cause impacts to reef areas. Development of upland areas, even at low densities with an extensive road network, creates added stormwater runoff on highly erodible soils and steep slopes, which can transport high levels of sediment to coastal waters. In addition, concentration of runoff with development occurring above natural quebradas/intermittent channels can also result in significant channel erosion and sediment transport to coastal waters.

Governance

Culebra is the smallest Municipality in Puerto Rico and is governed by an elected Mayor who serves a four-year term of office. Culebra is also one of the only municipalities in Puerto Rico to have an agency dedicated to environmental protection – this was created by a law called Act 66 – the Conservation and Development Act – which created ACDEC (the Authority of Conservation and Development of Culebra). It is charged with overseeing the conservation and protection of Culebra as well as providing oversight for new development. ACDEC provides an important opportunity to further protect the environment (e.g., limiting clearing, mandating erosion and sediment control practices and measures to minimize the impact of dirt roads during the development process). This local control is important to safeguard the natural resources of Culebra, though one challenge is that ACDEC sometimes lacks the training and resources to do its job.

Culebra Subwatersheds

Culebra is approximately 11.6 square miles and to heighten our focus on the resources in different areas of Culebra we have broken the island into 37 subwatersheds (Figure 13). This helps highlight specific management efforts needed in specific subwatersheds as well as identify the existing and future threats and stressors to these systems.

Figures 14 and 15 show the relative contribution of various watersheds to nitrogen and sediment pollution. Appendices A-3 and A-4 show the land use breakdown analysis that was to be performed based on zoning and existing land use in order to create an accurate land use layer for Culebra. That layer and additional assumptions in Appendix A-3 served as the basis for our model.

Figure 13. Culebra Subwatersheds

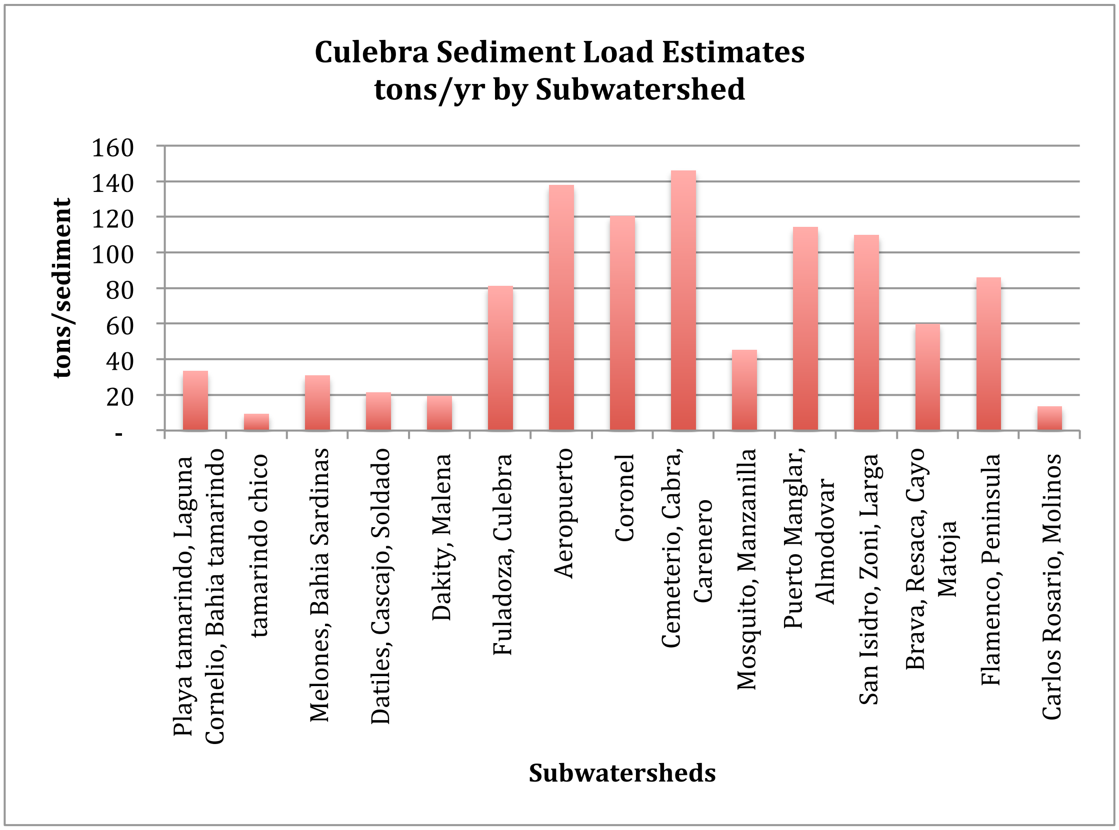


Figure 14. Sediment loadings by grouped (adjacent) subwatersheds

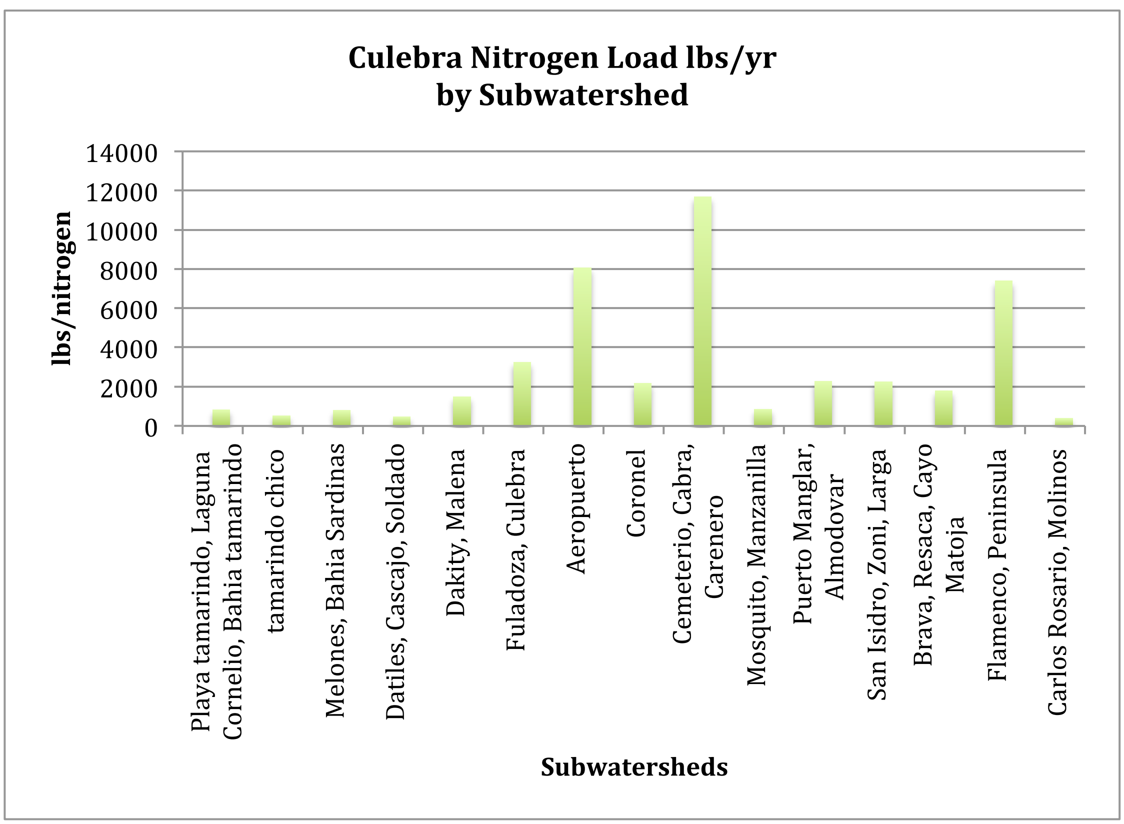


Figure 15. Nitrogen loading by Subwatershed groupings

Several notes are useful when interpreting the sediment and nitrogen loading graphs:

1. The WTM produces relative (expected) loading estimates based on land use, impervious cover and point sources (assumptions can be found in Appendix A-4).
2. The model does not account for situations where sediment loads or nutrients loads may be trapped or processed by wetland or lagoons (i.e., sediment loads for Flamenco are high but most are trapped in Flamenco Lagoon).
3. Some subwatersheds or groups of subwatersheds have larger land areas than others and can be reflected in higher loads in contrast to some subwatersheds like Tamarindo Chico, which are very small.
4. Loads associated with the WWTP are reflected in Cemeterio/Cabra and Carenero as that is where the effluent is discharged despite the source of the sewage being from more developed subwatersheds.
5. Sediment loads are not estimated based on individual dirt roads (where there can be a lot of variation) but rather on the sediment losses expected from dirt roads in general – a more detailed analysis was beyond the model capability – but the impact of individual road sections were evaluated in our fieldwork and that of Ramos-Scharron (2009) and we have used that information to prioritize the unpaved road sections that we evaluated (Section 4).
6. The amount of channel erosion was estimated in the model based on observed field conditions and high, medium or low coefficients were applied.
7. Subwatersheds were grouped to reflect similar land uses and drainage to particular areas of interest such as important coral reef areas.

Conclusions

- Aeropuerto is a subwatershed of particular importance due to the amount of impervious cover, bare soil areas, stormwater runoff, leaking septics and rapid conveyance into Ensenada Honda.
- Cabra, Cemetario and Carenero are important due to the high nitrogen load from the WWTP and the sediment load due in part to the size of the subwatershed.
- Flamenco generates a tremendous amount of nitrogen and there is high potential for losses into the marine environment since the infrastructure there is aging.
- Fulladoza has a high potential for both nitrogen and sediment due to the density of unpaved dirt roads and the use of septic systems.
- Coronel is an important focus area for sediment due to the high loads generated in part due to the lack of effective stabilization and sediment control practices.
- Puerto Manglar and Almodovar are important due to the density of unpaved dirt roads and the estimated sediment loads.

Section 4. Restoration Measures and Opportunities

Restoration/Protection opportunities were identified through the fieldwork and the stakeholder process and include:

1) **Green infrastructure/ stormwater retrofit** practices that address stormwater runoff or other sources of pollution using natural landscapes, vegetation and soils.
2) **Community stewardship and pollution prevention** -- these include restoration projects with significant community involvement and planning such as urban agriculture, trash cleanups, reforestation and rain gardens. Also included are pollution prevention projects including addressing existing construction sites with poor erosion and sediment control.
3) **Stabilization of dirt roads and bare soils** – these projects have been prioritized based on research by Ramos (2009) and our field evaluations. It should be noted that the list is not complete since some areas were not accessable due to private property/lack of access and new impacts are continually created.
4) **Illicit discharge: water quality pollution monitoring and source tracking** is where confirmed or potential sources of contamination are located and eliminated, in many instances the elimination of a confirmed illicit discharge will either be structural (plumbing fix, connecting to sewer) or a form of treatment of sewage (wetlands, small-scale wastewater treatment).
5) **Constructed treatment wetlands and advanced treatment of septic effluent –** constructed treatment wetlands are intended to address an existing pollution source or a source of elevated nutrients by creating wetlands, which serve to process nutrients and other contaminants, similarly treatment wetlands or even landscaped areas with a liner or impermeable layer can be used to treat sewage or septic effluent to process the nutrients so they do not get released to the marine environment.
6) **Coral restoration and coral farming –**is the process of cutting and raising small bits of coral for future planting on coral reefs where coral has died due to bleaching or other events.
7) **Coastal lagoons – determining the functionality and sediment deposition** – Coastal lagoons help to protect nearshore coral reefs and coastal waters by providing a natural filter and depositional area for sediment – they often form naturally due to the active formation of a beach berm and intermittent sources of water and runoff – evaluating these natural features for restoration potential is an important scientific effort that needs to occur.
8) **Improved policies –** improved policies, enforcement and local control over the development and protection process is critical to effectively safeguard the natural resources of Culebra.

The following descriptions provide some additional information and photos of suggested restoration methods and policy improvements. The restoration projects and dirt road and bare soil projects are prioritized based on criteria summarized in the respective sections. Potential illicit discharges were noted when identified during the upland green infrastructure/stormwater retrofit fieldwork but are summarized in the more extensive monitoring and source area tracking portion of this section. Locations of the potential restoration projects in the first three categories -- green infrastructure and pollution prevention are mapped, as are the locations of road and bare soil stabilization projects and potential source areas for pollution that were monitored.

Green Infrastructure and Treatment of Stormwater Runoff

Green infrastructure (GI) is constructed to intercept stormwater runoff and utilize plants (often native vegetation), soils and natural processes to filter and reduce runoff pollution through incorporation into vegetation and evapotranspiration. Examples of GI include rain gardens, biofilters including bioretention, and recreating wetlands and natural processes to reduce pollution. Figures 16 and 17 show several examples of green infrastructure projects. While in the field evaluating opportunities for GI, we also came across locations where potential or confirmed illicit discharges (some obvious form of contaminated water was entering the a street, coastal waters or a conveyance channel) were identified. These were noted and described in Table 4, along with the prioritized green infrastructure projects – additional illicit discharge detection and elimination projects have been highlighted in the monitoring portion of this Section.

Each of the green infrastructure restoration opportunities was evaluated for 4 factors:

1. Its impact on water quality focused on the priority pollutants established for Culebra (nutrients, sediment, and bacteria) on a scale of 1-5. 1 represents a low beneficial impact on water quality and 5 being a high beneficial impact on water quality.
2. Its impact on community and public education on a scale of 1 to 5, with 5 being a high potential for public education.
3. Its feasibility of implementation reflecting ownership, permitting, and space available. With 5 being highly feasible and 1 reflecting low feasibility.
4. Impact reflects the overall scale and impact of the project and its ability to address critical problems in the Culebra watershed area. 10 being the highest impact and 0 being the lowest impact.


Figure 16. Rain garden from St. Croix and streetscape biofilters from Santa Monica, CA

Community Stewardship and Pollution prevention

Pollution prevention and residential stewardship projects are important for community engagement and include projects such as trash cleanups at the northern beaches (Resaca and Brava) and projects to increase urban agriculture in the community. Pollution prevention projects in Culebra were focused ESC on construction sites.

Road and Bare Soil Stabilization

Stabilization of bare soils (Figure 18) involves the rapid re-stabilization of vegetation and generally a transition to more native and stable forms of vegetation. One effective way to re-establish vegetation in an area is to utilize hydroseeding followed by watering to rapidly transition to a more stable vegetated system where runoff is reduced. Dirt roads are stabilized using methods to remove water from the road and reduce erosion. These include concrete or dirt cross-swales, check dams and sediment traps. The recommendations for dirt road and bare soil stabilization are found in Table 5, maps are found toward the end of the section in Figures 23 and 24, and a dirt road layer created for the island is shown in Appendix A-5.

Each of the restoration projects is important in its own right – some of the smaller projects may lack the magnitude of change that higher ranked projects, but their lower costs make them worth considering. This suggests bundling some of these projects during implementation (e.g., a project may be to address stabilization practices on ten dirt road sections in the same week).

The bare soil and dirt road prioritization used several factors for evaluating the importance of individual projects; these include:

1. The severity of potential erosion: based on slope and the percentage of fine particles available for sediment transport and the perceived frequency of maintenance of the dirt road. Ramos (2009) demonstrates that frequency of maintenance and the percentage of fine particles available for transport are key factors in sediment loss. Maintenance is defined as maintenance using heavy equipment backhoes and bulldozers, which results in considerable disturbance exposure of fine soil particles.
2. Transport factor: the ability of the sediment to be transported to the nearshore marine environment and to a lesser degree to be transported to coastal lagoons important for processing/trapping sediment and other contaminants before reaching the marine environment. A high transport factor leading to the marine environment, particularly with likely transport to coral reefs would rate a 5 on a scale of 1 to 5. A site that drains to a coastal lagoon or wetland may receive a score of 2 to 4, based on the size and level of impact on the lagoon or wetland.

Figure 17. Before and after stabilization at Tamarindo Beach in Culebra

Figure 18. Dirt roads as a source of sediment (note the surface runoff over the roads creating erosion and resulting in fine sediment losses

It should be noted that all exposed soil and dirt roads transport sediment at a rate of 5x to 100x the natural transport rate from a forest or a field, so maximizing the amount of roads treated is a critical element of the watershed plan, as is reducing the impact of future road development.

Constructed Treatment Wetlands and Advanced Treatment of Septic Effluent

Constructed treatment wetlands and advanced treatment systems for on-site septic/wastewater systems are key components of reducing nutrients to nearshore waters. Constructed wetlands are created using either existing soils in a low area or by using clay or a manufactured liner then adding plants and organic matter creating a wetland, which is nature's way of reducing nutrients and other contaminants. Advanced treatment of septic system effluent refers to methods that significantly reduce nutrients (particularly nitrogen from wastewater). There are various ways to treat the effluent using wetlands or a vegetated landscaped area, but the key is to keep nitrogen from infiltrating into the soil and maximizing nutrient removal via vegetation and uptake or by promoting denitrification. Examples of a pump and treat system are found in Figure 19 - the effluent can be pumped to a constructed wetland such as is shown in the figure. These efforts should be focused at the WWTP (that historically used wetlands to treat the effluent) and at hotels and small communities on septic systems that cannot be easily connected to the WWTP.

Figure 19. Pump and treat system effluent is pumped from homes to a constructed wetland or landscaped area

Coral Restoration

Coral restoration involves the propagation of corals, in this case Staghorn coral (*Acropora cervicornis)* (Figure 20), and to a lesser extent other species including Elkhorn coral (*Acropora palmata*). These species have been decimated in the Caribbean - over the last 30 years there has been an 80 – 90% decline. Tamarindo Beach and Punto Soldado are two areas in Culebra where there have been restoration efforts. The goal of coral restoration efforts and out planting of corals has been to re-establish *Acropora* populations in the area. The community project of Coral Reef Rehabilitation and Aquaculture began in 2003 and has been led by the Society of Marine Environment (SAM) and Coralations in collaboration with the University of Puerto Rico Center for Applied Tropical Ecology and Conservation (CATEC). Subwatershed restoration efforts should also be implemented to protect these important coral propagation areas that also contain coral reefs that are being restored and that are in relatively good condition.


Figure 20. Coral restoration efforts in Tamarindo (Photo credit: CESAM)

Coastal Lagoons – determining the functionality and sediment deposition

Coastal lagoons serve as natural filters for contaminants and runoff, however many of the coastal lagoons in Culebra have had extensive sediment deposition due to often poorly controlled sediment on construction sites and on dirt roads (e.g., Zoni, Mosquito, Flamenco). Additional investigations by UPR Rio Piedras or other investigators are necessary to determine the extent to which these lagoons have filled with sediment in more recent times and the extent that their holding and processing capacity for sediment and other contaminants has been diminished. This lost capacity would result in a reduced ability to protect the coastal nearshore ecosystems. The study would be accomplished by hydrologic modeling as well as by studying soil cores to determine the historical rates of deposition in the lagoons. This would help to determine any need to address the deposition of sediment within the lagoons.

Improved Policies

A number of improved policies, enforcement and management are proposed to reduce sediment transport to local waters:

1. Decrease the disturbance size limit triggering mandatory erosion and sediment control (ESC) on new construction sites and provide local training and enforcement by ACDEC and Rangers including the issuing of stop work orders and fines. Reduce the current policy in Culebra for ESC (a 1-acre threshold for disturbance - the federal minimum standard) to a 2000 sq/ft disturbance minimum threshold. This is important since development in Culebra is occurring frequently at small- and medium-sized parcels, often below the current threshold, which cumulatively can contribute on average more than two tons/acre of sediment to coastal waters. To enforce the new limit, hire an erosion and sediment control inspector for the island – the position could also serve as a restoration coordinator working to address illicit discharges and help to implement the watershed plan and restoration projects. Impose fines and stop work orders for non-compliance as a standard, as well as a fee-based ESC permit based on the amount of clearing.

Figure 21. Silt fence at the Tamarindo restoration holding back sediment from nearshore waters from an upland dirt parking lot and restoration project

2. Create guidelines for the construction and maintenance of dirt roads in order to reduce their impact. This should include the specific options for best management practices to reduce sediment losses. These standards would be endorsed by ACDEC, DNER and USEPA and would be mandatory and subject to enforcement. Provide training for local contractors and agency staff.

3. Increase education about and enforcement of MPAs and in the future consider expansion of Marine Protected Areas (MPAs),. Include enforcement of no anchoring, no fishing and other regulations pertaining to MPAs. There may need to be an additional enforcement and education entity - perhaps ACDEC or a local nonprofit. Recent studies have suggested that MPAs should be at least 100 square kilometers in size and effectively enforced or they will be ineffective at protecting species and ineffective at providing a source area for fish and other marine species to help repopulate nearby areas (Edgar et. al., 2014). In the future, convene a panel and process to expand the MPAs in Culebra with strong representation from Culebrenses, tourism operators, scientists, the commercial and sport fishing communities and agencies such as DRNA.

Table 4. Green Infrastructure and Pollution Prevention Projects

Site	Project Type	Description	Next Steps
Very High Priority			
AP-8 Airport concrete channel ROW	Green Infrastructure	Diversion of road-side swale (AP-7) and two existing drain inlets into a series of surface sand filters in the grassed area between the concrete channel and the fence line to capture and treat runoff from PR-251 and residential area on the adjacent hillside. Surface sand filter to have underdrain and overflow back into ex. concrete channel; grassed surface that can be mowed; and will not have permanent standing water (meeting FAA policies).	Investigate depth to groundwater and infiltration potential to determine if an infiltration basin may work here.
DT-4	Green Infrastructure Retrofit	Create streetscape bioretention, inset bioretention and a constructed wetland area to drain large hillside paved area - road, El Eden, and Library	Determine property ownership; Vet project with community
AP-6 JI Concrete	Pollution prevention/ Green Infrastructure	Treat as active construction site requiring ESC practices; install gravel pad above paved entrance; use swales and vetiver grass attenuate sediment and convey flows to a sediment basin; in the basin use vetiver grass to attenuate flow and trap sediment using vegetated half moons leaving two areas for cleanouts; perforated pipe outlet structure from sediment basin to a level spreader near vegetation at entrance; clean up sediment deposited across PR-251 where drains to concrete channel at airport.	USEPA to share permit and pollution prevention plan; Discuss options with owners; and go to concrete plant up the road to evaluate conditions.
AP-7 (A-D) PR-251 Right-of-Way (ROW)	Green Infrastructure	There are 4 locations along the curbless, north side of PR-251 where concentrated drainage from the road network is currently eroding through the grassed ROW down to the concrete channel at the airport. In some cases this runoff carries a lot of sediment, has created a 2 ft. deep trench, undermined a fence, or contributed to slumping of the concrete panels in the channel. We recommend installing either a grass swale or concrete swale/curb combination to carry flows down road to a larger retrofit (AP-8). If not addressed as part of a larger retrofit project, it is recommended to install paved flumes with pretreatment sumps at these locations at a minimum.	Investigate drainage area coming to each potential inflow point and to existing box culvert (AP-13) that comes in to concrete channel about mid-runway (this was probably a tributary that was piped). Determine if this drainage area can be captured by proposed practice;· Calculate required sizing for facilities to get a better sense of the surface area required;· Talk to airport and DPW about options and potential maintenance requirements (mowing, sediment removal, herbicides etc);· Discuss if it makes sense to remove concrete channel completely and replace with grass-lined channel; Weigh cost/benefits of surface sand filter vs gravel wetland.
AP-4 Carlos Jeep Rental	Green Infrastructure, Source Control	Tie in existing trench drain to a linear bioretention with underdrain along wall. Underdrain and overflow to discharge to PR-250 at existing rear discharge pipe. Hook business up to sewer line which runs along PR-250.	Talk to owner about feasibility of installation along wall; and Determine if garage area should be drained to the sanitary sewer rather than stormwater system.

Table 4. Green Infrastructure and Pollution Prevention Projects

Site	Project Type	Description	Next Steps
EC-1	Pollution Prevention	A new residential development has a post-construction stormwater pond that is discharging turbid water. This pond was likely also used as a sediment basin during clearing and construction period, it was perhaps never excavated before turning "on" the permanent stormwater drainage. Recommend excavating sediments, stabilizing exposed slope adjacent to facility, and perhaps modifying existing outlet structure to provide better water quality treatment. The pond outfall drains under road through residential area and discharges to Ensenada del Coronel. Turbid discharge was noted at this location, as well as potential illicit discharges.	USEPA to pull application and design plans for stormwater; and Contact owner/engineer to discuss potential options; Test water quality at outfall for indicators of sewage and detergents; and Determine if repaving of road in front of store/neighborhood entrance needs to be done by owner (was this due to heavy construction vehicles)
High Priority			
EC-3	Pollution prevention	Investigate active construction/road paving; stabilize hillside cuts	USEPA to pull application and design plans for stormwater; and Contact owner/engineer to discuss potential options.
RB-1 Resaca Beach	Community Stewardship/ Pollution prevention	Organize a trash cleanup for previously collected and newly deposited trash. There are a number of piles of trash that have been compiled in the vegetation behind the beach already; these are difficult to remove given limited access and distance from road/parking lot.	Discuss with fish and wildlife options for hosting a cleanup day and whether removal by boat is possible (during summer months when seas are calmer); and Coordinate with local schools or college students to organize volunteers.
BB-1 Brava Beach	Community Stewardship/ Pollution prevention	Organize a trash cleanup for previously collected and newly deposited trash. There are a number of piles of trash that have been compiled in the vegetation behind the beach already; these are difficult to remove given limited access and distance from road/parking lot.	Discuss with USFWS options for hosting a cleanup day and whether removal by boat is possible (during summer months when seas are calmer); and coordinate with local schools or college students to organize volunteers.
DT-1	Green Infrastructure	Runoff from Port area as well as the area around Ricky's Gas Station. Retrofit could take several shapes – sand filter at Rickey's station, Cantilevered sand filter with native vegetation/grasses, DE sand filter at end of port.	Determine ownership—Port Authority or Municipality; Input from community; Feasibility of cantilevered practice.
DT-2	Green Infrastructure	Main Port area with heavy use and high IC – difficult construction activities since port is always open.	Sand filter/bioretention; Determine port/ municipality schedule and ownership.
DT-3	Green Infrastructure	Port Admin area and steps down to old landing – limited space.	Feasibility based on port interest and willingness.
DT-3B	Green Infrastructure	Delaware Sandfilter.	Feasibility based on interest and willingness.

Table 4. Green Infrastructure and Pollution Prevention Projects

Site	Project Type	Description	Next Steps
DT-8	Green Infrastructure Community Stewardship/	Zoni Beach area has potential for soil stabilization of a dirt road, road improvements for an eroding road and a biofilter for treatment of road runoff.	Evaluate conditions during a storm event to determine preferential flow paths and transport of pollutants to sea; Discuss potential project with community; hold a design charrette with community if this is a high priority site for them.
AP-5 PR-250 outfall	Green Infrastructure	Install series of baffles/weirs in concrete channel to trap sediments. Consider diversion of low flows into a shallow rain garden adjacent to channel, although depth to water table and tidal backup may be issues. Repave concrete dip across PR-250.	Further investigate depth to groundwater and tidal issues; Discuss options with two adjacent homeowners; and discuss maintenance with DPW.
AP-14	Green Infrastructure	Direct runoff at end of residential road spur is causing erosion down slope into the large grassed channel. Install catch basin and outflow pipe at end of road to safely convey flow to channel.	Check property ownership and coordinate with municipality.
AP-15 East Airport road and PR-250 intersection	Green Infrastructure	Vacant land on east side of road intersection could be used to manage runoff from coastal road and CII 1, and potentially from residential area uphill in a constructed wetland. Install catch basins in residential roads and vegetated swales along road to convey runoff to constructed wetland. Overflow can tie into existing culvert at intersection or a new discharge to mangroves.	Investigate property ownership and potential for acquisition; Evaluate neighborhood road drainage and potential for curb inlets; and evaluate whether conveyance swale can extend up to the boat repair yard.
FB-1	Green Infrastructure	Install rain garden in existing grassed are on the south-eastern edge of parking lot at Flamenco Beach. Use existing paved swales in parking lot to convey flows into practice. Include interpretive signage linking watersheds and blue flag beaches.	Determine feasibility given unexploded ordinance issues;· Evaluate whether a second practice downstream of septic and grease trap would also be desirable behind maintenance building.· This would be a great and highly visible project.
AP-12 A/B Airport Parking Lots	Green Infrastructure	Two rain garden options in existing grassed areas to collect parking lot runoff: A) install shallow drain in existing concrete swale, or install trench drain along curb; route to highly visible location by flag pole; raise and use existing catch basin as overflow. B) lower lot drains to southern corner; block or curb around existing catch basin to direct flows into an excavated area; tie into existing drain pipe for outlet or use simple overflow spill way towards concrete channel. Also, add a cigarette butt collector in the smoking area similar to the one out at Flamenco Beach.	Further investigate amount of excavation required for rain garden B, since the area is slightly elevated from the current elevation of the existing catch basin; and talk to airport about potential options and maintenance requirements.
TO-1	Community Stewardship/ Green Infrastructure	Locate food production farms and gardens around the community to increase availability of healthy foods and increase independence and food security.	Assist in Grant Writing for existing groups who are interested.

Table 4. Green Infrastructure and Pollution Prevention Projects

Site	Project Type	Description	Next Steps
RS-1	Community Stewardship/ Pollution Prevention	Culebra Sanctuario -- Spaghetti of old sewage pipes -- investigated and removed -- plus re-vegetation of coastal mangroves.	Determine ownership and request permission. Coordinate with CESAM, high school students and Coralations
PS-1	Community Stewardship/ Green Infrastructure	Punto Soldado - currently bare soil parking lot and vehicle access to the shoreline and erosion of a dirt access road heading to Soldado.	Determine quantity and cost estimate, determine ownership.
DT-6	Green Infrastructure/ Pollution Prevention	Dakity gas station sandfilter and pollution prevention – for fuel leaks and spills – the station and fuel pumps are 10-15ft from the water and constitute a significant risk to nearby coral reefs and a marine protected area.	Begin discussions with gas station ownership; Work on a full pollution prevention plan with owner.
DT-9	Green Infrastructure	USFWS, ACDEC, DNER Vigilantes complex area with opportunities to reduce road runoff from the site from entering the Bay using speed bumps and potentially bioretention.	Determine ownership, coordinate with partners.
AP-2 Calle Jose Narzario	Green Infrastructure	Install constructed wetland on vacant parcel at low point in the road to capture large residential drainage area. May need to be done in conjunction with AP-3.	Need to calculate DA to see if sufficient space is available; Find property owner; and Investigate existing flow path behind homes.
AP-3 Playa Clara Residential Developme nt	Green Infrastructure	New development project with paved road. There are two existing drainage inlets (one near water tank and other at bottom of road); the outfall near water tank was not located, the outlet at bottom of hill was never completed and this causes flooding issues at intersection Calles Joaquin Parilla and Jose Nazario. There are opportunities to disconnect runoff at various locations along length of road, including a rain garden.	EPA to pull drainage plan (the permit for project is up for renewal end of year and now is the time to deny approval until stormwater is revised); and Look for outfall by water tank.
TO-2	Green Infrastructure/ Energy production	Identify opportunities to create local jobs and source renewable energy for the residents and businesses in Culebra.	Assist in Grant Writing for existing groups who are interested.
Medium Priority			
AP-16	Pollution Prevention/ Residential Stewardship	At outlet of grassed channel (east of airport) consider creating a small park to include benches/tables and watershed interpretive signage. Plant additional mangroves along banks of short quebrada section.	Work with community on design funding and implementation.

Table 4. Green Infrastructure and Pollution Prevention Projects

Site	Project Type	Description	Next Steps
AP-19 Curriculum Center	Green Infrastructure	This is a good opportunity to integrate redevelopment/community recreation improvements with improved stormwater management. If potential for moving hospital here, would be good to have a stormwater drainage plan that utilizes LID (cisterns, pervious pavers, bioretention). Could use as a case study at a site design training in Puerto Rico.	Get a copy of existing design plans; Propose a redesign for stormwater and share with local government; Look for redevelopment funding opportunities.
RS-2	Community Stewardship/ Green Infrastructure	Park Creation with community and landscape architects, as well as small biofilter for any runoff from the adjacent areas.	Determine ownership and request permission; Coordinate with community.
AP-17	Pollution Prevention	Stabilize (or completely remove) the existing dirt vehicle crossing of grassed channel, just upstream of DPW yard.	Obtain gabion basket stabilized crossing detail from PR NRCS; Evaluate whether this crossing is even needed.
DT-5	Green Infrastructure	Area near work area for boats in middle of town – runoff from the adjacent DT-4 plus small untreated area.	Determine ownership.
DT-10	Community Stewardship/ Green Infrastructure	Small community use area on the way to Fulladoza Bay – used for kayaking, storage and water access. Runoff is conveyed through this area and could be treated via a sand filter or wetland and bioretention	Determine ownership or perceived ownership as the area has clearly been adopted though is likely publically owned.
DT-11	Green Infrastructure	Small area near church and Fulladoza Bay used currently to convey runoff – good location for pretreatment and treatment of runoff from unpaved roads and compacted areas. Early action project.	Determine ownership and request permission.
AP-1 Calle Jesus Maria Ortiz	Green Infrastructure	Install rain garden in corner of private lot at road intersection to reduce ponding on road surface and drainage issues on downstream property.	Talk to property owner to determine interest (name and # on field sheet).
DT-7	Green Infrastructure	Area near the police station where runoff from the parking lot would be treated. Concept is for a bioretention that would also serve as a nice amenity being close to the street as well as the police station.	Evaluate infiltration potential of soils Discuss potential project with community
EC-2	Green Infrastructure	Although this runoff is managed by a downstream detention basin, the grassed island at road intersection is large and would be a simple rain garden retrofit that could be an educational focal point for eventual residents and could be landscaped to improve aesthetics. Flows can be conveyed into practice via wide curb cuts with localized low points in asphalt OR using trench drains with curb cut overflow on downhill side.	Discuss with owners; Consider which native/ornamental plants would be most appropriate; Consider buildout potential when estimating drainage area to practice.

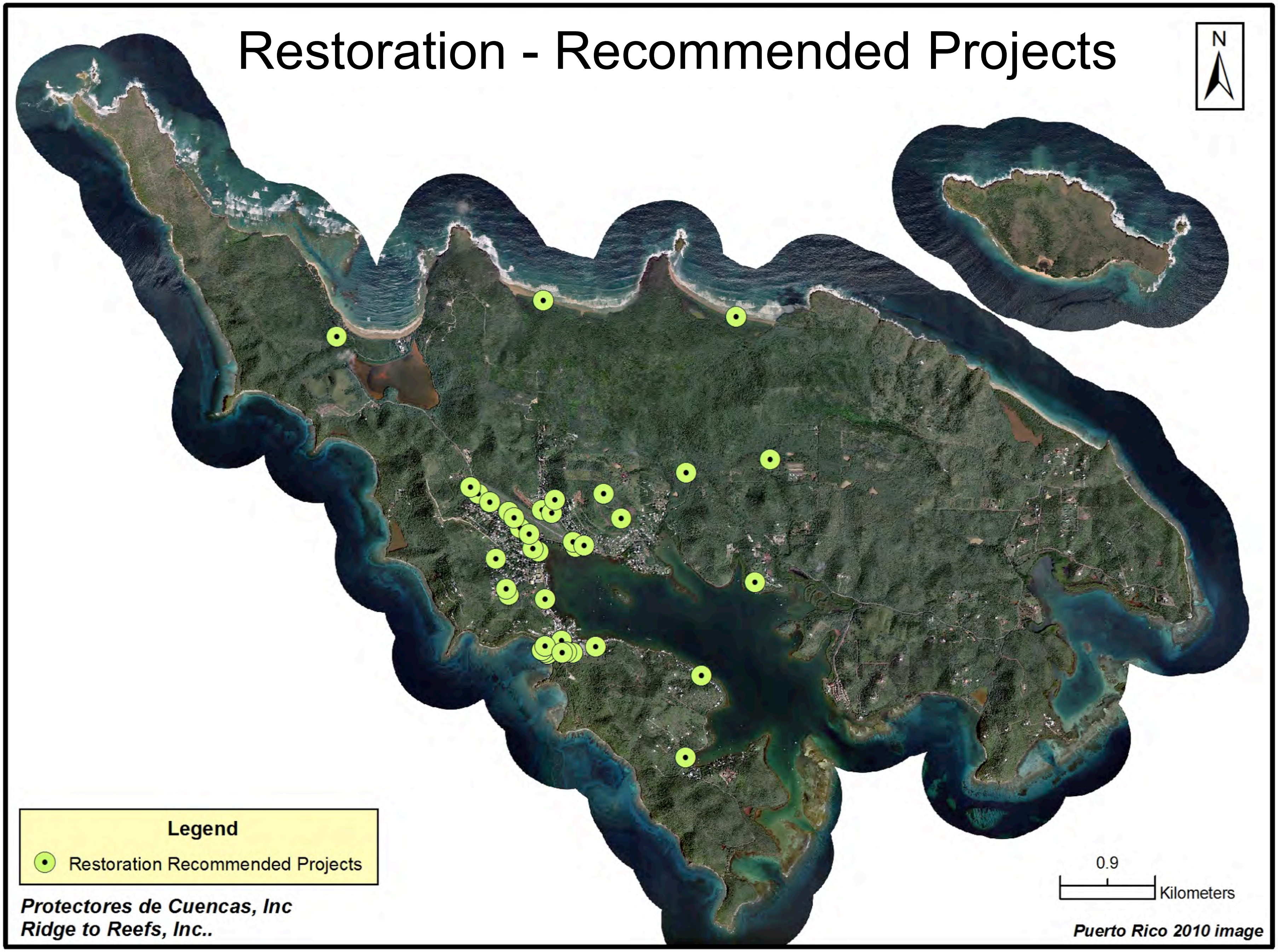


Figure 22. Locations of Recommended Restoration Projects in Culebra

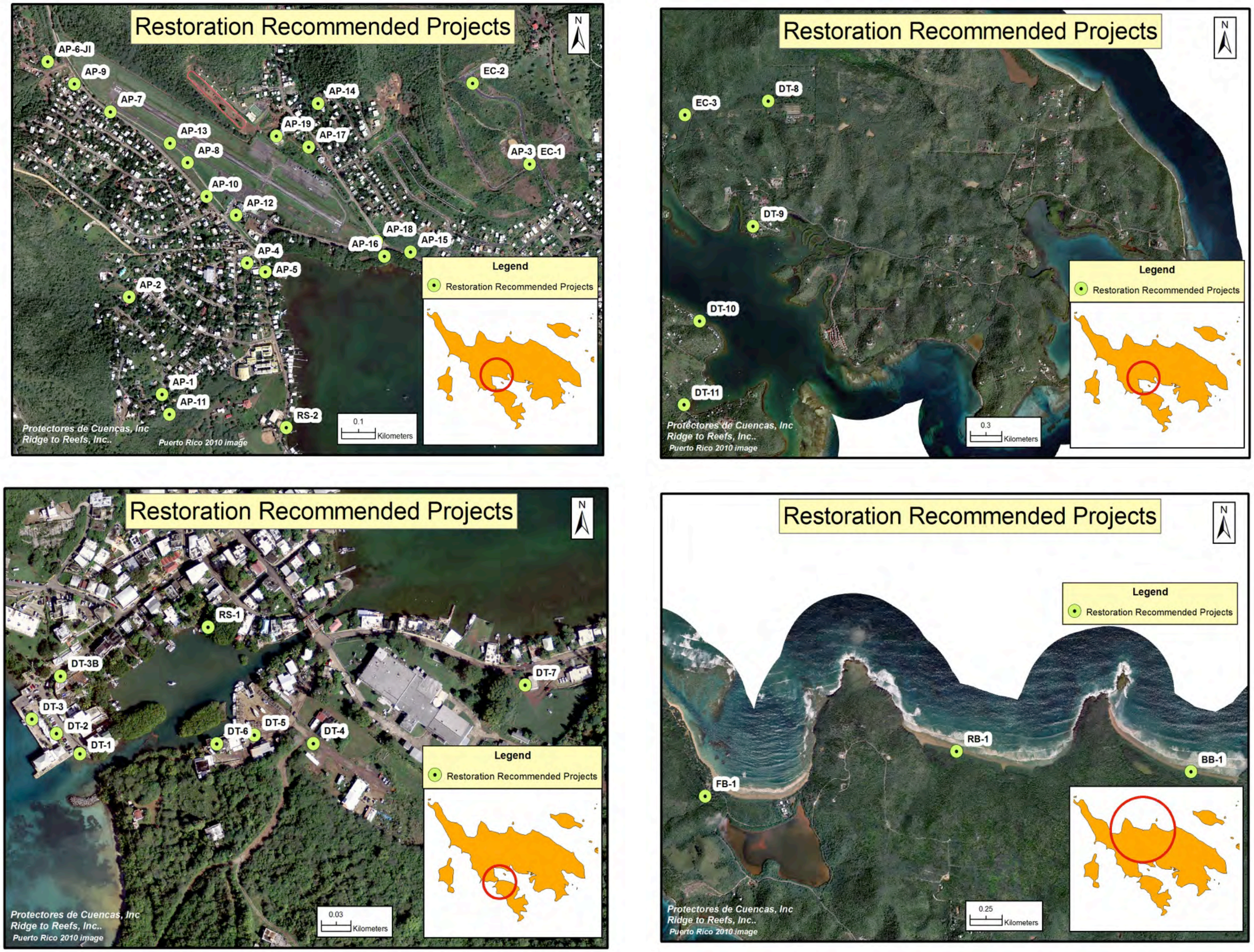


Figure 23. Site locations for restoration projects

Table 5. Soil Stabilization Opportunities

Site[1]	Description	Next Steps	Slope (%)		Estimated Dimension (ft)			Road Maint.[2]	Surface Type	Shoulder Type	Convey-ance[3]
			Avg.	Max	Length	Width	Area (ft2)				
High Priority											
PDV-3	Area of Punta del Viento Estates that generates significant runoff on a steep road. Opportunities for additional cross swales to minimize runoff and fixing a cross drain to better distribute runoff. Short Steep road- Pikey.	Discuss with HOA and request to have improvements included in maintenance efforts; Do in conjunction with sediment trap and stabilization efforts	30	45	350	20	7000	Med		95% veg, 5% gravel	High
PDV-5	Stone outlet protection. PDV Maintenance.	Stone outlet protection -- coordinate with HOA (3 buckets)			10	5	50	NA			High
PDV-7	Add a concrete cross swale or a cross drain -- should coincide with two track concrete to reduce sediment load.	Coordinate with HOA						NA			High
SW-2	Runoff flows down from the water tower area carrying sediment-- crosses road and erodes the dirt area next to the road to Lobina channel -- cross swales and sediment traps.	Coordinate with PRASA	30	45	350	25	8750	Med			
FUL-2	Water flows down a steep slope -- potential to outlet flow to natural vegetation area with a flatter slope.	Coordinate with the major landowner in Fulladoza Bay	35	55	250	25	6250	Infreq	20% bare, 40% bedrock, 40% gravel	10% bare, 50% bedrock, 40% gravel	High
PDV-4	Short steep section of PDV estates -- where most of the runoff is conveyed to an arroyo that outlets to coastal waters. Opportunity to create a two track drive to minimize runoff.	Discuss with PDV HOA and request to have these improvements included in their maintenance efforts	30	45	150	20	3000	Med			High

Table 5. Soil Stabilization Opportunities

Site[1]	Description	Next Steps	Slope (%)		Estimated Dimension (ft)			Road Maint.[2]	Surface Type	Shoulder Type	Convey-ance[3]
			Avg.	Max	Length	Width	Area (ft2)				
CEM-1	Runoff from active portion of cemetery flows out of the entrance and across the road to coastal waters.	Discuss with cemetery management and request permission	25	35	100	30	3000	Infreq	70% bare, 20 gravel, 10 veg	n/a	High
PDV-2	Rolling hills location in PDV where stabilization efforts have taken place.	Set up a monitoring program for sediment deposition – add one to two concrete cross swales to reduce flow on road surface	20	25	800	25	20000	Med	80% bare, 20% gravel	15% bare, 15% bedrock, 10% gravel, 60% veg	High
PDV-6	Broken cross drain -- fix and create level spreader for outlet, add a 3rd cross drain or concrete cross swale.	Coordinate with HOA			5	5	25	NA			High
FUL-1	Water flows down road at slight slope but is conveyed to channel and the Bay -- series of cross swales to pull water off road and into flat depositional areas.	Coordinate with the major landowner in Fulladoza Bay	3	5	300	30	9000	Infreq	55%bare, 45%gravel	55%bare, 45%gravel	High
Medium Priority											
BAM-1	Bahia Mosquito entrance area off road to Cosa Bonita.	Determine ownership or Homeowners Association	20	35	200	20	4000	Infreq	85-90% bare soil, 10% veg	100%vege	
BAM – 2	Dirt road drainage from house or homes which is conveyed to road then to a series of ponds.	Discuss with owners -- request to have improvements made and formalize in a maintenance contract	7.5	15	600	20	12000	Infreq	45% bare, 50% gravel, 5% veg	33% Vege, 33% gravel, 33% veg	Low
BAM-3	Bare soil area with potential for hydroseeding and rain garden plus diversion of runoff to relatively flat vegetated area.	Discuss with landowners/HOA for this area--North View Estates	35	45	50	30	1500	Paved	--	bare soil	Low

Table 5. Soil Stabilization Opportunities

Site[1]	Description	Next Steps	Slope (%)		Estimated Dimension (ft)			Road Maint.[2]	Surface Type	Shoulder Type	Convey-ance[3]
			Avg.	Max	Length	Width	Area (ft2)				
BAM-4	Soil Stabilization/ Pond creation. Liz and David's property opportunity to restore a pond that blew out during a large storm event.	Help them coordinate with NRCS/Local District	na								Low
PDV-8	Soil Stabilization/Sediment trap creation. Create a sediment trap at the 1st intersection between the dirt roads to Mosquito and to other parts of PDV.	Coordinate with HOA	20	35	400	35	14000	Med	More bedrock out to road/ more soil to middle	45% bedrock, 45% gravel, 10% soil	Low
SW-1	Unpaved roads past Library and water storage are eroding due to water flow on the roads -- opportunities for cross swales.	Coordinate with municipality to install after being trained in installation of concrete cross swales	25	45	450	20	9000	Infreq	40% bare, 20% bedrock, 40% gravel	10% stone, 90% veg	Low
ZU-1	Series of cross swales to take water off the road -- also excavate small storage area.	Coordinate with HOA and Bill Maileaux	12.5	25	750	22.5	16875	Infreq	70% bare, 10% bedrock, 20% gravel	30% bare, 30% gravel, 40% veg	Low
ZU-2	Soil Stabilization/Sediment trap creation. Create a series of cross swales to take water off road surface and return to channel where bedrock exists, create a large sediment trap for sediment that is lost -- 20x30ft and track deposition. Flows to Zoni lagoon.	Coordinate with HOA and Bill Maileaux	35	45	600	20	12000	Infreq	35% bare, 20% bedrock, 35% gravel	50% bedrock, 20% gravel, 30% veg	Low
FLA-1	Stabilization of a dirt road adjacent to Flamenco Lagoon.	Coordinate with FWS	3	5	100	30	3000	Infreq	55%bare, 45%gravel	n/a	Low

[1] Site ID corresponds to Map Figures 24 and 25. Initials indicate subwatersheds.
[2] Frequency of road maintenance/disturbance.
[3] Conveyance is the probability of direct drainage to coastal waters (though it should be noted that coastal lagoons are losing their capacity for attenuation of sediment).

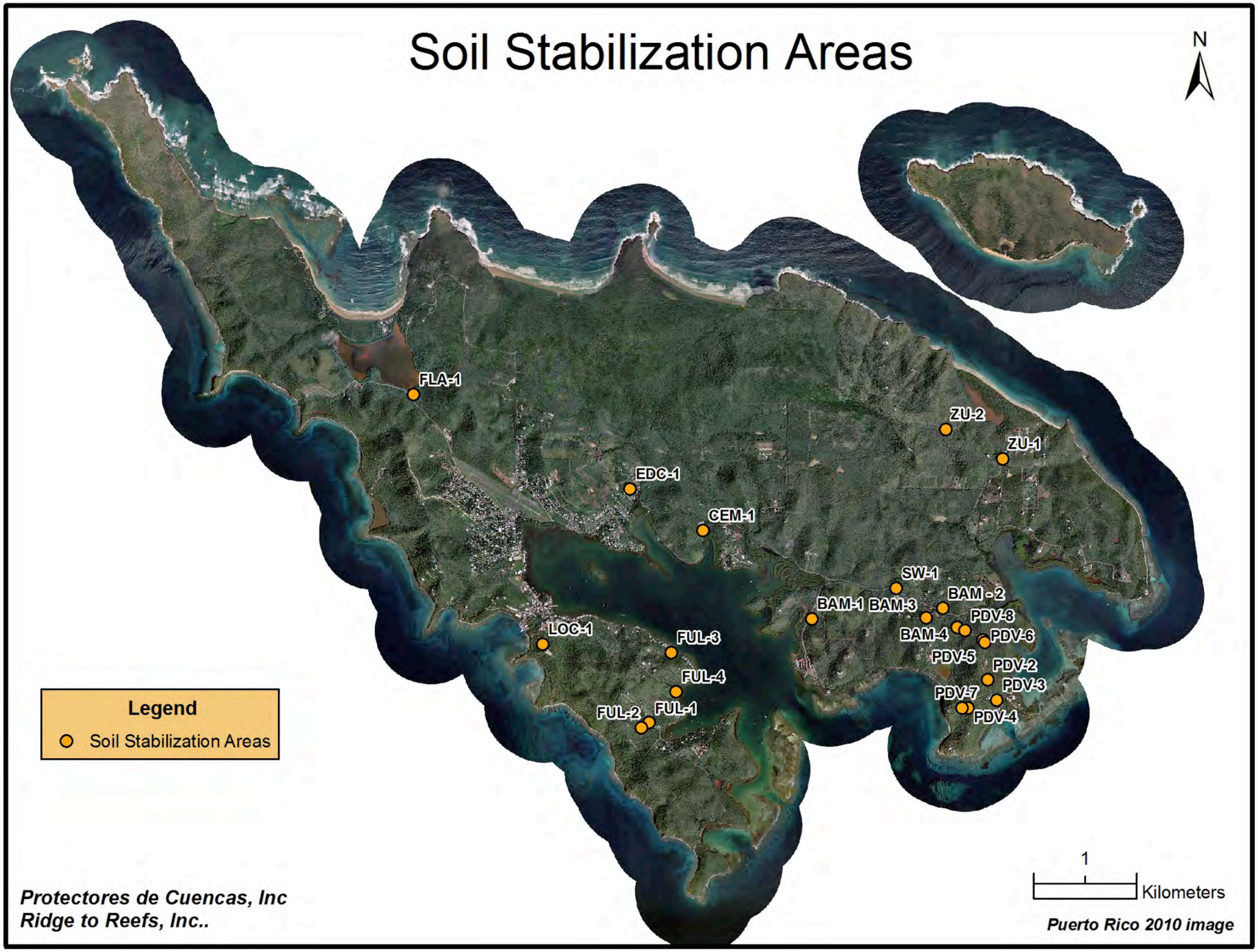


Figure 24. Soil stabilization areas (note not a complete list as several roads were marked private property and were not assessed)

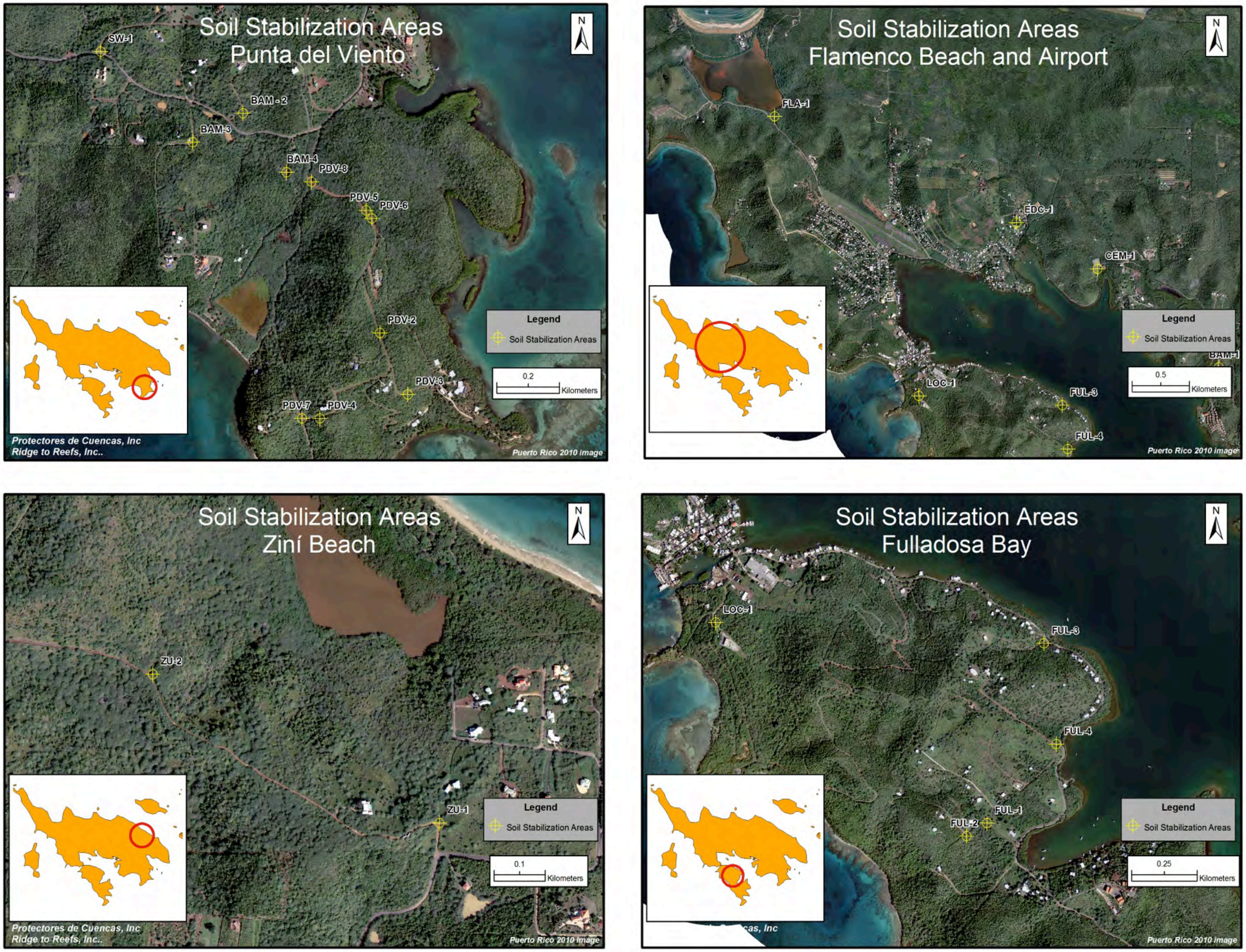


Figure 25. Site locations for some of the soil stabilization efforts

Illicit Discharge: Water Quality Pollution Monitoring and Source Tracking

As part of assessment, water quality parameters were measured in both nearshore areas and in freshwater drainages in order to begin to identify and track down sources of pollution. Areas where "freshwater" was flowing in this very dry climate were generally derived from wastewater treatment plant discharges, illicit discharges, washwater, failing septic systems and drinking water leaks. Determining sources of contamination to the nearshore and marine ecosystems is a critical component of watershed management. Potential pollution locations were monitored on land as in the nearshore marine environment through the assistance of DNER. Some of the initial findings based on our monitoring of bacteria, ammonia, optical brighteners, and Chlorophyll a included: specific locations (Table 6) (Figures 26 and 27) where sewage leaks and illicit discharges enter the marine ecosystem. Additional information is needed from PRASA about the sanitary sewer system to determine where homes and businesses are connected to the sanitary sewer and where they are not.

Key conclusions from this effort are summarized in Table 6 and in more detail in Table 8 where red colored rows highlight potential and confirmed contamination areas. Serious concerns include: the performance of the WWTP particularly on weekends - where concentrations on one occasion were 8x the ammonia standard of 1 mg/l and on a second occasion (a visit from USEPA, NOAA and the project team), when the plant operators measured 3 mg/l of ammonia. Elevated bacteria concentrations were also found at the treatment plant outfall when it was monitored on the weekend. Septic or sewage effluent was also found leaking into the drainage channels on both sides of the airport and into the street in other locations. A bathroom at the Flamenco campground was also identified as possibly leaking into a nearby coastal lagoon. High bacteria and ammonia concentrations were found in the lagoon, which interchanges water with the nearshore coastal areas during rain events. Also found were elevated coastal concentrations of washwater (optical brighteners) and bacteria, in some cases associated with dense clusters of septic systems and at the WWTP embayment.

Table 6. Summary of Illicit discharge concerns

Station	Description and Contamination Source
C2	Likely illicit discharge
C3	Illicit discharge (likely from C4)
C4	Illicit discharge of sewage
C5	Likely same sewage source as C4 tracked it higher up
C7	Potential contamination from nearby septic systems in Flamenco apartments
C8, C8-A	Contamination from the treatment plant
C9	Flamenco - potential sewage leak from the Campground
C18	Numerous illicit discharges from waterfront residences and school area
C22	Potential contamination from waterfront residences or failing septic systems
C23/C24	Contamination from a poorly controlled construction site and failing septics
C25	Unknown; possible discharge of waste from boats
C26	Discharge from the sewage treatment plant
D1	Washwater and potential sewage contamination
D2	Ferry Docks – elevated Chlorophyll a – unknown
D5	Contamination from the airport channel and sewage leak in C4

Elevated turbidity, nutrients, and bacteria were found in several embayments including: an urban area under development with poor erosion and sediment controls; the WWTP embayment; as well as both drainages near the airport. Addressing these major sources of contamination in Culebra is a critical piece of the plan to improve conditions and ensure resilient coral reefs.

The majority of elevated discharges have a likely source of contamination – in some cases the source of contamination has already been identified or probably comes from a nearby source. The highlighted sites with indicators of contamination are summarized by station and probably cause of contamination. These discharges all reflect probable nutrient contamination as well as bacteria in most instances and sediment is also indicated in one or two instances.

In addition, a number of additional potential source areas of pollution were identified during the upland green infrastructure and stormwater retrofitting. These potential sources are summarized in Table 7. These sites are all indicative of the lack of connection to the WWTP of most homes and businesses, as well as frequent washwater discharges on or near impervious surfaces.

Table 7. Summary of Illicit discharge concerns identified during the upland fieldwork

Location	Description	Next Steps
AP-9	Investigate 3" PVC pipe in back yard of single family home that discharges directly onto PR-251 (near Cll6 or Cll5 and across from AP-7B). Likely septic or wash water.	Test water quality of outflow for indicators of sewage and detergents.
AP-10	Investigate discharge at drain inlet located behind the yellow headwall on PR-251 across from the restaurant. Suspicious odors detected that may indicate a connection to sanitary sewer line in middle of road.	Test water quality of outflow for indicators of sewage and detergents.
AP-18 (Calle 3?)	Potential sewer connection leak at residential home/major pollution prevention on street (uphill east of airport); this drains down to Cll 4 catchbasin and discharges to last outfall on right bank (looking downstream) in grassed channel.	Work with PRASA to investigate and repair.
Various Locations	Investigate 4 outfall pipes in grass channel for dry weather flow: 4" white PVC on left bank (looking downstream); 24" blue PVC (right bank); 36" at DPW (right bank); large outfall across from Cll 4 (right bank).	Various IDs and locations. Test water quality of outflow for indicators of sewage and detergents.
AP-11	Observed likely failing septic system near AP-1, probably characteristic of much of neighborhood.	Test water quality of outflow for indicators of sewage and detergents; Get a better sense of how many homes are not connected to the sanitary sewer (maybe island-wide); and Work with PRASA to identify grant opportunities to subsidize residential (and possibly commercial) hookups.

Table 8. Monitoring summary from pollution source monitoring and illicit discharge tracking effort

STATION	DATE	Latitude	Longitude	Optical Brighteners	CHLORO A	Ammonia	E. COLI	Coliform	Dilution	Non Coliform bacteria	Notes
C1	2/26/13	18.28898	-65.286168	17.78	66.11	0.15	0	3000	10x		Shade - sample 75m DS of Bahia Marina Pond
C2	2/26/13	18.308084	-65.302518	29.44	86.96	0.91	0	5000	10x		Across from school – lots of algae
C3	2/26/13	18.311499	-65.304015	41.1	106.9	0.32	0	35500	10x		Airport Bridge
C4	2/26/13	18.31335	-65.30552	46.75	109.4	7.86	265000	TNC 100			Airport Sewage from Community
C5	2/26/13	18.31161	-65.30026	70.66	280.07	6.16	20000	TNC 100			Other side of airport sewage from community
C6	2/26/13	18.32697	-65.31477	30.44	56.73	0.38333333	500	11000	10x		
C7	2/26/13	18.326917	-65.314491	46.78	644.1	No reading	2500	4500	10x		Salt Marsh
C8	2/27/13	18.317764°	-65.282109	35.64	34.67	0.42	50	700	1x		Treatment plant (Sample #1) Weekday see Sample #2 as well
C9	2/27/13	18.334675°	-65.323493	53.65	1514						Flamenco Upper
C10	2/27/13	18.335076°	-65.323514°	0.307	3.714						Flamenco shore near algae/rocks
C11	2/27/13	18.30186	-65.30117	0.876	9.016						Lobina
C12	2/27/13	18.28716	-65.28268	0.256	3.336						In reality closer to shore
C13	2/27/13	18.29196	-65.28857	0.668	7.188						Fullodoza
C14	2/27/13	18.29597	-65.28709	0.187	4.111					600	Large houses near Fulladoza
C15	2/27/13	18.302406	-65.299274	0.411	0.489		0	0			Near Dingy Dock
C16	2/27/13	18.30237	-65.29833	1.281	5.527					50	Up from Dingy Dock
C17	2/27/13	18.3023	-65.29533	1.032	8.198		0	0		400	Yelllow house above C-16
C18	2/27/13	18.30829	-65.30167	1.775	15.72		0	0		250	Near Eco school off a bit due to shallow water
C19	2/27/13	18.30961	-65.29848	0.825	4.255		0	0		450	NEAR PINK BUOY
C20	2/27/13	18.30894	-65.29515	1.599	7.713		0	0		400	Near Casa Culebra
C21	2/27/13	18.30796	-65.29245	0.7	9.707		50	50		750	Near Kaya boat
C22	2/27/13	18.3078	-65.29372	2.055	8.234		0	0		18	No mangroves
C23	2/27/13	18.3098	-65.29221	1.859	16.37		0	0		31	Close to sediment corner
C24	2/27/13	18.31061	-65.29182	1.618	15.27		100	0		105	Sed Corner
C25	2/27/13	18.30831	-65.28489	1.112	15.94		0	0		55	w/ cemetery and DNER
C26	2/27/13	18.30684	-65.27998	1.965	16.33		250	0		28	treatment plant embayment
C27	2/27/13	18.29921	-65.27714	0.877	8.059		0	0		18	Cosa Bonita 1
C28	2/27/13	18.29577	-65.27567	0.478	8.633		50	0			Cosa Bonita 2
D1	2/28/13	18.301443	-65.301636	1.219	14.53						Near Lobina channel
D2	2/28/13	18.301185	-65.302644	0.31	10.32						Ferry docks
D3	2/28/13	18.301281	-65.300685	0.558	3.326						gas station
D4	2/28/13	18.310013	-65.299381	0.331	4.278						Sed channel near airport
D5	2/28/13	18.310272	-65.302259	1.594	11.16						corner near airport
C8 -A	3/3/13	18.317764°	-65.282109	39.16	48.34	8.2					Treatment Plant Sample #2
Landfill Monitoring w		18.321474	-65.322572								Will need support from the landfill operators or one of Protectores de Cuencas or Ridge to Reefs staff or both in locating the wells for sampling

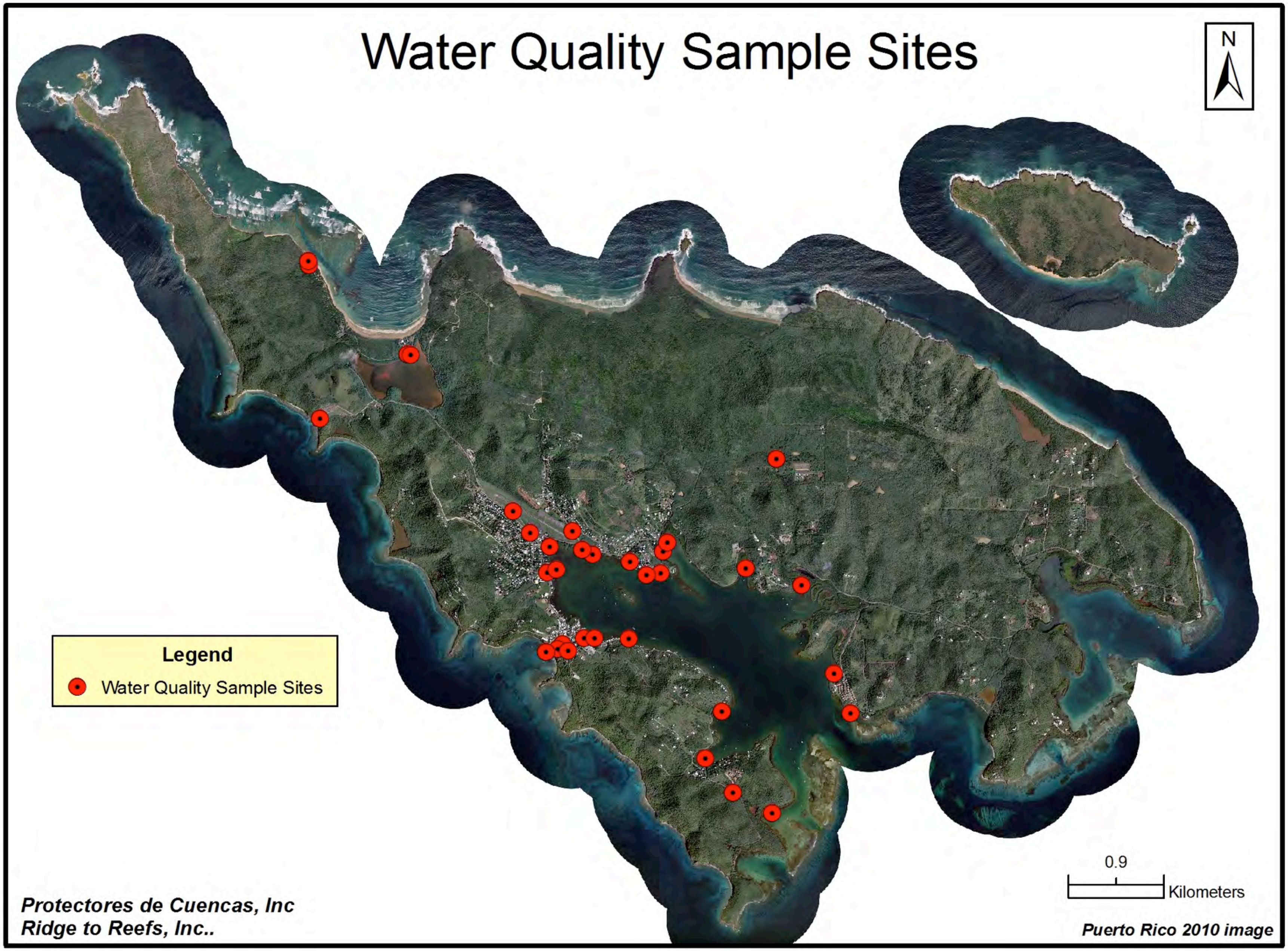


Figure 26. Water Quality Sampling and Pollution Tracking Sites

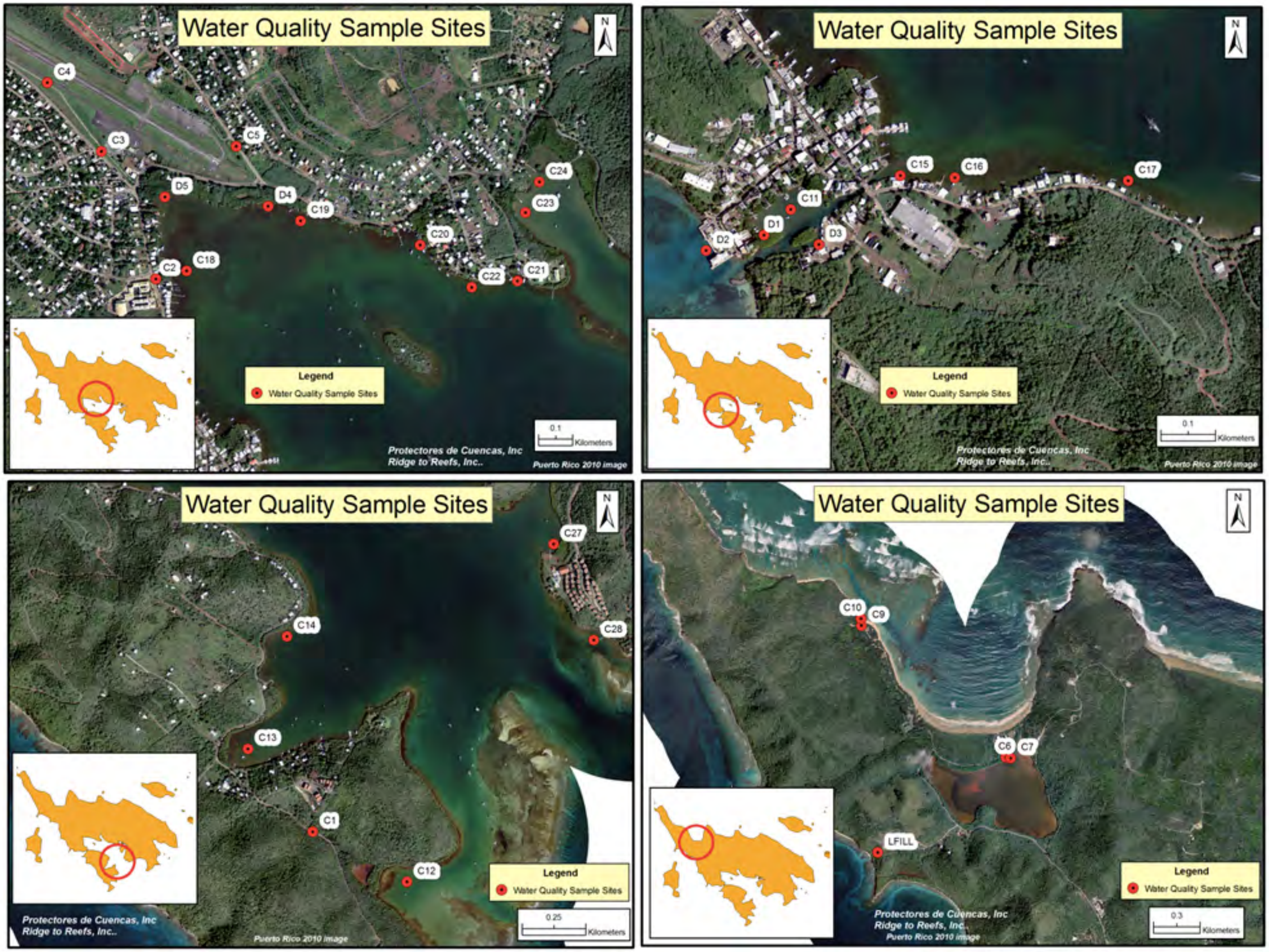


Figure 27. Pollution Tracking Water Quality Sample Sites

Section 5. Implementation and Monitoring Strategy

The restoration and monitoring strategy and timeframe are presented in this section. The implementation schedule prioritizes projects that are straightforward and easier to implement (e.g., addressing sediment from dirt roads) into the first three years. Projects that are more intensive (e.g., addressing sewage issues in Flamenco and closing and stabilizing the landfill) are projected to take a longer time to develop and complete. The monitoring strategy combines early indicators of pollution reduction with indicators of both medium and longer-term improvements in coral reef ecosystems.

Load Reductions and Schedule

Table 9 provides a preliminary implementation strategy over a 10-year timeframe. The restoration timeline and anticipated nutrient load reductions, an estimate of the type and quantity of restoration and the resulting sediment and nitrogen reduction associated with each of the recommendations is shown in Table 9. Several projects have already been constructed including one in Tamarindo and one in Punta del Viento Estates and funding is in place to construct several more over the next few years.

Monitoring Strategy

The monitoring strategy focuses on four types of monitoring: 1) Baseline fixed-station and restoration practice water quality monitoring (early detection sites). These sites help determine the effectiveness of early implementation practices and help test and refine restoration methods; 2) Annual or Bi-annual nearshore reef, habitat and fish monitoring (these stations help to establish an aquatic resource baseline and track changes in both short-term parameters (reduction in algal cover) as well as longer term aspects such as live coral cover; 3) Remote sensing monitoring that can be done by existing satellites and can evaluate conditions on a more frequent basis but for a limited number of parameters, including Chlorophyll a and temperature; 4) In-situ monitoring buoy which would provide daily data allowing for better tracking of stressors to coral reefs and also allow for rapid detection of high temperature or turbidity events and can help alert researchers and managers to potential impacts and seasonal variations.

As part of the watershed planning effort, over 30 baseline stations/ source areas were assessed at discharge points on land or in nearshore waters, particularly around Ensenada Honda. In addition, eight baseline sites for coral, habitat and fish monitoring have been established by Edwin Hernández-Delgado (UPR/CREST) and Sociedad Ambiente Marino (SAM) – these are off of Ensenada Honda in a expected disturbance gradient beginning at the mouth of Ensenada Honda and extending east to the reefs south of Culebrita (Figure 28). The survey data is summarized at the end of this section. Edwin Hernandez has additional historical sites in and around Culebra including sites in the Luis Peña Marine Reserve. It is important to resurvey and designate a number of fixed long-term monitoring stations in Luis Peña

Marine Reserve and in other areas around Culebra such as in Flamenco. A mix of long-term coral monitoring sites and fixed water quality stations in Ensenada Honda near current sources of contamination are critical in order to establish baselines and measure watershed restoration success over time.

Table 9. Anticipated load reductions and proposed schedule

Recommendation	Quantity Estimate	Estimated Annual Load Reduction	
		Total Nitrogen (TN)	Total Suspend. Sediment (TSS)
Short-term 0-3 Years			
1. Reduce erosion and sediment runoff from roads	Approximately 5 miles of road are high priorities for stabilization - based on a 50% load reduction efficiency with a multiple BMP approach to load reduction.	200lbs N	400,000 lbs.
2. Improved sewage treatment and reduced discharge of effluent	16,000 gallons per day increasing to 32,000 gallons per day – based on 1 project to improve the function of the treatment wetlands and create a zero discharge system by using drip or spray irrigation.	6,200 lbs N	Minimal
4. Address runoff and erosion and sediment control from new development	Policies and training in place to limit clearing, preservation of buffers, require and enforce erosion and sediment control and stormwater management (requires institutional authority for fines) and training for staff persons (Need a Restoration and Enforcement Coordinator).	Preventative	Preventative for new sources (80% reduction of future sources)
8. Connection of businesses and homes to sewer	Connect the businesses and residences served by the sewer line to the sewer line so that sewage is conveyed to the treatment plant.	5,000 lbs.	Minimal
9. Address sources of pollution including illicit discharges and failing septic systems	Continued monitoring and enforcement and working directly with businesses and homeowners on improvements; includes poor ESC in Ensenada Coronel.	150 lbs. – number is much higher but part is covered in connections to sewer	90,000 lbs.
14. Support small-scale community agriculture	Support the self-sufficiency and food security of Culebra.	Small or NA – may include capturing rooftop runoff	NA
Short-term longer duration to implement (1-5 years)			
15. Close and decommission landfill reducing its long-term impact on the environment	Close, decommission and stabilize the landfill site and reduce the potential for future leachate problems, recycle a portion of existing trash.	NA	10,000 lbs. 50% reduction
5. Treatment of stormwater runoff	Implementation of 10-15 green infrastructure practices (80% reduction in sediment and 40% reduction in nutrients) standard efficiencies in model (Caraco, 2004).	1,000 lbs.	350,000 lbs.
7. Development of long-term funding sources for restoration/ management and protection	Selling of conservation products, surcharge on ferry, flights etc. to go back into conservation efforts – will help to implement a fuller suite of conservation projects.	NA (will result in reductions – not able to estimate quantity)	NA
10. Support small-scale renewable energy efforts	Goal of 500 homes getting the majority of their energy from solar or small scale wind	Minimal	NA
11. Evaluate extensions to Marine protected areas and	Convene a taskforce to evaluate extensions to MPAs in Culebra as well as protected areas for	NA	NA

Table 9. Anticipated load reductions and proposed schedule

Recommendation	Quantity Estimate	Estimated Annual Load Reduction	
		Total Nitrogen (TN)	Total Suspend. Sediment (TSS)
protections for various sectors (local commercial fisherman, biota)	various sectors, evaluate the current and needed level of enforcement.		
19. Reduce impact of sewage from moored/ transient vessels (busy weekends)	Institute a pump out and Harbor Master program creating a local business and ensure there is adequate legislation and mechanism for enforcement (Harbor Master) .	100-200 lbs.	Minimal but reductions in trash, marine debris, and bacteria
Short-term longer duration to implement (1-10 years)			
12. Education and curriculum on the natural history of Culebra	Development of curriculum on the natural resources and natural history of Culebra, adult and family led trips to different areas.	NA	NA
6. Expansion of coral restoration efforts	Goal of 4,000 -5,000 out plants per year.	NA	NA
18. Accelerate the cleanup of ordinances and permanently protect the former impacted lands	Raise awareness and a petition drive to accelerate the timeframe of the cleanup operations.	NA	NA
21. Monitoring program to ensure reduction in pollution	Tracking of coral conditions and biological communities at defined stations, water quality at key locations and effectiveness monitoring of implementation programs, assess the storage loss in natural filters.	NA-Prevention and early warning	NA- Prevention and early warning
20. Ecologically sensitive growth and re-development to minimize the impacts of growth	Foster ecologically sensitive development which minimizes the impact of the ecosystems of Culebra and designs with nature and conservation in mind.	Prevention	Prevention
Mid-term 3-5 years			
3. Improved treatment of sewage and washwater in Flamenco Beach and apartments	Connection to sewer or the use of composting toilets and washwater gardens to minimize impacts to the marine environment in Flamenco (assumes reuse or export of fertilizer from the watershed).	3,000 lbs. N	Minimal
13. Address nutrient loss from large septic systems including Costa Bonita, large homes on fractured soils with year-round use, Flamenco	1 large project, several small projects (60-80% reduction in nitrogen).	800 lbs.	NA
16. Reduce impact on coastal zone and properties in hazard areas	Identify areas likely to be most impacted by hurricanes, tropical storms and coastal flooding – phase out most vulnerable structures, hold roundtable in Culebra.	Minimal	Minimal
Longer-Term 3-10 years			
17. Long-term protection of sensitive lands	Create a plan for conservation of lands that help ensure the long-term health of the marine environment in Culebra.	Prevention	Prevention
Summary **21 Projects**			

Table 9. Anticipated load reductions and proposed schedule

Recommendation	Quantity Estimate	Estimated Annual Load Reduction	
		Total Nitrogen (TN)	Total Suspend. Sediment (TSS)
Policies that minimize future pollution **Total Nitrogen** **13,950 lbs./yr** or **20,000 lbs./yr** (45% load reduction) 20,000 lbs. assumes future sewer connection of all existing homes in the service area and the plant operating at zero discharge. **Total Suspended Sediment** **850,000 lbs./yr**– 41% reduction assuming full implementation.			

Monitoring Metrics

The importance of monitoring in Culebra is paramount, since implementation measures here should rapidly reduce stressors to reefs and nearshore habitats. Four types of monitoring are envisioned (Table 10):

1) **Baseline fixed-station and restoration practice water quality monitoring** (blue): Monitoring stations to track progress should be established as a subset of the stations that were monitored. Perhaps 12 of the 30+ water quality monitoring sites that were established during the initial fieldwork portion could be continued to evaluate progress. Also at a practice monitoring should be implemented at typical restoration practices, new practices and especially large and important practices such as the sewage treatment plant. In addition, adaptive management as is practiced by the restoration team (on-going evaluation and tweaking of improvements) should be a part of each project.
2) **Nearshore reef, habitat and fish monitoring (annual or biannual)** (orange);
3) **Remote sensing** (RS) monitoring that could be done by existing satellites (yellow): Remote sensing could be established with existing satellites and technology by NOAA, USEPA and NASA to track water parameters including Chlorophyll a, total suspended solids (TSS), Carbon Dissolved Organic Matter (CDOM) and also sea surface temperature.
4) **An In-situ monitoring buoy** (purple): At least one in-situ real-time monitoring buoy is needed to to track on-going conditions to better understand the factors affecting change in the reef ecosystem. The in-situ buoy and a weather/rain gauge could capture a number of key parameters including: ambient temperature, rainfall, water temperature, Chlorophyll a, turbidity, oxygen and pH. Near Tamarindo in the Luis Peña Marine Reserve would be an ideal location due to the daily presence of daily ecotourism operations and the on-going coral farming and restoration sites.

In addition, it is critical that these stations are monitored on an on-going basis with a lead entity such as a local university UPR CREST and CESAM or DNER with a dedicated funding source. That way monthly baseline conditions can be established for water quality, in-situ equipment can be maintained, and coral and coral habitats can be monitored on an annual or biannual basis.

Metrics recommended to be measured were divided into the type of metric, the relative response rate (fast, moderate or slow) which the parameter may change as well as potential sources for data collection and BMPs. Stressor monitoring includes water quality measures, and response measures include secondary parameters that may change after reduction of stressors. Generally, the rate of change will be due in part to the amount of reduction of stressors. We anticipate that generally water quality parameters will change more quickly than coral conditions. Intermediate response variables may include algal cover.

Table 10. Recommended Monitoring Metrics for the Culebra Watershed Plan

Metric	Type	Response	Source/Data collection	BMPs that address
Baseline WQ info (In-shore, watershed)	Stressor	Fast	CATEC, UPR RM, RTR/PC, SAM, CESAM, DNER	Treatment plant, IDDE, Septics, Sediment
At a practice monitoring	Stressor	Fastest	CESAM, SAM, RTR/RC, DNER, NOAA	Erosion/sediment traps, treatment plant
Nearshore reef nutrients, Chl(a)	Stressor	Fast	CATEC/ NOAA	Treatment plant, IDDE, large septics
Nearhore reefs Turbidity, clarity	Stressor	Fast	CATEC/CESAM/NASA/ NOAA	ESC, dirt roads, stormwater runoff
RS CDOM	Stressor	Fast	NASA/USEPA/NOAA	
RS TSS	Stressor	Fast	NASA/USEPA/NOAA	ESC, dirt roads, stormwater runoff
RS Chl(a)	Response	fast	NASA/NOAA/USEPA	Treatment plant, IDDE
Algal cover/ biomass	Response	Moderate	CATEC/NOAA/ DNER/SAM/ CESAM	Treatment plant, IDDE, large septics
Coral cover	Response	Slow	CATEC/NOAA/ DNER/SAM/ CESAM	Treatment plant, IDDE, large septics
Coral demographics	Response	Slow	CATEC/NOAA/ DNER/SAM/CESAM	All slowly over time
Coral disease	Response	moderate?	CATEC/NOAA/ DNER/SAM/CESAM	Stormwater runoff, IDDE, failing septics
Coral recruitment	Response	moderate	CATEC/NOAA/ DNER/SAM/CESAM	All over time (perhaps nutrients which reduce algal cover)
Coral species richness	Response	slow	CATEC/NOAA/ DNER/SAM/CESAM	All over time
Fish recruitment	Response	moderate	CATEC/NOAA/ DNER/SAM/CESAM	Expansion and management of MPAs
Grazers	Response	moderate	CATEC/NOAA/ DNER/SAM/CESAM	Expansion and management of MPAs, supplemental stocking
Reef fish diversity	Response	moderate	CATEC/NOAA/ DNER/SAM/CESAM	Expansion and management of MPAs
Temperature	Ancillary	NA	NASA/NOAA/USEPA	
RS temperature	Ancillary	NA	NASA/NOAA/USEPA	
Turbidity, Nutrients, current/ direction, Temp	Response and ancillary	Real-time in situ data	NOAA/USEPA/DNER	
RS= remote sensing, RTR/PC - Ridge to Reefs/Protectores de Cuencas, SAM – Sociedad Ambiental Marino, CESAM – Student chapter of Sociedad Ambiental Marino, chl a - Chlorophyll A * thanks to Dave Whitall, NOAA NCCOS, Susie Holst, NOAA CRCP and Edwin Hernandez CREST/UPR/SAM for input into the monitoring metrics				

Baseline Coral Reef Monitoring

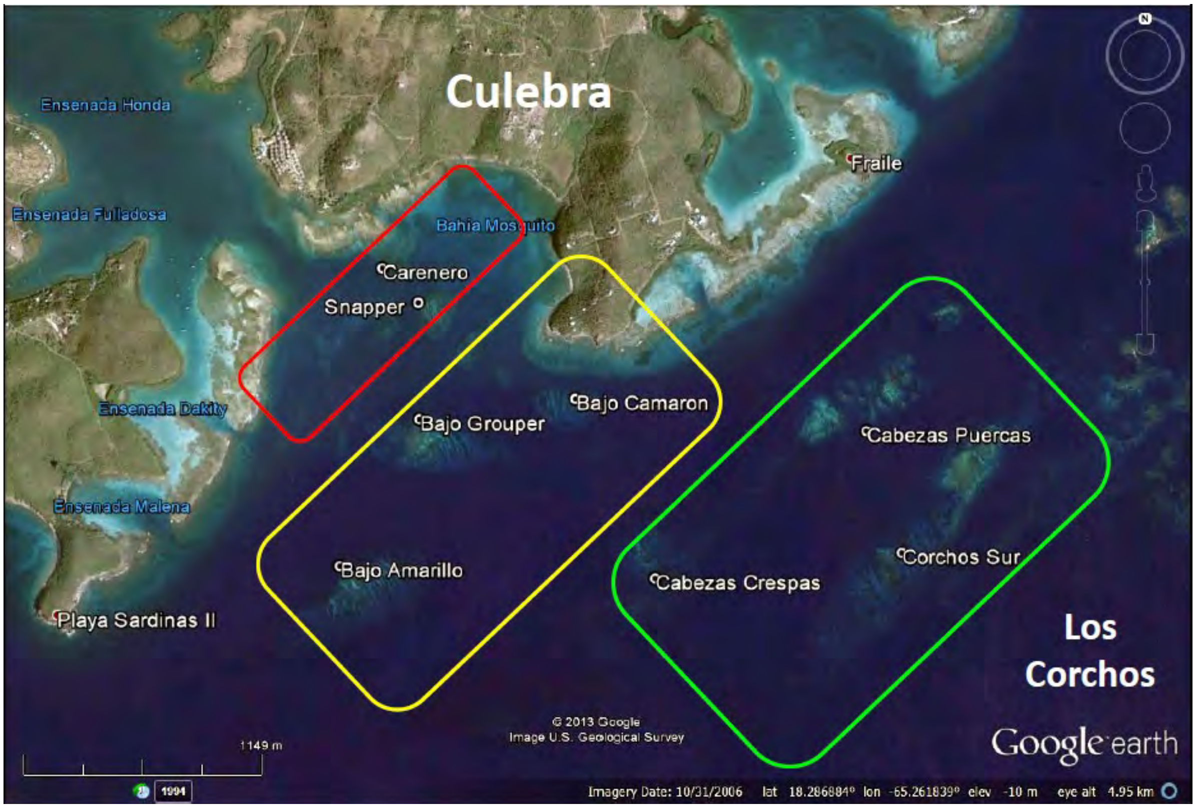


Figure 28. Study sites across land-based source pollution stress gradient in Culebra Island, Puerto Rico. Sites were subdivided in three regions: Inner reefs (red polygon: Arrecife Carenero, Bajo Snapper); Mid reefs (yellow polygon, Bajo Camarón, Bajo Grouper, Bajo Amarillo); and Outer reefs (green polygon, Cabezas Puercas, Corchos Sur, Cabezas Crespás) (Hernandez-Delgado et. al, In press).

A partial baseline coral reef monitoring program was established as part of the watershed planning process by Edwin Hernández-Delgado and his team from University of Puerto Rico CREST and Sociedad Ambiente Marino. Funding is needed for additional stations that would be established around Culebra in order to effectively track key changes across coral reefs and several disturbance gradients. From the data collected and the proposed additional stations, a set of baseline metrics can be established for comparison to future conditions after implementation of restoration and protection efforts. For example, Chlorophyll a levels are an important indicator of eutrophication and coral health (Wooldridge and Done, 2009 and Otero, 2009), Otero suggests 0.3-0.5 ug/l as a threshold for healthy coral reefs. In the Culebra sites all sites ranged from 1 ug/l to 4 ug/l suggesting enrichment factors of 2 to 8 times healthy levels. These levels appear to illustrate a significant risk to these coral reefs particularly if another high SST (sea surface temperature) event were to occur. The measured values at the stations can be tracked over time to determine if a response can be measured due to implementation efforts. Macroalgal levels also suggest enrichment at all three sites.

The assessment sites are shown in the graphics are as follows from east (greater LBSP disturbance) to west (less LBSP disturbance): CAR= Carenero Reef; SNA= Bajo Snapper; AMA= Bajo Amarillo; GRO= Bajo

Grouper; CAM= Bajo Camarón; CRE= Cabezas Crespás Reef; COS= Corchos South Reef; PUE= Cabezas Puercas Reef.

Land-based source of pollution (LBSP) gradient

This study produced a snapshot view of LBSP impacts across coral reefs southeast of Culebra Island, across a distance gradient from the Ensenada Honda bay (Figure 28). Horizontal water transparency increased with increasing distance from LBSP, from 12 m at Carenero Reef to about 50 m at Cabezas Puercas Reef (Figure 29). Similarly, chlorophyll *a* concentration decreased with increasing distance from LBSP, with mean values of 1.30 mg/L at the remote Cabezas Puercas Reef to 4.05 mg/L at inner Carenero Reef (Figure 30). These parameters provide evidence of a water quality stressor gradient suggesting deteriorated water transparency and potential eutrophication effects as a result of LBSP.

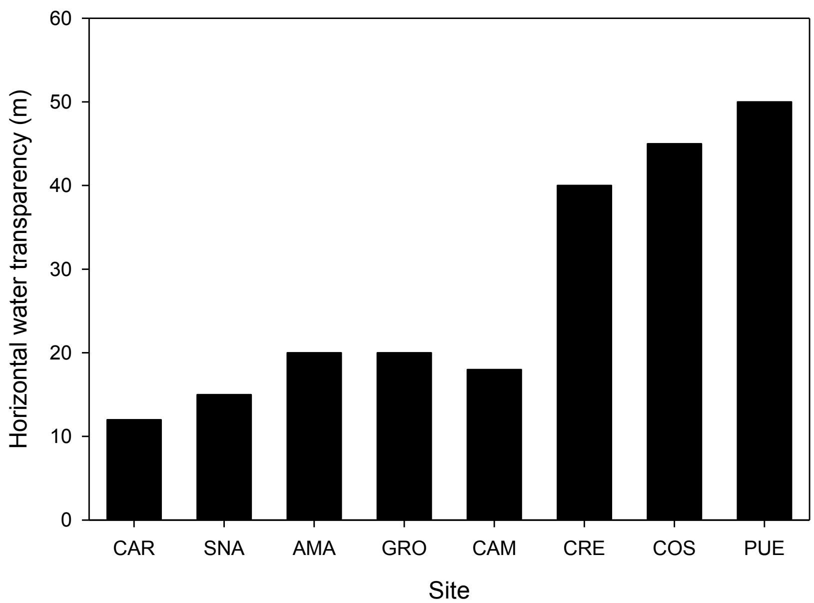


Figure 29. Secchi horizontal water transparency

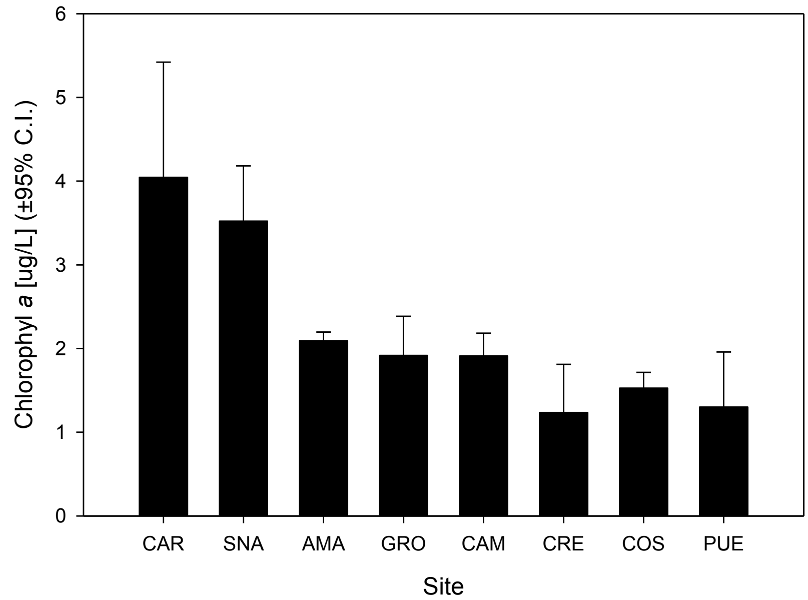


Figure 30. Chlorophyll *a* concentration

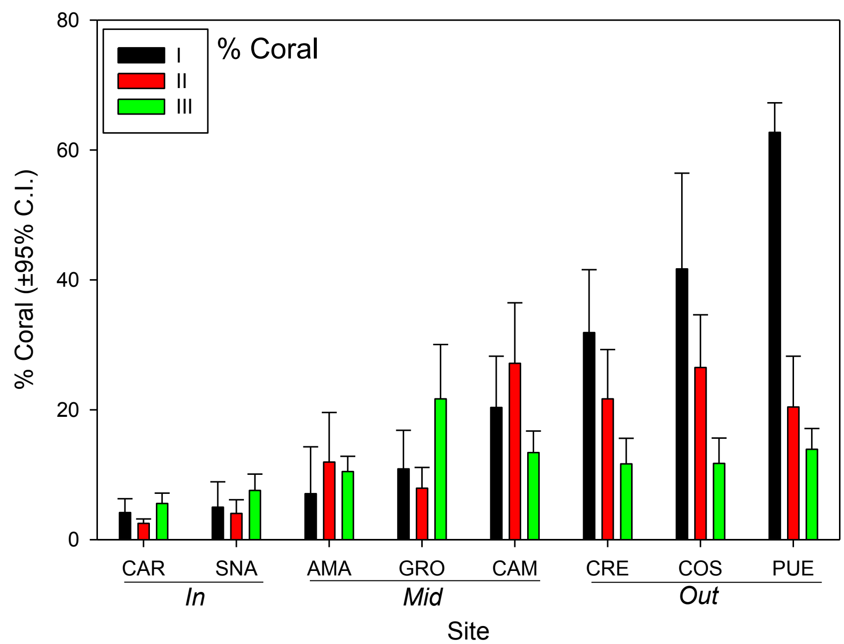


Figure 31. Mean percent live coral tissue cover (±95% confidence intervals)

Coral reef benthic community structure is impacted by LBSP and climate change

The coral reef benthic community shows evidence of LBSP and climate change impacts. But impacts by chronic LBSP seem evident across nearshore reefs. Mean percent live coral cover averaged 4.1% at Carenero Reef, but remains at 32.3% at remote Cabezas Puercas Reef, which still supports a 63% live coral cover across the shallow reef zone (Figure 31). Shallow reef zones at Corchos South Reef averaged 43% coral live tissue cover. Most reefs also showed a significant declining trend with increasing depth and dominance by brown macroalgae *Lobophora variegata*. These trends could have resulted from a combined long-term impact from chronic LBSP and recent climate change-related massive coral bleaching and mass coral mortalities.

Corals showed a highly significant linear increase in percent live colony tissue cover with increasing water transparency (Figure 32). However, corals showed a rapid decline in percent live coral tissue cover with increasing chlorophyll *a* concentration (Figure 33), suggesting that coral reefs adjacent to Ensenada Honda Bay outlet are significantly degraded by chronic LBSP.

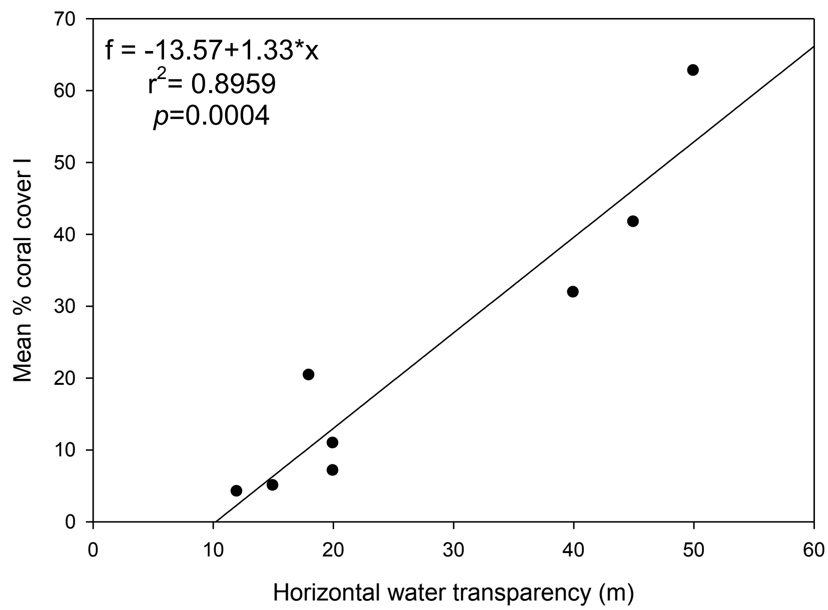


Figure 32. Linear regression between mean % coral cover from shallow reef zone and horizontal water transparency.

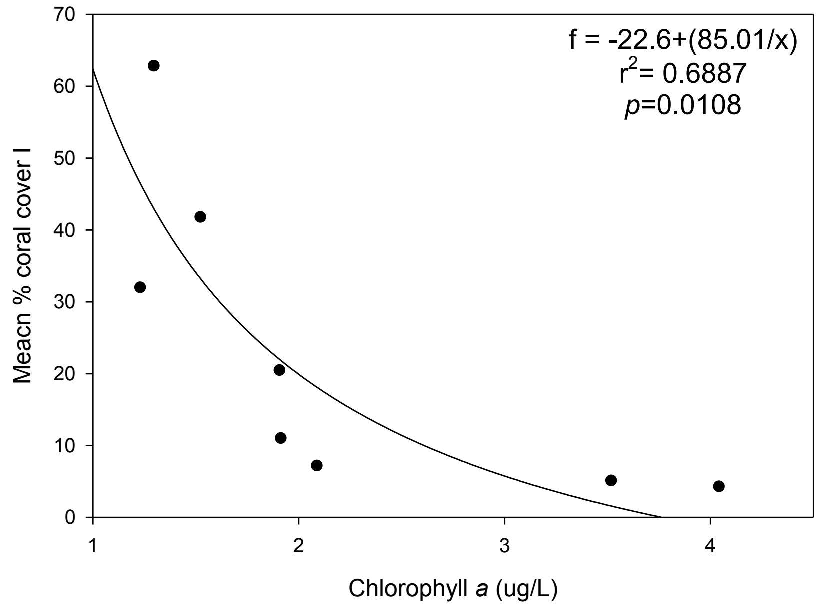


Figure 33. Exponential decay regression between mean % coral cover from shallow reef zone I and chlorophyll *a* concentration.

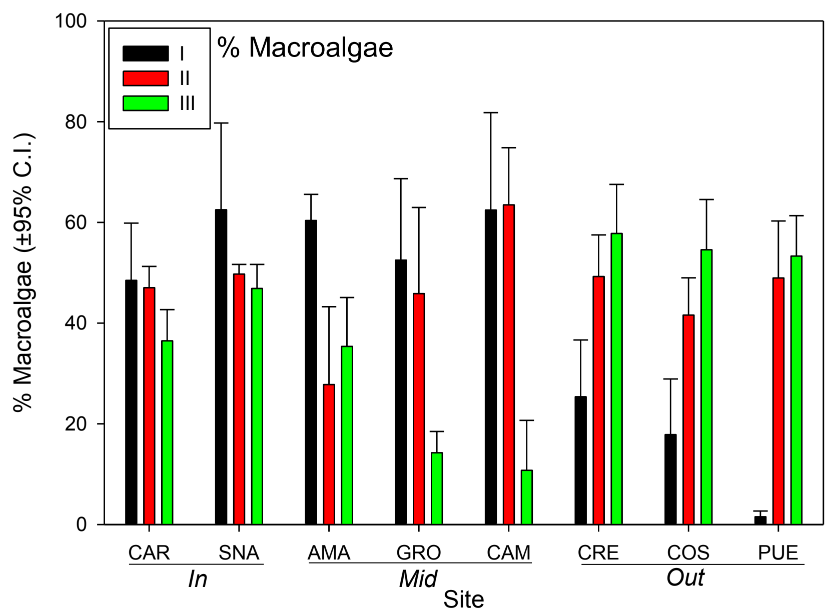


Figure 34. Mean percent macroalgal cover (±95% confidence intervals).

Macroalgae have become the dominant benthic component of coral reefs across the LBSP gradient. Two contrasting patterns were evident (Figure 34). First, shallow reef zones across nearshore (inner reefs) and mid-distance reefs, which were chronically more exposed to LBSP, showed mean macroalgal cover values >50% and were dominated by a combination of species that included high abundance of brown *Dictyota* spp., *Turbinaria turbinate*, *Lobophora variegata*, and red encrusting *Peysonnelia* spp. Macroalgal cover across off-shore reefs declined in shallow reef zones from values <25%. Macroalgal cover was often higher on shallow reef zones than on deeper zones across the nearshore and mid-distance reefs. But the pattern reversed on offshore reefs, with deeper reef zones showing mean percent macroalgal cover in excess of 50%. Most of this dominance was exerted by *L. variegata* (Figure 35). With few exceptions, this species was often dominant across deeper reef zones, particularly on offshore reefs, and across deeper reef zones where it has significantly overgrown large stands of threatened Staghorn coral (*Acropora cervicornis)* and of rapidly declining Star corals, *Orbicella (Montastraea) annularis* and *O. faveolata* across deeper reef terraces.

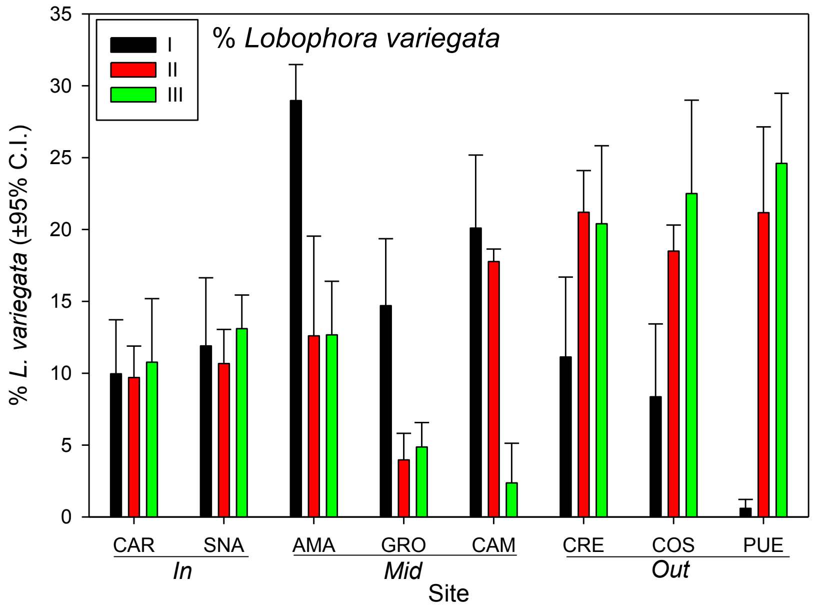


Figure 35. Mean percent *Lobophora variegata* relative cover (±95% confidence intervals).

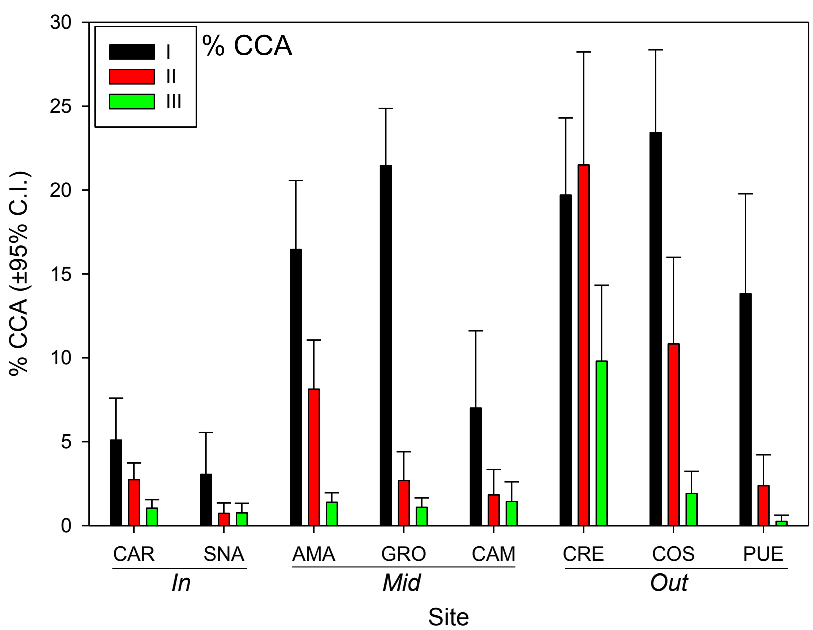


Figure 36. Mean percent crustose coralline algae (CCA) cover (±95% confidence intervals).

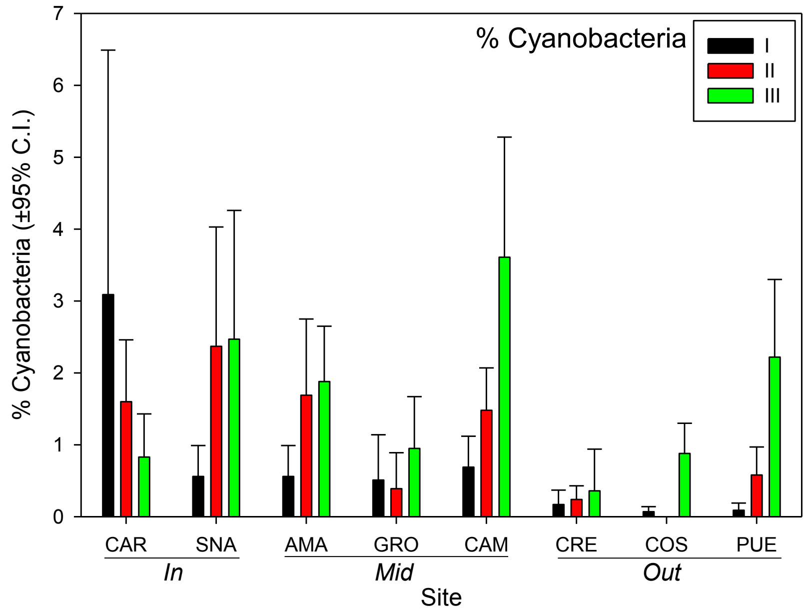


Figure 37. Mean percent cyanobacterial cover (±95% confidence intervals).

Crustose coralline algae (CCA) are a critical benthic component of coral reef communities since they provide the chemical clues to coral larvae for settlement and recruitment. CCA was significantly lower (<5%) across nearshore reefs chronically exposed to LBSP (Figure 36). Also, CCA was significantly higher across shallower reef zones, particularly on mid and outer reefs where *L. variegata* was dominant on deeper zones. Macroalgae outcompeted and overgrew CCA on both, nearshore reefs exposed to chronic LBSP, and on deeper offshore reefs. Cyanobacterial percent cover was generally low (<4%), but there was also a general trend of increasing percent cyanobacterial cover across nearshore reefs impacted by LBSP in comparison to offshore reefs (Figure 37).

Spatial distribution of critical coral species across a LBSP gradient

Critically-threatened coral species also showed significant spatial distribution patterns closely resembling that of the LBSP gradient. Threatened Staghorn coral (*Acropora cervicornis*) was significantly more abundant across offshore reefs than on mid-distance or nearshore reefs chronically exposed to LBSP (Figure 38). No specific bathymetric distribution pattern was observed, with some reefs showing higher *A. cervicornis* abundance at shallower zones and some others across deeper zones. Nonetheless, *A. cervicornis* shows a steep and rapid decline due to out-competition by *L. variegata* overgrowth.

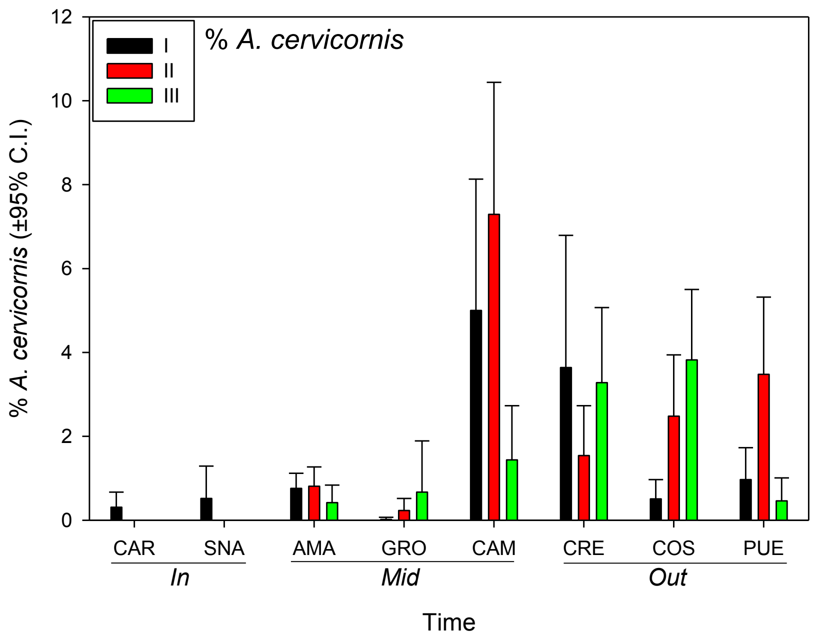


Figure 38. Mean percent *Acropora cervicornis* relative cover (±95% confidence intervals).

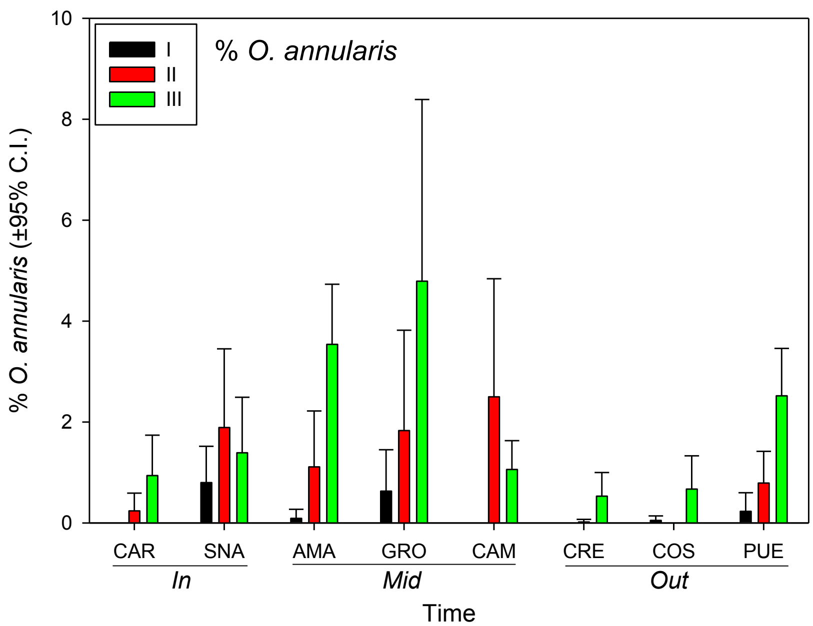


Figure 39. Mean percent *Orbicella annularis* relative cover (±95% confidence intervals).

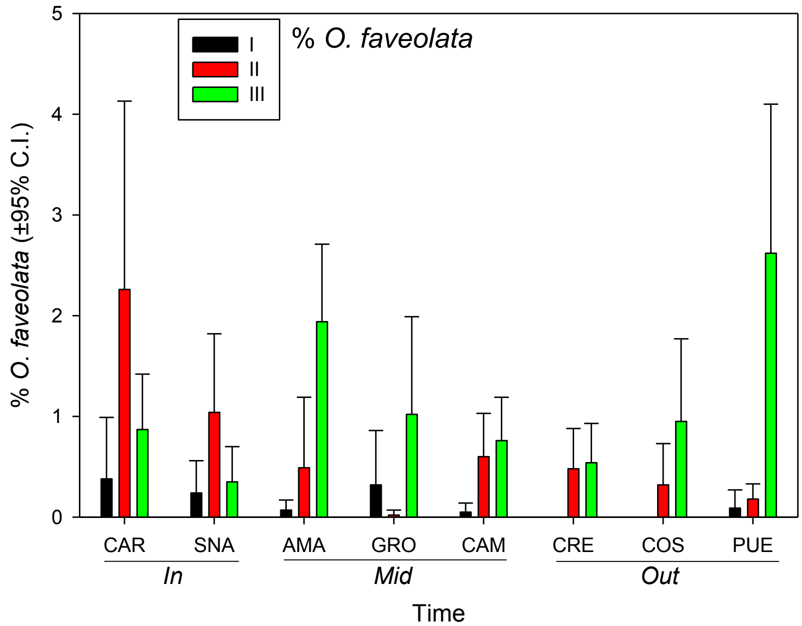


Figure 40. Mean percent *Orbicella faveolata* relative cover (±95% confidence intervals).

The spatial distribution of Star corals *O.annularis* (Figure 39) and *O. faveolata* (Figure 40) showed a complex pattern of variable distribution, but following a consistent pattern of higher percent cover across deeper reef zones. However, it was alarming that most of the reef bottom that was formerly dominated by large, massive colonies of both species, was found dead and covered by either red encrusting algae, *Peysonnelia* spp., and *Ramicrusta textile*, or by brown macroalgae, *Dyctiota* spp. and *L. variegata*.

Coral recruit distribution patterns across a LBSP gradient

Coral recruitment is a key process aimed at fostering the recovery of coral reefs following disturbances. Therefore, coral recruitment patterns and spatial distribution can be a fundamental indicator of the ecological condition of coral reef communities. Coral recruit density showed a highly significant increase with increasing distance from LBSP (Figure 41). Nearshore reefs chronically exposed to LBSP showed higher percent macroalgal cover, lower percent CCA cover, lower percent live coral cover and also lower coral recruit density. In contrast, offshore reefs showed slightly lower percent macroalgal cover, higher percent CCA cover, higher percent live coral cover and also higher coral recruit density. However, coral recruit density was significantly lower on deeper reef zones, even across offshore reefs, as a result of the dominance exerted by *L. variegata*. No coral recruits were documented on *L. variegata* substrates.

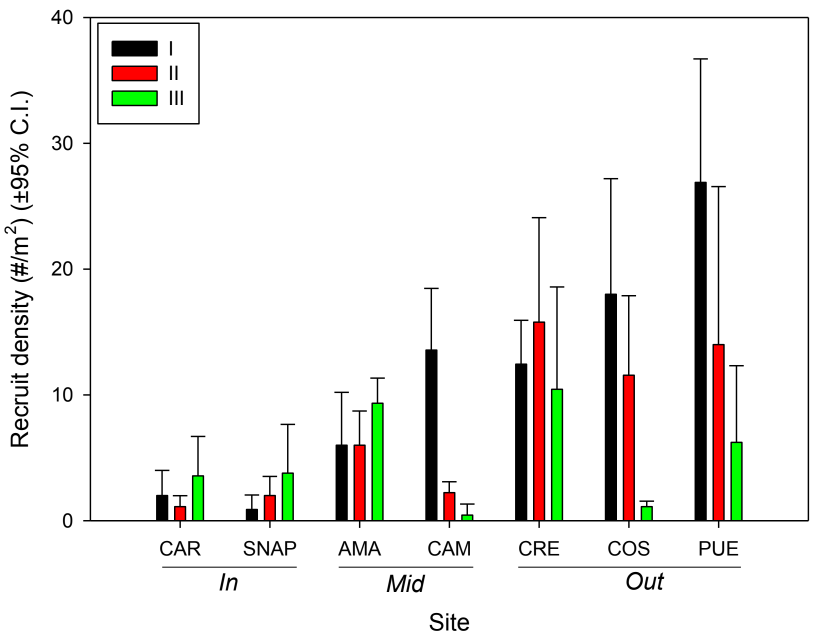


Figure 41. Coral recruit density (±95% confidence intervals).

The species composition of coral recruits were significantly different across the LBSP gradient, as well as across depth zones (Figures 41-44). This suggested that coral reef benthic conditions, as well as prevalent water quality conditions can significantly influence the species composition of coral recruits, as well as the coral reef's ability to recover from disturbance. The species composition of recruits is important because you want to have a well-balanced age distribution for key reef-building coral species. If the recruits you are only pollution tolerant coral species, and not those key reef-building corals, you will not return to a healthy reef. Recruits will significantly influence future coral reef community trajectories, potentially resulting in a permanent state of decline.

While over 60 species of scleractinian corals inhabit the Western Caribbean, reefs in Puerto Rico were historically dominated by the reef-building coral taxa, *Montastraea annularis* (complex), *Agaricia agaricites*, *Montastraea cavernosa, Porites asteroides* and *Colpophyllia natans*. Additionally, *Acropora palmata* and *Acropora cervicornis* often formed dense, high relief monospecific thickets; *A. palmata* in shallow exposed fore reef habitats, and *A. cervicornis* in fore reef and in shallow, protected back reef (Morelock *et al.* 2001).

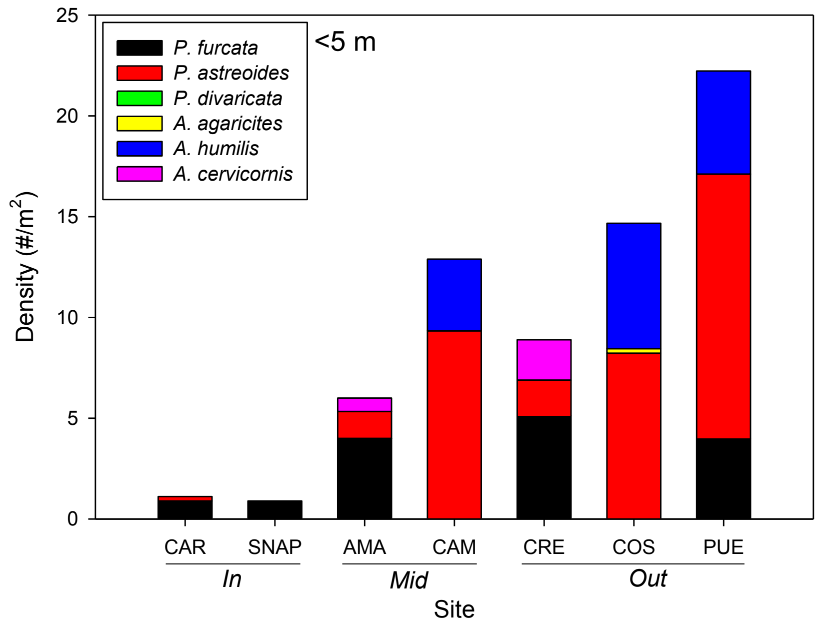


Figure 42. Coral recruit species dominance at shallow depth zone I (<5 m).

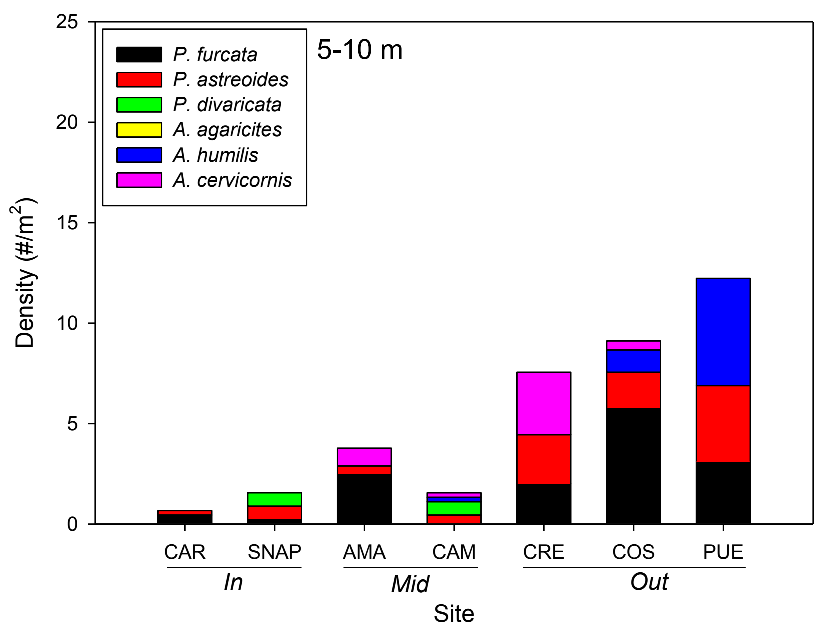


Figure 43. Coral recruit species dominance at shallow depth zone II (5-10 m).

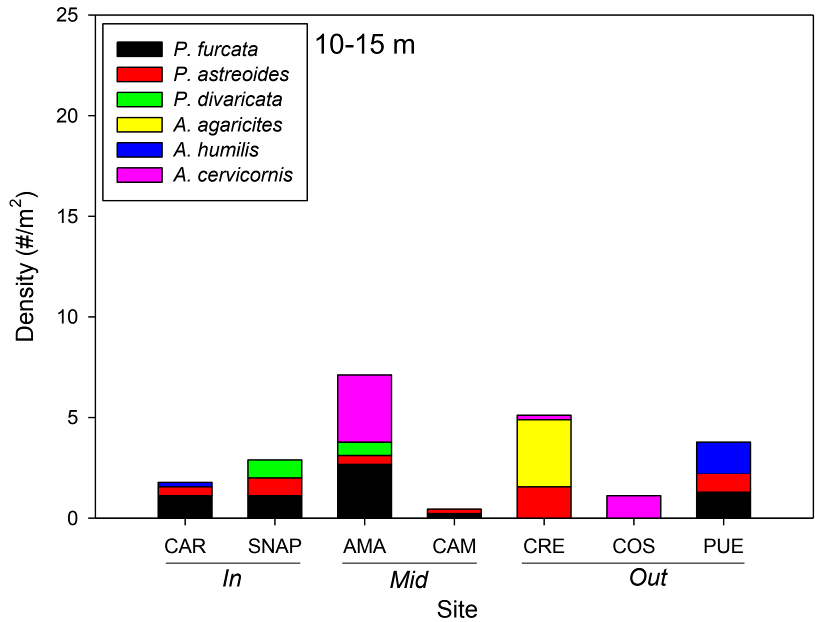


Figure 44. Coral recruit species dominance at shallow depth zone II (10-15 m).

Long-term implications of LBSP on Culebra Island's coral reefs

This preliminary characterization of coral reef ecosystem conditions across a LBSP gradient showed several important patterns. Mean percent live coral cover showed a significant linear decline with declining water transparency and a significant exponential decline with increasing chlorophyll-*a* concentration. Nonetheless, this was just a very short-term analysis and it will require continuous coupled monitoring of changes in water quality and reef ecological condition to address spatio-temporal patterns of change. However, our preliminary evidence was very solid. Coral reefs chronically exposed to LBSP were characterized by having lower percent living coral cover, a highly diverse, high percent macroalgal cover, lower percent CCA cover, and lower coral recruit density. Offshore reefs less exposed to LBSP were characterized by having higher percent living coral cover, slightly lower percent macroalgal cover, higher percent CCA cover, and higher coral recruit density. Shallower reef zones across offshore reefs were also in better shape than either shallower zones from nearshore reefs, or deeper zones of offshore reefs. Dominance by macroalgae, mostly *Dyctiota* spp., and *L. variegata* are a major concern, particularly across deeper zones formerly dominated by *A. cervicornis* and *Orbicella* spp.

These results suggest that LBSP is a critical factor shaping the actual ecological condition of coral reefs communities in Culebra. Nonetheless, there were also evident climate-change related impacts, as well as chronic impacts due to declining herbivory and recurrent hurricanes. The northeastern Caribbean region was impacted in 1987, 1998 and 2005 by three massive, unprecedented coral bleaching events. The 2005 event was catastrophic, being followed by a mass coral mortality that resulted in a 50 to 80% decline in mean percent live coral cover. Also, the wider Caribbean region was impacted by a mass mortality event of Long-spine urchin (*Diadema antillarum*) in 1983-1984, with very limited recovery across the region. Most of the surveyed reefs still showed very low densities of *D. antillarum*, and little evidence of urchin recruitment. Further, fish census data (not shown here) showed preliminary evidence of very low densities of large individuals within herbivore fish guilds, including parrotfishes (Scaridae) and doctorfishes (Acanthuridae), with very high dominance by territorial damselfishes (Pomacentridae). This suggests a potential serial overfishing effect that should be thoroughly addressed through long-term monitoring efforts across the LBSP gradient to determine stressor interactions.

Finally, Culebra has been significantly impacted by recurrent hurricanes over the last four decades. The most notorious have been David and Frederic (1979), Hugo (1989), Louis and Marilyn (1995), and Georges (1998). Also, multiple minor storms have caused strong impacts by long-distance swells and wave action. Recurrent physical disturbance by hurricanes have contributed to the arrest of benthic community recovery to early successional stages, resulting also in significant declines of *Acroporid* corals, particularly across shallower grounds. This has been aggravated by recurrent disease outbreaks. Therefore, the combined impacts of these additional stressors have further contributed to the major long-term impact exerted by LBSP across coral reefs.

There is a critical need to implement a long-term monitoring program to address changes in water quality, and in coral reef benthic and fish community dynamics across a LBSP stress gradient. The monitoring program should also focus on coral recruitment trends, *Diadema antillarum* densities, herbivory activity across the LBSP gradient, and the interactions of corals and *L. variagata*. Such multi-component approach will allow respond to multiple management-oriented questions addressing impacts by LBSP on coral reef ecosystems, further providing key information to design potential solutions to reduce LBSP impacts.

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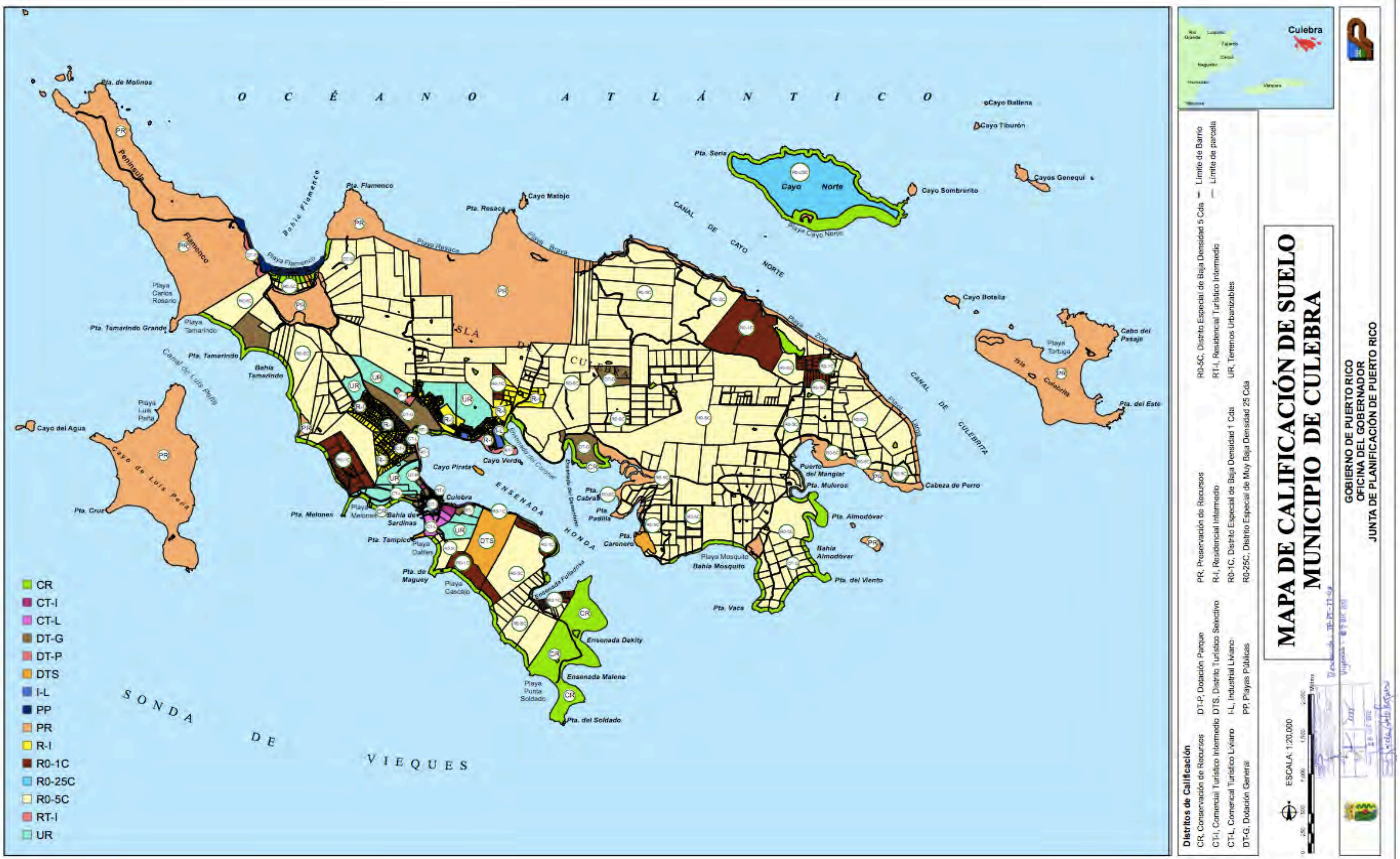
Appendix


MAPA DE CALIFICACIÓN DE SUELO
MUNICIPIO DE CULEBRA
GOBIERNO DE PUERTO RICO
OFICINA DEL GOBERNADOR
JUNTA DE PLANIFICACIÓN DE PUERTO RICO
Distritos de Calificación
CR, Conservación de Recursos
CT-I, Comercial Turístico Intermedio
CT-L, Comercial Turístico Liviano
DT-G, Dotación General
DT-P, Dotación Parque
DTS, Distrito Turístico Selectivo
I-L, Industrial Liviano
PP, Playas Públicas
PR, Preservación de Recursos
R-I, Residencial Intermedio
R0-1C, Distrito Especial de Baja Densidad 1 Cda
R0-25C, Distrito Especial de Muy Baja Densidad 25 Cda
R0-5C, Distrito Especial de Baja Densidad 5 Cda
RT-I, Residencial Turístico Intermedio
UR, Terrenos Urbanizables
Límite de Barrio
Límite de parcela
ESCALA: 1:20,000
CR
CT-I
CT-L
DT-G
DT-P
DTS
I-L
PP
PR
R-I
R0-1C
R0-25C
R0-5C
RT-I
UR
O C É A N O A T L Á N T I C O
S O N D A D E V I E Q U E S
Culebra
Cayo Norte
Isla Culebrita
Cayo de Luis Peña
Península Flamenco
Bahía Flamenco
Ensenada Honda
Canal de Cayo Norte
Canal de Culebrita
Canal de Luis Peña
Pta. de Molinos
Pta. Flamenco
Pta. Resaca
Cayo Matojo
Pta. Soña
Cayo Sombrerito
Cayos Geniquí
Cayo Ballena
Cayo Tiburón
Cayo Botella
Cabo del Pasaje
Pta. del Este
Playa Tortuga
Playa Flamenco
Playa Resaca
Playa Brava
Playa Zoni
Playa Larga
Playa Cayo Norte
Playa Carlos Rosario
Playa Tamarindo
Pta. Tamarindo Grande
Pta. Tamarindo
Bahía Tamarindo
Playa Luis Peña
Cayo del Agua
Pta. Cruz
Pta. Melones
Playa Melones
Bahía de Sardinas
Pta. Tampico
Playa Dátiles
Pta. de Maguey
Playa Cascajo
Cayo Pirata
Cayo Verde
Pta. Cabras
Pta. Padilla
Pta. Carenero
Ensenada Fulladosa
Ensenada Dakity
Ensenada Malena
Playa Punta Soldado
Pta. del Soldado
Playa Mosquito
Bahía Mosquito
Pta. Vaca
Bahía Almodóvar
Pta. Almodóvar
Pta. del Viento
Puerto del Mangler
Pta. Muleros
Cabeza de Perro

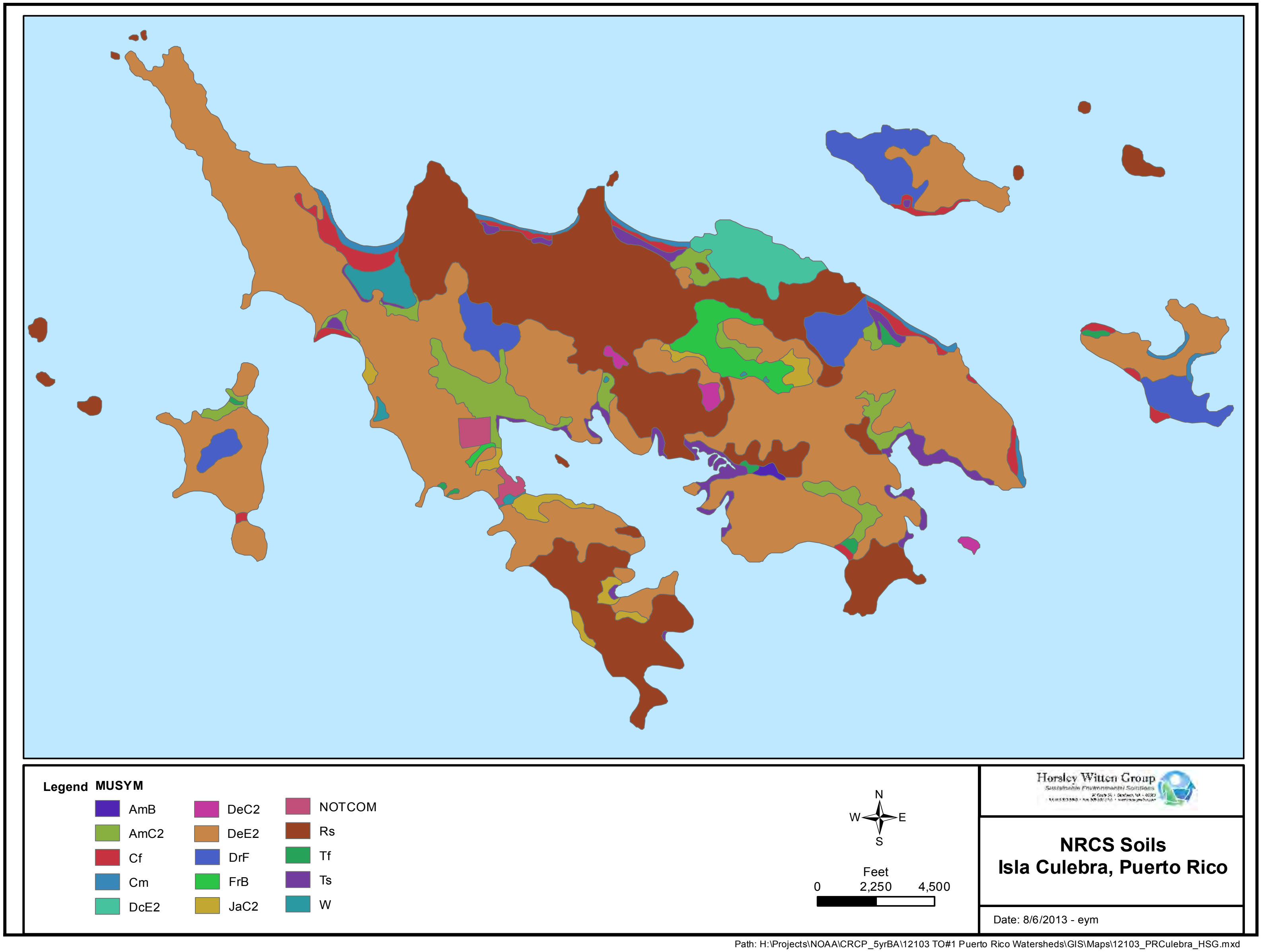


Figure A-2. NRCS Soils Map for Culebra

Appendix A-3. Land Use by Subwatershed in Culebra

Subwatershed	Very Low Density Residential	Low Density Residential (1/2ac)	Medium Density Residential (1/4ac)	High Density Residential (1/8ac)	Commercial	Industrial	Institutional/ Utilities	Cleared Land	Parks	Roads	Forest	Water/ Wetlands	TOTAL
Impervious Cover (default)	2-5%	21%	28%	32%	60%	30%	30%	5-10%	8%	90%	1%	1-5%	
Aeropuerto	**236.91**	19.44	15.35	80.37	9.82	54.87	52.45	20.17	9.30	49.01	88.17	6.90	**642.76**
Almodóvar	5.96	0.72								2.02	37.20	18.09	**64.00**
Bahía Sardinas	12.67	0.73		0.96	13.11	0.61	5.15	0.03		7.13	40.66	4.98	**86.03**
Bahía Tamarindo	23.36		0.02				19.74			2.84	34.53	11.86	**92.34**
Brava										2.45	387.58	17.04	**407.06**
Cabra	**153.97**	1.41	1.03				31.49			38.30	760.67	43.62	**1,030.49**
Carenero	15.31	0.41		0.34			0.01			8.61	65.04	7.27	**96.99**
Carlos Rosario										0.49	143.99		**144.47**
Cascajo	4.68									2.52	81.30	21.88	**110.38**
Cayo Culebrita											234.37	1.88	**236.25**
Cayo Luis Pe±a											292.94	0.44	**293.39**
Cayo Matojo												2.11	**2.11**
Cayo Norte										5.30	203.04	85.20	**293.54**
Cayo Sombrerito												2.42	**2.42**
Cementerio	20.77						17.06			1.78	9.70	7.93	**57.24**
Coronel	**95.72**	19.33	0.68	5.67		4.73		48.13		14.31	214.22	11.06	**413.84**
Culebra	**61.16**	2.20		0.35	4.08		1.99			8.94	6.88	3.58	**89.16**
Dakity		3.57								1.34	100.89	1.30	**107.10**
Datiles		0.54					0.26			1.55	18.33	6.86	**27.54**
Flamenco	**92.69**	0.96	1.89	0.39		0.49	1.96	7.46	6.33	15.73	434.76	94.05	**656.69**
Fulladosa	**96.29**	10.51	5.00							10.95	40.22	4.50	**167.47**
Laguna Cornelio	58.72									1.97	22.31	13.10	**96.10**
Larga	27.81									4.48	67.63	21.01	**120.93**
Malena										1.05	58.03	0.30	**59.38**
Manzanilla	10.56	4.17								2.70	10.39	13.66	**41.48**
Melones	15.87	0.93		0.36	0.51			1.85		6.62	16.29	5.73	**48.16**
Molinos										0.84	35.71		**36.56**
Mosquito	36.44	9.25								11.45	107.30	26.12	**190.56**
Península										4.26	154.77	0.06	**159.09**
Playa Tamarindo							7.04			0.45	31.73	9.39	**48.62**
Puerto Manglar	263.04	2.83								35.71	356.59	61.25	**719.43**
Resaca	11.98							5.18		0.12	358.56	0.22	**376.06**
San Isidro	101.61									7.97	85.67	23.05	**218.29**
Soldado										0.14	18.04		**18.18**
Tamarindo Chico	3.61	8.06								5.79	22.70	9.38	**49.54**
Zoní	39.26	12.32								6.46	108.34	25.07	**191.46**
Total	**1,388.39**	**97.39**	**23.96**	**88.44**	**27.52**	**60.70**	**137.14**	**82.83**	**15.63**	**263.27**	**4,648.56**	**561.28**	**7,395.11**

Culebra WTM Assumptions

			Concentrations				**Annual Loading Rates**		
		Impervious Cover	**TN**	**TP**	**TSS**	**FC**	**TN**	**TP**	**TSS**
Land use	**Description**	**%**	**mg/l**	**mg/l**	**mg/l**	**MPN/100 ml**	**lb/acre**	**lb/acre**	**lb/acre**
Residential	HDR	32	2.2	0.4	100	20000	6.0	1.1	275
	MDR	28	2.2	0.4	100	20000	5.4	1.0	246
	Low	21	2.2	0.4	100	20000	4.3	0.8	194
	Very low density	5	2.2	0.4	100	20000	1.7	0.3	77
Commercial		80*	2.2	0.4	100	20000	13.8	2.5	626
Industrial		50*	2.2	0.4	90	20000	8.9	1.6	366
Institutional		30*	2.2	0.4	90	20000	5.7	1.0	234
Roads - paved		95	2.2	0.4	100	20000	16.2	2.9	736
Roads - Dirt		**80**	**2**	**0.2**	**1000**	**5000**	**12.5**	**1.3**	**6265**
Grass/Parks		8	2.0	0.4	70	20000	2.0	0.4	69
Cleared land		20	2	0.2	1000	5000	3.7	0.4	1871
Forest	includes wetlands	1					2.0	0.2	100

Other Assumptions

Homes per subwatershed based on actual estimate in low density/ calculations in higher density

* These impervious cover numbers were edited based on estimates for each subwatershed as these categories had high variability

Annual Rainfall estimate used is 40 inches per year

Sediment estimates in bold are based on averages in Ramos-Scharron, 2009

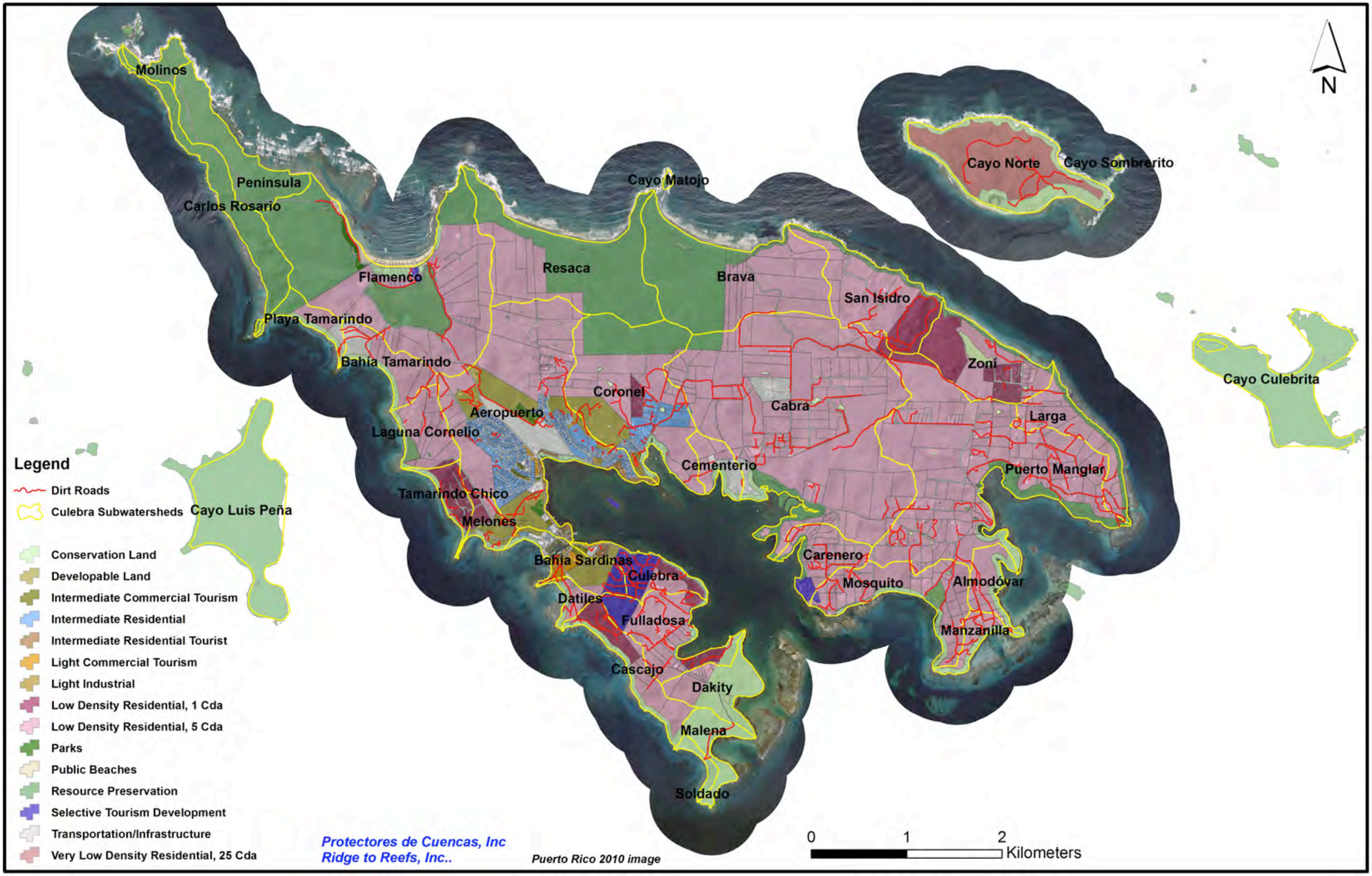


Figure A-4. Land Use Maps Created for Culebra

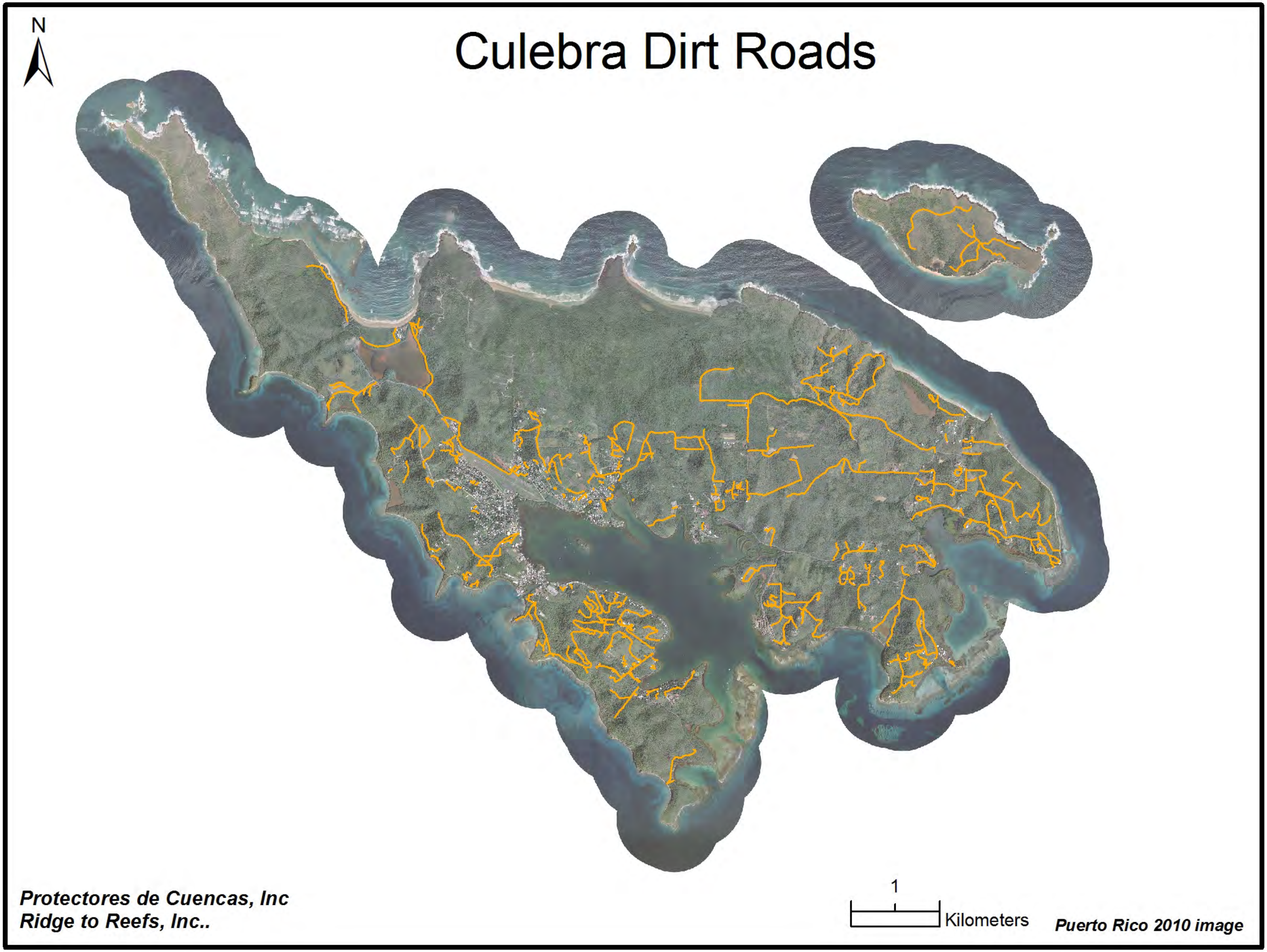


Figure A-5 DIrt Road Layer for Culebra

A-6 Restoration Concepts for Green Infrastructure and Dirt Roads