


CABO ROJO
COMMUNITY WATERSHED ACTION PLAN FOR WATER QUALITY AND CORAL REEFS

PREPARED FOR

NATIONAL FISH AND WILDLIFE FOUNDATION

NOAA CORAL REEF CONSERVATION PROGRAM

PUERTO RICO DRNA

MUNICIPALITY OF CABO ROJO

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Acknowledgements

This project was funded by the National Fish and Wildlife Foundation Coral Reef Conservation Grant and we appreciate their support in funding this effort. We would also like to acknowledge many of the partners and stakeholders who played an important role in the watershed planning process in Cabo Rojo. These individuals and organizations that contributed to the effort and its success include:

- The stakeholders from the community of Cabo Rojo itself – the many individuals who participated directly in the stakeholder process and fieldwork – sharing their information and knowledge with us.
- Municipality of Cabo Rojo
- Department of Natural and Environmental Resources of Puerto Rico (DNER) - special thanks to Cabo Rojo Management Officer – Idelfonso Ruiz, as well as the support from headquarters including Secretary Carmen Guerrero, Damaris Delgado, the Director Bureau of Coasts, Reserves and Refuges and Puerto Rico Coral Reef Point of Contact and Ernesto Diaz, the Director of the Coastal Zone Management Program
- Felix Lopez from US Fish and Wildlife Service (USFWS)
- Evelyn Huertas and David Cuevas from US EPA Caribbean Office (USEPA CEPD)
- Pat Bradley, US EPA Office of Research and Development (US EPA ORD)
- Rob Ferguson and Antares Ramos, NOAA CRCP, and Lisa Vandiver, NOAA Restoration Center
- Students from – Student chapter of the Marine Environment Society (CESAM) including Yasiel Figueroa and Alfredo Montañez
- Glenis Padilla and Jeiger Medina Muñíz, Protectores de Cuencas and Yasiel Figueroa (CESAM) for assistance with translations

"We acknowledge the support provided to E.A. Hernández-Delgado by the National Science Foundation through award NSF HRD 0734826 to the Center for Applied Tropical Ecology and Conservation, University of Puerto Rico."

Glossary of Acronyms

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

GI – Green Infrastructure

NOAA CRCP – NOAA Coral Reef Conservation Program

NOAA RC – NOAA Restoration Center

PDC - Protectores de Cuencas

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 watershed planning process in Cabo Rojo – 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 the Cabo Rojo/ Guanajibo watersheds including protecting public health, safe and healthy beaches and natural resources which serve to support the local economy.

Background Synopsis

The town of Cabo Rojo is located in the extreme southwest of Puerto Rico. Its watershed drains major drainage areas to both the West and South (Figure 1). Westward the main source of fresh water is the Guanajibo River and south is divided into several small dry basins within Corozo and Pitahaya. Cabo Rojo is one of the most important tourist destinations in Puerto Rico due to its vast marine resources and natural attractions. According to census data (1990-2010) the population has increased steadily from 38.521 to 50.917 inhabitants (Census 2010). Cabo Rojo is estimated to receive over 500,000 visitors annually. This combination of high visitation, quarry resource extraction operations, relatively ineffective on-site sewage treatment in coastal areas and growing urban development has created enormous pressure on fragile coastal ecosystems. Besides these factors, it is important to recognize stressors on marine ecosystems and coral reefs globally. These primarily have to do with the burning of fossil fuels and increased CO2 into our atmosphere causing increased ocean acidification and climate change. Climate change has led to more frequent elevations sea surface temperatures causing coral bleaching and greater susceptibility to disease. This is important because local factors join together with global impacts multiplying the impact on ecosystems.

Cabo Rojo is a municipality made up of a number of smaller communities and coastal towns including Boquerón, Buyé, Combate, Corozo, Joyuda and Puerto Real. The town of Cabo Rojo itself drains to the Guanajibo watershed which also includes the towns of San German and Sabana Grande; portions of the upper watershed extend into the highlands in Maricao. The SW Coast that includes the beach towns of Buyé, Combate and Boquerón as well as the El Faro Lighthouse reserve and Playa Sucia are important tourism destinations in Puerto Rico and support a strong local economy. Coral reef diving and snorkeling, and fisheries have historically been important in these communities especially Puerto Real, Corozo and Joyuda. The coral reefs face both local pressure from fishing and land based sources of pollution and global impacts associated with ocean acidification and climate change. Despite the pressures, many of the reefs remain in good condition but there future is at risk due to land-based sources of pollution and climate change. Maximizing the resilience of the existing reefs and reducing the pollution from the land can help preserve these reefs into the future. Cabo Rojo 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 which charts a course for recovery (DRNA, 2013) (NOAA, 2009).

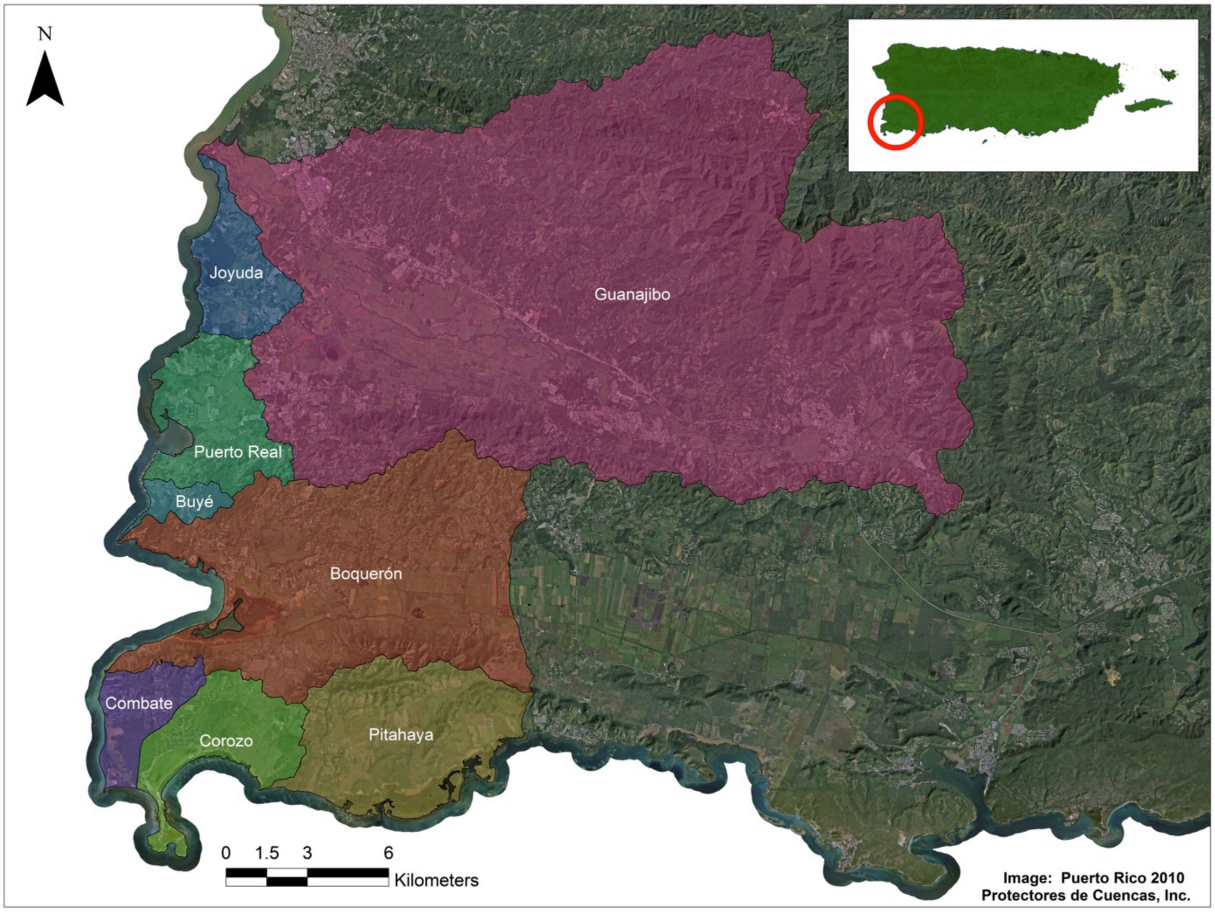


Figure 1. Cabo Rojo Subwatersheds

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. Fortunately, these local stressors are also reversible through direct action and most stressors can be kept at bay through effective protective measures and policies.

The Clean Water Act provided that the territories of the United States should adopt quality standards since 1972 and pollution control programs help reduce discharges of pollutants into water bodies. The National System for Pollutant Discharge Elimination (NPDES for its acronym in English) has helped to significantly reduce the loads from point sources. Point sources, as described by the EPA are: "any discharge pipe, gutter and drains that can be easily identified and refers to all municipal wastewater and industrial waste discarded into bodies of water" (USEPA, 2000). Yet another type of discharge, nonpoint, are responsible for most of the problems of aquatic ecosystems, especially after rain events. Non-point sources are commonly associated with agricultural operations. However, for Cabo Rojo, pollution related to urban development is critical. Therefore, the main objectives of this plan are decreasing pollution associated with residential, commercial and industrial development, bare soils, the indiscriminate use of fertilizers and pesticides, persistent sewer overflows and failing septic systems. The most critical local environmental insults are identified in Cabo Rojo include poor management of wastewater and sediment inputs into bodies of water impacting the use of coastal resources (recreational boating, fishing and beaches).

Addressing these stressors through restoration practices, improvement of infrastructure and prevention of future impacts through improved policies are critical steps to ensure a sustainable future for Cabo Rojo and the region especially with the advent of climate change. A focus on these parameters also helps address other stressors that include bacteria, heavy metals and polycyclic aromatic hydrocarbons (PAH for its acronym in English) presented in Table 1.

Table 1. Priority Pollutants in Cabo Rojo

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 contaminants	Toxicity to coral reefs, potential for human health issues	Legacy contaminants, pesticides for control of insects and vegetation

PROCESS

Cabo Rojo communities have helped to chart their own course to address local environmental stressors and establish goals to reverse the impacts through the recommended actions through a consultation process. In this plan, actions and specific costs have been identified to reduce sediment and nutrients by roughly 10%, but importantly key areas of known pollutants have been identified within the coastal watersheds closest to many of the reefs areas. We believe improving local water quality it is possible to improve the prognosis for reefs in this area of SW Puerto Rico with a reasonable budget and collective community action in the next 5-10 years.

This Management Plan represents the sum of a process of comprehensive watershed planning to Cabo Rojo. The main purpose of it is to help visualize a course of action for improving water quality and coral reefs in Cabo Rojo while serving the needs identified by citizens. A conceptual model used approach is presented in Figure 2. The process to complete the Plan included:

- A study that summarizes previous work and environmental information of the watershed area and nearshore reefs and habitat
- A consultation process with stakeholders which include meetings with individuals, agencies and community organizations as well as a series of open public meetings where participants set goals and objectives to be addressed by the Plan
- Initial field work to establish existing freshwater and tidal water quality conditions and to establish the current status of coral reefs in the Cabo Rojo region
- Fieldwork to identify sources of pollution and points of illegal discharges
- Identification and categorization of opportunities for restoration projects including implementation of green infrastructure to address runoff and contamination issues including priorities for specific projects and legal and public policy improvements
- Strategies that represent a quantitative approach to measuring improvements
- Preparation of a draft for discussion with communities and agencies prior to approval of the final plan.

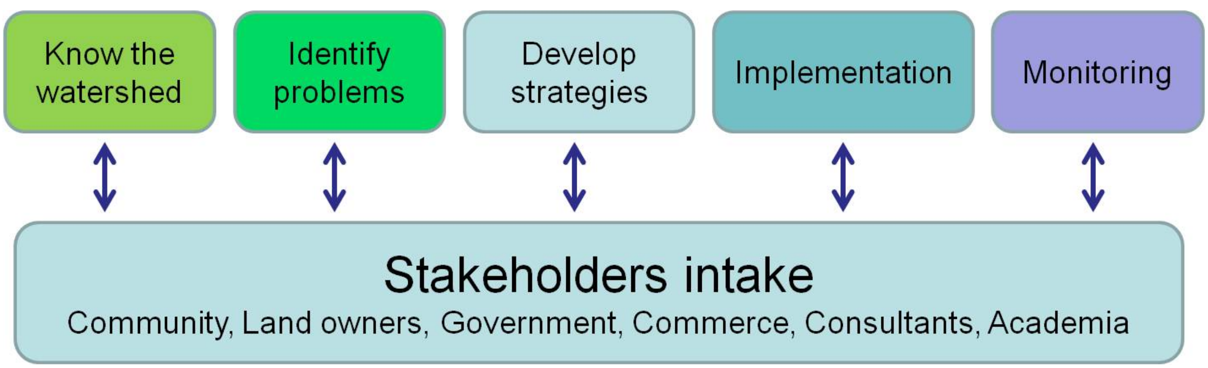


Figure 2. Conceptual Model of our Community-Based Approach to Watershed Planning and Restoration

EPA A-I CRITERIA

In order to strengthen the competitiveness of the sources of funding, this plan has been written to meet A-I criteria established by EPA (EPA, 2008). These criteria help prioritize projects and actions, estimate costs and benefits, and identify funding sources. The Criteria and the location in this document where the criteria are met are summarized in Table 2.

Table 2. EPA A-I Criteria and where located the watershed plan

Criteria	Location in Plan
A. Identification of the causes and sources to be controlled to achieve the load reductions estimated in the watershed management plan	Table 1
B. Set the estimated reduction in pollutant loading is expected by implementing management measures and restoration proposals	Table 10
C. Description of implementation measures	Table 3 and Section 4
D. Estimate the amount of technical and financial assistance needed to implement the plan	Table 10
E. A component of information / training that will be used to improve public understanding and encourage their participation	Section 1 Stakeholder Process
F. Establish a schedule for evaluating management measures nonpoint source pollution	Table 10
G. A description of measurable goals and timeline	Table 10
H. A set of criteria for determining pollution load reduction and measures of progress	Table 11
I. A monitoring component to determine whether the watershed plan is being implemented effectively	Table 11, Appendix A-7

Pollution Source Estimates

ESTIMATED SOURCES OF POLLUTION

A watershed pollutant model was constructed for some of the key priority pollutants in Cabo Rojo, 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 Cabo Rojo, such as forest, cleared land, dirt roads, paved roads and high, medium and low intensity developed areas (modified from Caraco, 2002) as well as NPDES permitted discharges from sewage treatment plants (EPA ECHO, 2015). Information from Ramos-Scharron (2009), Warne et. al. (2005), the EPA compliance website (ECHO) and information collected during our fieldwork and water quality monitoring were used to help populate the model. For bare soils estimates were made based Appendix A-1 and A-4 summarizes land use input maps (2001 National Land Cover Dataset) and land use coefficients that were used.

Figures 3 and 4 illustrate the sources of nitrogen and sediment in the watershed based on the model output. Septic systems particularly those close to the coastal waters are the largest source of nitrogen in the watershed followed by grass and forestland and NPDES discharges (sewage treatment plants). For sediment the major sources include forest land and grassland as well as channel erosion, and bare soil areas. Bare soil areas include the network of unpaved roads in the area of Los Pozos near Combate. Mining and extraction operations as well as agriculture in the valley and headwater coffee farms are also significant contributors to sediment loading particularly in the Guanajibo watershed.

It is important to note that on a per acre basis forests, wetlands and grasslands produce the least pollution for any land use, so few strategies are available to achieve further reductions other than preserving or restoring coastal lagoons and mangroves which can intercept water from diverse land uses and improve water quality.

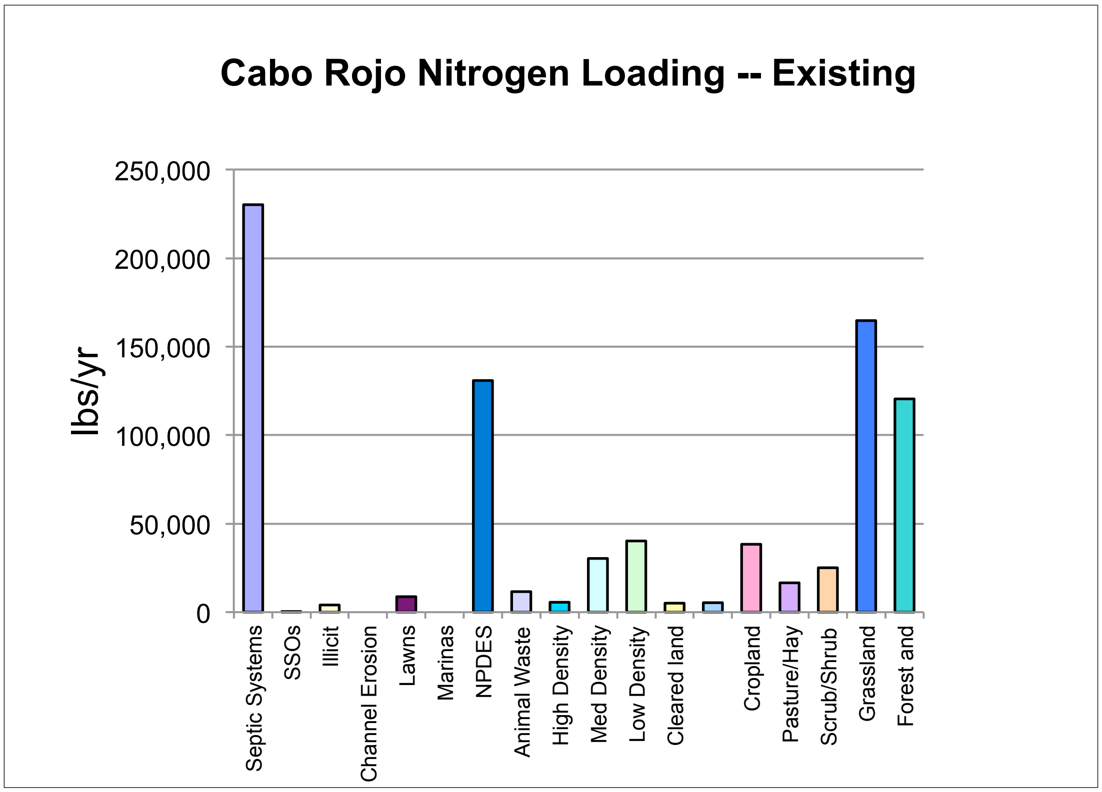


Figure 3. Nitrogen Source Estimates in Cabo Rojo using the WTM (HDR and MDR refer to High and Medium Density development)

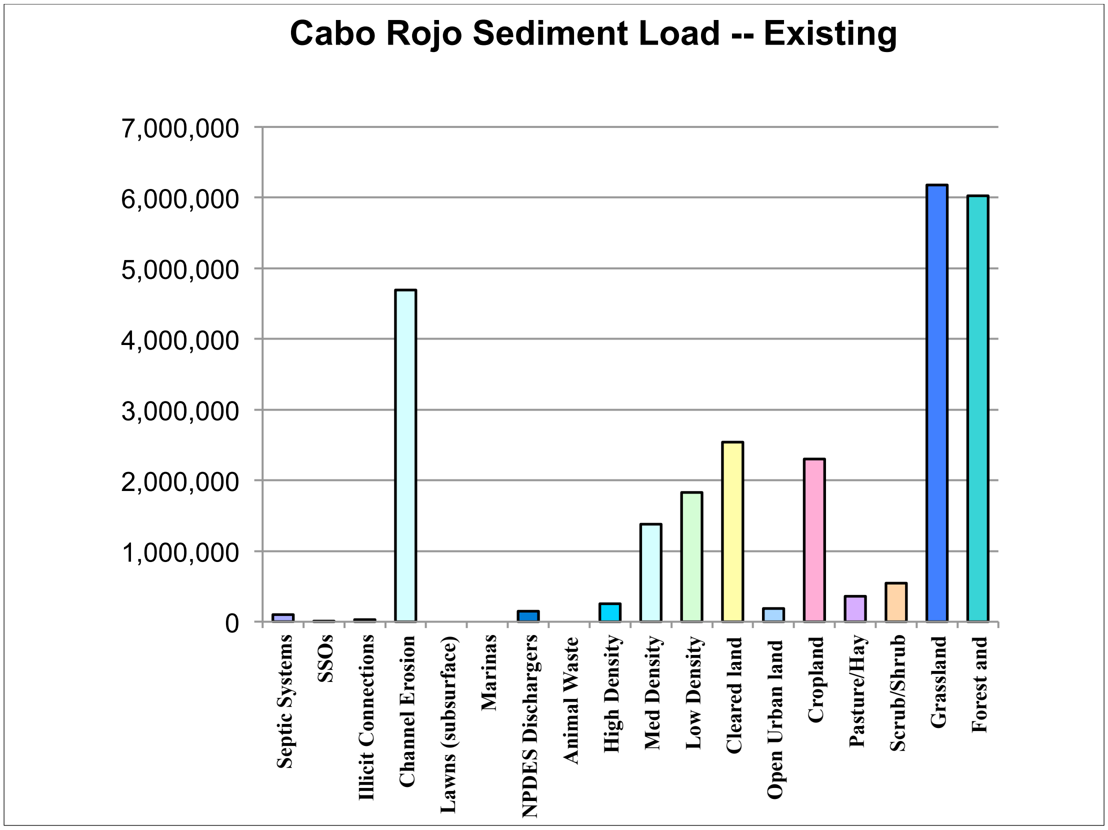


Figure 4. Sediment Source Estimates in Cabo Rojo using the WTM

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 or through natural denitrifying processes.
3. 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 bare soils, dirt roads, land uses in general – a more detailed analysis was beyond the model capability – but the impact of bare soils were evaluated in our fieldwork and we have used that information to identify areas for stabilization.

Conclusions

- Combate is of significance in terms of nitrogen losses to the coastal and marine ecosystems due to the high density of septic systems. This issue is confirmed by the high levels of Chlorophyll A which are seen in the beaches along Combate.
- Puerto Real has a significant nitrogen and bacteria load due to illicit connections and homes that have not connected to sewer despite having access.
- Guanajibo due to its size has significant nutrient and sediment loads as well as impacts from sewage treatment plants and illicit discharges particularly those in the Town of Cabo Rojo that were active at the time of our screening.

- Boquerón has significant impacts from the Las Pozos area where a lot of sediment is generated as well as the sewer system at the Balernario that seems in some disrepair and is supposed to be extended in order to be connected to the Lajas WWTP.
- Joyuda is a priority for having a number of areas not connected to sewer including some homes, restaurants and other businesses which do not have adequate space for septic systems but still rely on them as their only method of treatment.

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 5), 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 Cabo Rojo.

Involving the local community and stakeholders in the planning process is one of the most important components of a watershed management plan. Ultimately, it is the community that determines whether the plan is implemented and who helps hold public officials responsible for the implementation of the plan. As part of the watershed planning process for Cabo Rojo, six community meetings were held with around 50 community leaders and members participating. At these meetings the goals and objectives and actions of the Watershed Management Plan were dicussed and the future vision for the town of Cabo Rojo was defined. The list of goals suggested in this process were:

Overall

1. Control flooding and uncontrolled stormwater runoff
2. Reduce pollution from sewage and septic systems.
3. Address illicit discharges (sewage and washwater discharges) from establishments and businesses on the coast of Cabo Rojo.
4. Stabilize exposed soil
5. Protect coral reefs
6. Control and prevent of erosion and sedimentation from both urban and rural areas
7. Provide environmental education for the community and the youth through the school system
8. Communication - improve and promote communication and teamwork between different sectors
9. Implement and monitor the benefits of the Watershed Management Plan.
10. Create a monitoring plan to ensure healthy water quality at beaches.
11. Improve and expand the sewer system.
12. Promote and practice reforestation to improve ecological function and reduce runoff.
13. Ensure natural filters/buffers in streams and creeks
14. Use restoration practices to help beautify communities.
15. Identify sources of funding
16. Prevent the disturbance of natural areas


Figure 5. Stakeholder Meeting; Small Groups Setting Goals and Priority Areas (insert photos)

Recommendations

Prioritized implementation recommendations for the Cabo Rojo watershed are summarized in Table 3 and Figure 6. 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 the greater Cabo Rojo area 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 Cabo Rojo by 10% and reduce sediment to the coastal waters by 10% of the "treatable load" (meaning the existing load minus the baseline load if the watershed were in forest and grassland) 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 $400,000 -$500,000 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., connections to the WWTP) as well as significant investments in large restoration projects. 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 Cabo Rojo 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). Reefs habitat is conservatively estimated at over 16 square kilometers in the study area and estimated to provide values and services equivalent to over $8,000,000 annually. 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 Cabo Rojo, this consists of monitoring the effects of management measures on bare soil and dirt roads, quarry related operations, polluted discharges and measuring the benefits of efforts on coastal resources (i.e., fisheries, coral reefs, sea grass beds, water quality). Monitoring will also enable effective adaptive management and outcome-based implementation that achieves long-term protection and preservation of resources and a healthy economy.

Table 3. Cabo Rojo Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Fiscal Sponsor/ Partners	Estimated
PR-1 Puerto Real Connections	2,3,11	Connect all homes and businesses along the waterfront to sewer as well as in other targeted locations were septic failures were obvious	PRASA, USEPA, USDA Rural Dev, NOAA, PDC/RTR, EQB	$200,000
PR-2 Stormwater Treatment Wetlands	3,4,9, 10	Runoff from the town area is conveyed through a ditch in an adjacent farm into a stream and them the coastal environment	NOAA, NFWF, NRCS, PDC/RTR, EQB	$100,000
PR-3 Pilot Oyster Restoration Project	3,4,9, 10	Pilot a project for dock owners to grow oysters after the connections to sewer are done -- the goal primarily would be to improve water quality and filtration	DNER, UPR, USEPA, PDC/RTR	$20,000
PR-4 Illicit Connections	2,3,11	Track down and address other water quality issues and illegal connections/ sources of pollution	PRASA, USEPA, EQB, PDC/RTR, DNER	$20,000
PR-4a Illicit Connections	2,3,11	Additional area of needed connections to sewer	PRASA, USEPA, EQB, PDC/RTR, DNER	$20,000
PR-5 Local Volunteer Water Quality Monitoring Program	6,9,10, 12	Engage the community in a volunteer monitoring program to track conditions in Puerto Real	Local Community Nonprofits, UPR, Surfrider, EPA	$10,000
CBR-1 Illicit Connections Cabo Rojo	2,3,11	Fix illegal connections and sewer leaks	PRASA, USEPA, NOAA, PDC/RTR, EQB	$15,000
CBR-2 Urban Drainage GI	8,11	Integrate green infrastructure and vetiver into the urban drainages and the river -- the help address infow of stormwater runoff and other pollutants	PDC/RTR, SAM, DNER, ACDEC	$50,000
CBR-3 School GI project	4,9,10	Create a pilot Green Infrastructure stormwater retrofit at a local school	PRASA, USEPA, USDA RD, Businesses, PDC/RTR, Municipality, EQB	$15,000
CBR-4 Treatment wetland at Public Works	4,9,10	Reduce the impact of the public works yard and create a model for addressing runoff from a large industrial site -- treat first flush separately from flood flow	PDC/RTR, USEPA, DNER, EQB	$75,000

Table 3. Cabo Rojo Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Fiscal Sponsor/ Partners	Estimated
B-1 Impact of septics in Buyé	7,10, 11	Determine the impact of septics in Buyé and determine a strategy to address the likely impacts of nitrogen moving to the coastal environment partner with USGS or UPR	USGS, UPR, PRASA, USEPA, NOAA, PDC/RTR, EQB	$25,000
COM-1 Reduce impact of septic systems	2,3,11	Fully funded sewer connections throughout Combate, or vetiver and beach berm buffer restoration to intercept flow of nutrients to coastal waters	PRASA, USEPA, USDA Rural Dev, NOAA, PDC/RTR, EQB, Municipality of Cabo Rojo	$40,000 or 1M*
COM-2 Dirt Road Stabilizations	8,11	Reduce impact of dirt roads on water quality in the Combate area -- implement runoff controls and sediment traps	PDC, DNER, Municipality, USFWS	$60,000
COM-3 Large sediment trap	3,4,9, 10	Create a large sediment trap downstream of the eroding ATV (4-track) trails -- determine if any of the existing trails can be shut down to reduce the overall impact	NRCS, USFWS, PDC, RTR	$200,000
COM-4 Boat Ramp	13,14	Runoff from the boat ramp area is currently not being effectively treated due to a clogged BMP -- fix the BMP or replace the practice with Green Infrastructure -- considered a grassed or paver lot for a portion of the site	PDC, DNER, Municipality	$15,000
COM-5 Park area	10,14	Integrate GI into the new park area	Municipality, DNER, PDC, EPA	$20,000
COM-6 Monitoring Program	6, 9	Set up monitoring program working with the community to monitoring beaches around Cabo Rojo and specifically Combate beaches	Municipality, DNER, UPR, PDC/RTR, Surfrider, NOAA	$15,000
COM-7 Septic Education	8,9,12	Septic education and pumping	Municipality, Health Dept, PRASA, USEPA, PC/RTR, EQB	$20,000
BOQ-1 Sewer connection for Balineario	2,3,11	Provide a direct connection to the sewer line from the Balineario beach area to the WWTP in Lajas -- leaks/clogs and limited treatment have been noted in the current system	PRASA, USEPA, NOAA, PC/RTR, EQB	In process**
BOQ-2 Oxidation Ponds around manholes	3,4,6, 9,10	Place rain garden type oxidation ponds with vetiver and other plants known for uptake around manholes that have overflow issues	PRASA, USEPA, NOAA, PC/RTR, EQB	$15,000

Table 3. Cabo Rojo Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Fiscal Sponsor/ Partners	Estimated
BOQ-3 Sediment Traps in the Poblado	1,2,3, 4,10, 12, 15	Sediment trap and raingarden in the dirt parking lot for Boquerón to reduce sediment transport to the mangroves	DNER, PDC, NOAA, Municipality	$30,000
BOQ-4 Raingarden at scuba shop	4,6,9	Construct a raingarden to capture and treat the 1st flush of runoff from the adjacent street in Boquerón	DNER, Community, PC/RTR, NOAA	$12,000
BOQ-5 IDDE in Boquerón	2,3,11	Elevated bacteria concentrations were noted adjacent to the businesses and oyster farming in Boquerón as well as in some of the more rural drainages	PRASA, USEPA, NOAA, PC/RTR, EQB, Municipality	$10,000
BOQ-6 IDDE Grease	2,3,11	Make sure grease traps and effective storage are provided for grease in Boquerón	PRASA, USEPA, NOAA, PC/RTR, EQB	$10,000
BOQ-7 DNER Nursery	1,4,6	Install sediment traps, rain gardens and rainwater harvesting practices at the nursery to reduce sediment runoff from the site which has been considerable	DNER, PDC	$35,000
BOQ-8 Implement Oysteria Streets GI	1,7,13, 14	Implement a sea streets approach in Boquerón to address stormwater runoff and reduce threats to shellfish populations	DNER, PDC, Municipality of Cabo Rojo, Tourism Company or Public Health	$100,000
BOQ-9 Stormwater wetlands on farms	1,4,9	Locate stormwater wetlands in areas with contaminated flow	NRCS, DNER, PDC	$100,000
BOQ-10 Shellfish and oyster farm outreach and education on ensuring quality	3,7,9	Work on a conservation and education program with oyster farmers and the public	DNER, PDC/RTR, Municipality of Cabo Rojo, Tourism Company or Public Health	$15,000
BOQ-11 Sediment traps	1,6,9, 16	Construct sediment traps to capture runoff and soil before it enters mangroves and protected areas	DNER, PDC, Municipality of Cabo Rojo	$80,000
GUA-1 Buffer Zones/ Agricultural Best Management practices (BMPs)	1,6,13	Establish buffer zones along the Guanajibo River, upper tributaries and reduce runoff from unpaved farm roads and bare soils, Convert sun coffee to shade coffee	NRCS, USFWS, PDC, RTR	$100,000
GUA-2 Extraction/Industrial sites	1,6,7	Creation of a program to address runoff from Quarry and aggregate plants and distribution centers -- there is a concentration of them in the watershed impact water quality as many are poorly controlled based on observation	EPA, DNER, EQB, PDC	$150,000
GUA-3 IDDE Guanajibo	2,3,11	Track additional sources of contamination including site near Hormingueros/edge of Mayaguez	PDC/RTR	$10,000

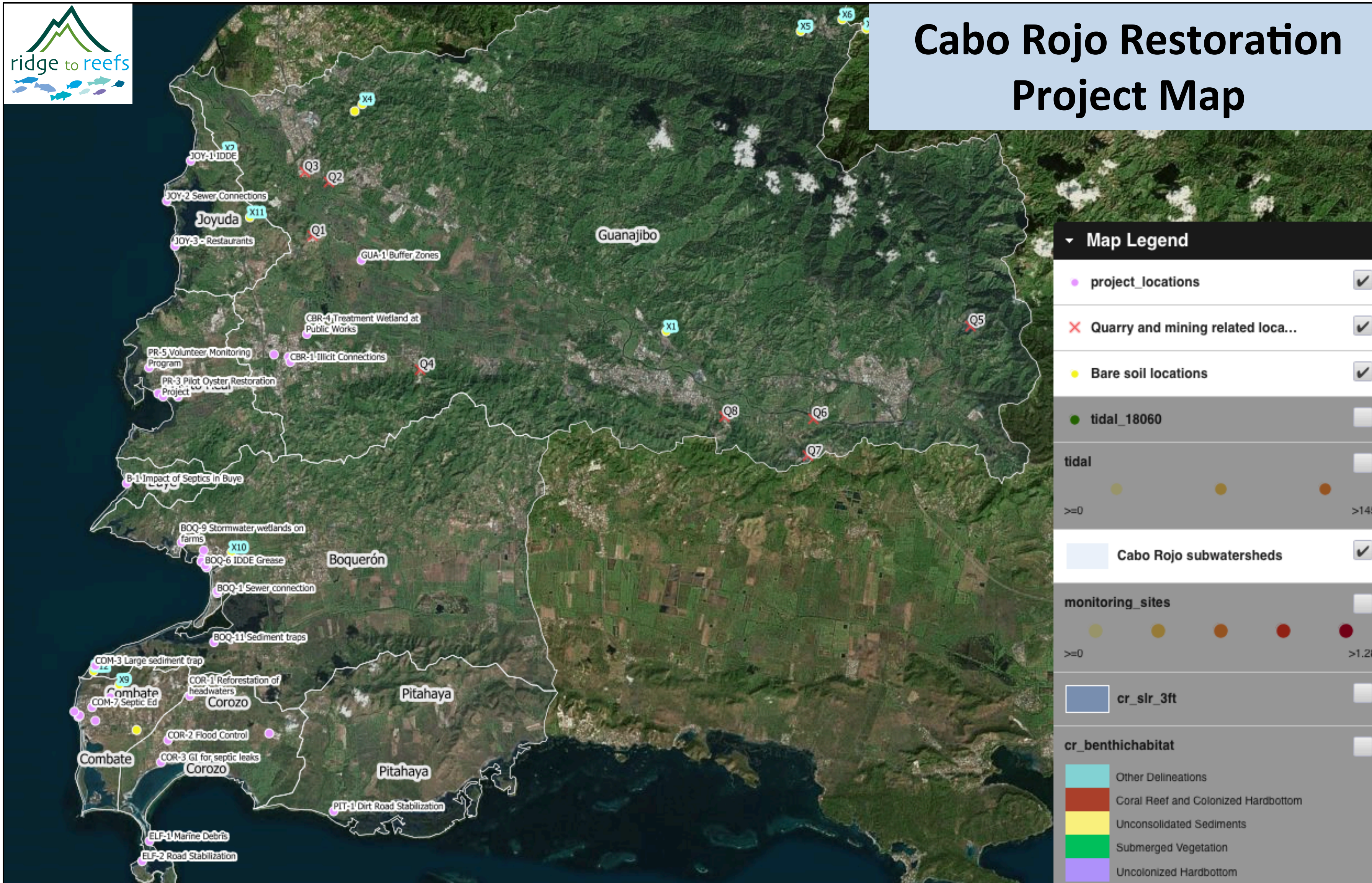
Table 3. Cabo Rojo Watershed Implementation Plan Recommendations

Recommendation	Goals Met	Description	Potential Fiscal Sponsor/ Partners	Estimated
JOY-1 IDDE	2,3,11	Track down and address water quality issues and illegal connections/ sources of pollution in areas identified in monitoring effort	PDC, Municipality, PRASA, EPA	$10,000
JOY-2 Sewer Connections	2,3,11	Work with homes and businesses that are not connected to the sewer to get connected -- this may require extension of sewer in some areas -- where and if extension is not possible alternative treatment systems should be investigated (pump and treat)	PRASA, USEPA, NOAA, PDC/RTR, EQB	$150,000
JOY-3 Restaurants	2,3,7	Work with restaurants on potential sources of pollution including stormwater runoff, grease and sewage contamination -- work with a sustainable distinction and public education program for restaurants meeting minimum criteria	PRASA, USEPA, NOAA, PDC/RTR, EQB	$100,000
COR-1 Reforestation	1,12	Reforestation of critical areas in the headwaters of the drainage to Corozo	DNER, USFWS, Municipality	$40,000
COR-2 Address Stormwater	1,9,14	Integrate a green infrastructure project with the Municipality for flooding control	Municipality, DNER, NFWF	$30,000
COR-3 Wetland Construction	1,2,9	Construct wetland or landscape treatment systems to address failing septic systems	PRASA, USEPA, NOAA, PDC/RTR, EQB	$40,000
COR-4 Sediment Traps	4,6,16	Construct sediment traps and address flow from landfill and adjacent dirt and paved roads -- use vetiver and dirt road practices	DNER, Municipality, PDC	$80,000
ELF-1 Marine Debris	7,13, 14	Reserva Bosque Los Murillos – Marine Debris Control Project and Wetland Restoration to increase connectivity	NOAA Marine Debris, DNER, PDC	$40,000
ELF-2 Stabilize Roads	4,6,16	Stabilization of roads to El Faro	DNER, PDC	$150,000
PIT-1 Stabilize Roads	4,6,16	Stabilization of dirt roads running perpendicular to shoreline (investigate additional locations)	DNER, FWS	$20,000
Total	*$2M to $3M depending on whether efforts to address septics in Combate results in sewer ** the treatment plant/s at the Balenario are slated to be connected to sewer in the near future and funding is reportedly in place			

CATEC -- Center for Applied Tropical Ecology and Conservation, DNER – 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, PRTC -- Puerto Rico Tourism Company, RTR – Ridge to Reefs, SAM – Marine Environment Society (Sociedad Ambiente Marino), UPR – University of Puerto Rico, USDA Rural Development – US Department of Agriculture (USDA RD), USEPA – US Environmental Protection Agency, USFWS – US Fish and Wildlife Service

In addition to the maps provided in this report – we have prepared a map viewer for the project which allows the viewer to choose variables they would like to project in GIS and overlay them on a watershed map or the SW Coast. You can also view the data in more detail and also click on points and layers for more detailed information and to perform analysis and investigate special topics of your concern. Layers include water data for various parameters from freshwater and coastal areas, restoration projects and details, info on quarries and bare soil areas, NOAA's sea level rise viewer at a 3ft rise, a land use layer, NOAA Coastal Habitat, etc. These maps will be available though the Ridge to Reefs and Protectores de Cuencas websites as follows:

www.ridgetoreefs.org and www.protectoresdecuencas.org


Cabo Rojo Restoration Project Map
ridge to reefs
Guanajibo
Joyuda
Boquerón
Pitahaya
Corozo
Combate
JOY-1 IDDE
JOY-2 Sewer Connections
JOY-3 - Restaurants
GUA-1 Buffer Zones
CBR-4 Treatment Wetland at Public Works
CBR-1 Illicit Connections
PR-5 Volunteer Monitoring Program
PR-3 Pilot Oyster Restoration Project
B-1 Impact of Septics in Buye
BOQ-9 Stormwater wetlands on farms
BOQ-6 IDDE Grease
BOQ-1 Sewer connection
BOQ-11 Sediment traps
COM-3 Large sediment trap
COR-1 Reforestation of headwaters
COM-7 Septic Ed
COR-2 Flood Control
COR-3 GI for septic leaks
PIT-1 Dirt Road Stabilization
ELF-1 Marine Debris
ELF-2 Road Stabilization
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
X1
X4
X5
X6
X9
X10
X11
Map Legend
project_locations
Quarry and mining related loca...
Bare soil locations
tidal_18060
tidal
>=0
>145
Cabo Rojo subwatersheds
monitoring_sites
>=0
>1.28
cr_slr_3ft
cr_benthichabitat
Other Delineations
Coral Reef and Colonized Hardbottom
Unconsolidated Sediments
Submerged Vegetation
Uncolonized Hardbottom

Section 2. Scientific Imperative for Action in Cabo Rojo

Coral Reefs

The combination of natural factors (i.e., hurricanes) with chronic non-point source pollution and other potential anthropogenic reef degrading factors, such as sedimentation and overfishing, have contributed to a dramatic phase shift in coral reef community structure. Phase shifts have favored dominance by macroalgae and non reef-building taxa. There is a pressing need to implement sound management strategies to reduce and/or prevent non-point source sewage pollution impacts in coral reef habitats and coastal habitats before the reef ecological and socio-economic damage turn irreversible. Live coral cover is widely variable throughout the Cabo Rojo coast. This can vary from 4% at Punta Guaniquilla NR to 73% at Arrecifes de Tourmaline NR showing significant differences in the distribution of live *A. palmata* (Weil *et al*, 2003). A. palmata has been virtually eliminated from other reefs near shore reefs of the west coast, especially near Mayagüez, possibly from anthropogenic disturbances (Morelock & Bruckner, unpublished data). One of the largest remaining healthy stands of elkhorn coral is located in 3-5 m deep in Bajo Gallardo reef, 13 km off Cabo Rojo.

As for fisheries, many commercially important species have been overharvested historically including grouper, snapper and parrotfish. Parrotfish, while not that commercially important, it too has been overharvested likely as other species declined which has likely impacted coral health as parrotfish serve as an important trophic role as key consumer of algae and macroalgae (Jackson et. al, 2014). The loss of parrotfish combined with the Caribbean wide loss of the sea urchin grazer Diadema antillarum in the mid-1980s (Lessios, 1988). Efforts to reduce impacts to known spawning aggregation sites for red hind (Epiniphelus guttatus), established seasonal closures at the request of commercial fishers at Bajo de Sico, Tourmaline Bank and Abrir La Sierra to protect spawning sites for this grouper species, which is important for commercial and recreational fisheries. Each closure measures 16.7 km2 and prohibits all fishing from December 1 to February 28. Additionally, in 2005, the use of all bottom-tending gear (traps, pots, bottom longlines or gill and trammel nets) was prohibited from these areas year-round (Garcia-Sais, *et al* 2008). A detailed analysis on current coral reef conditions is presented in Appendix A-7.

Studies by Ramos-Scharrón et al. (2009) in similar areas of Puerto Rico 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. Cabo Rojo in fact is named for its red clay earth that is very pronounced in the area around Combate and at higher elevations in Boquerón, Joyuda and Guanajibo watersheds.

Past coral studies have documented some troubling trends in the nearshore reefs in Cabo Rojo. In 2006, Norat and Mattei documented problematic bacteria and turbidity water quality conditions in Puerto Real and near the mouth of the Guanajibo River. They also identified over 300 of 400 septic systems (Figure 7) that were likely experiencing failure and contributing sewage and contaminants to the Belvedere wetlands and Puerto Real Bay. In addition, for this watershed plan, baseline data was collected for nearshore coral reefs by Sociedad Ambiente Marino (SAM), UPR CATEC, and CESAM in a gradient from areas close to land and sources of pollution to areas further off the coast. Widespread degradation was identified at nearshore reefs and as well as sites just outside Boquerón Bay.

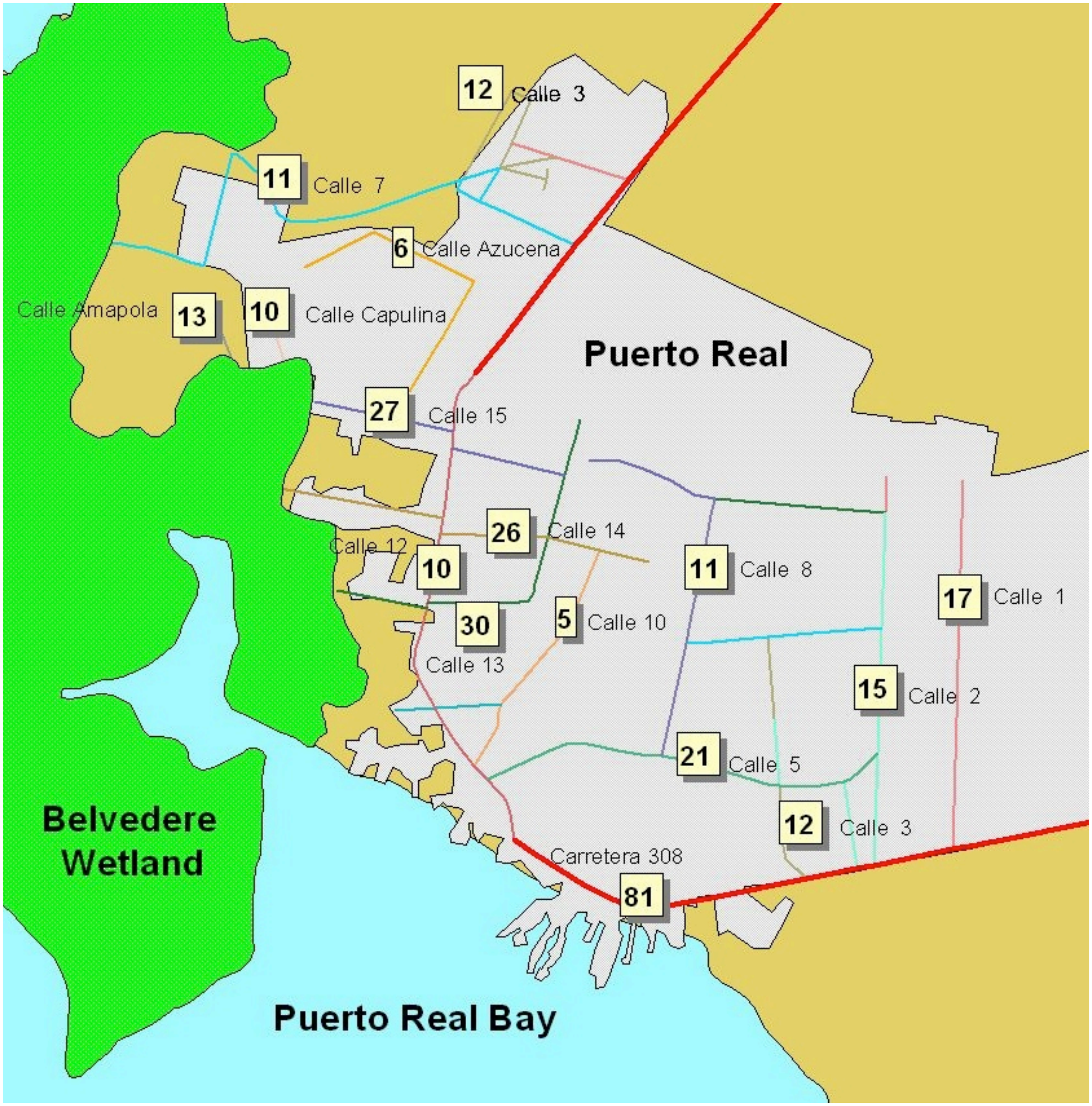


Figure 7. Puerto Real number of septic systems per street shown in the yellow box (from Norat and Mattei, 2006) – two priority areas in our analysis were the 81 along the coast on Carretera 308 and Calle El Fangito with no buffer and those along Calle 1 where we observed high rates of failure via water quality sewage indicators

Studies by CEICIA and NC State University have documented contamination of shellfish harvesting sites in Boquerón Bay and Puerto Real with potentially dangerous levels of pathenogenic bacteria and viruses observed in the harvest areas during both dry and wet weather (Ballester et. al. 2011). The remediation of contamination sources within both of these bays is particularly important to reduce the potential for illnesses for those consuming shellfish. Not to mention that these areas are also a potential threat to public health with water contact recreation.

A recent study by Vega-Thurber et al. (2013) from the Florida Keys, and past studies by Wooldridge and Done (2009) 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. Wooldridge (2009) demonstrates in Figure 8 the importance of reducing nutrients/ and resulting chlorophyll A in helping reefs withstand higher sea surface temperature occurring with climate change. 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.

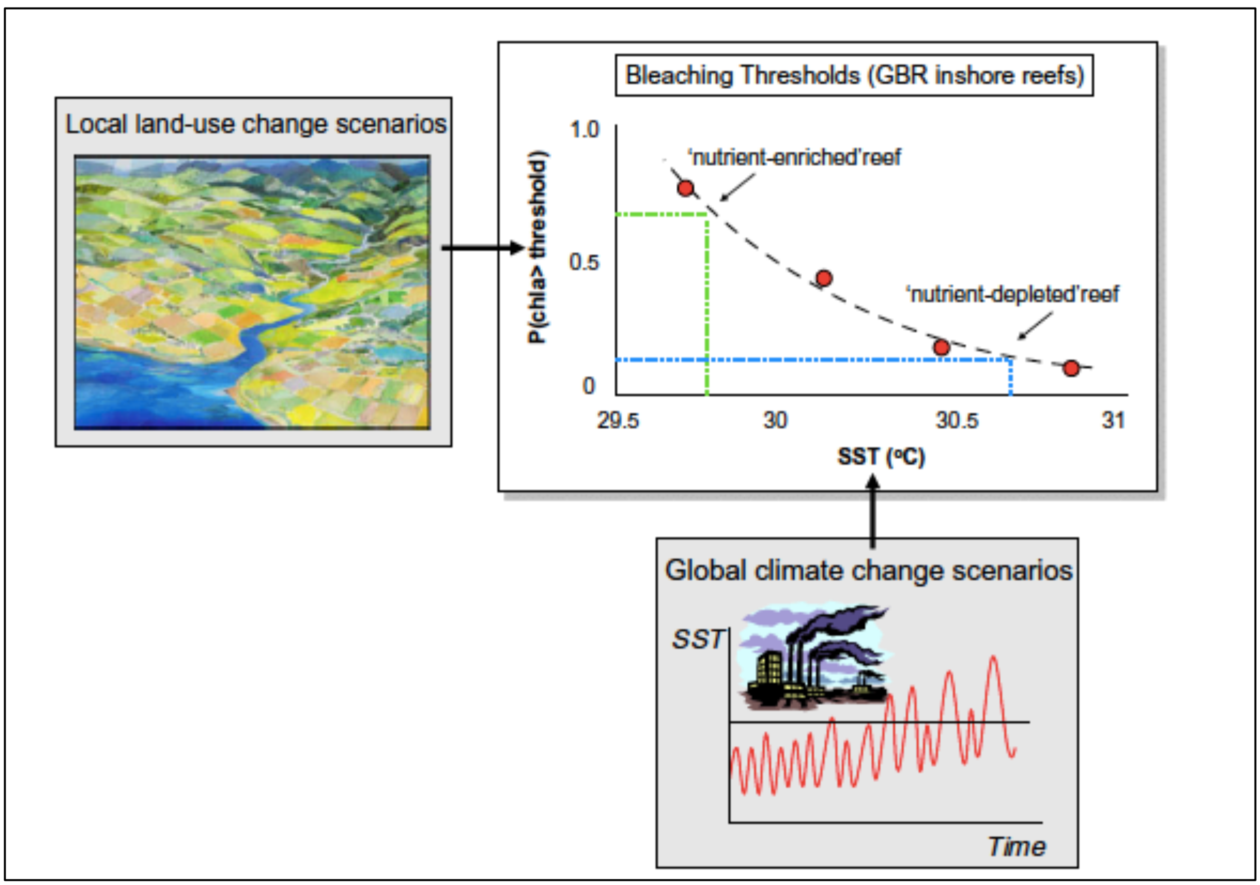
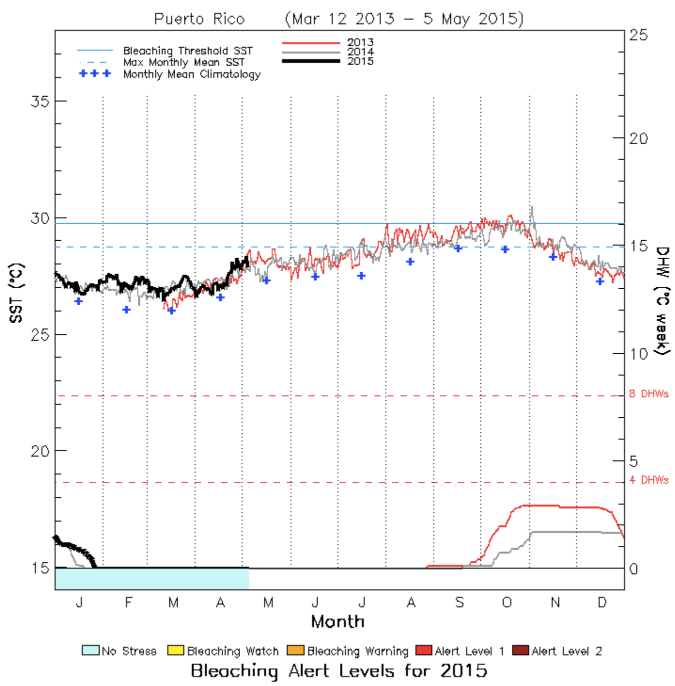


Figure 8. Graphics from Wooldridge, 2009 which demonstrate the interplay between managing local land use and sources of nutrient pollution to make reefs more healthy and resilient and better managing the global climate by reducing levels of CO2 and its corresponding impacts on SSTs

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 9 (left) illustrates the typical annual pattern of high SST in the fall of the year and that the temperatures are generally above the historic mean – when these events happen for a long duration ie. weeks or months bleaching can occur (NOAA Coral Reef Watch, 2015). Figure 9 (right) shows recent high energy activity associated with hurricanes in the Atlantic/Caribbean (NOAA, 2013). Figure 10 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 Cabo Rojo. However, increasing acidity of the oceans is an issue that can only be dealt with by reducing CO2 emissions globally.



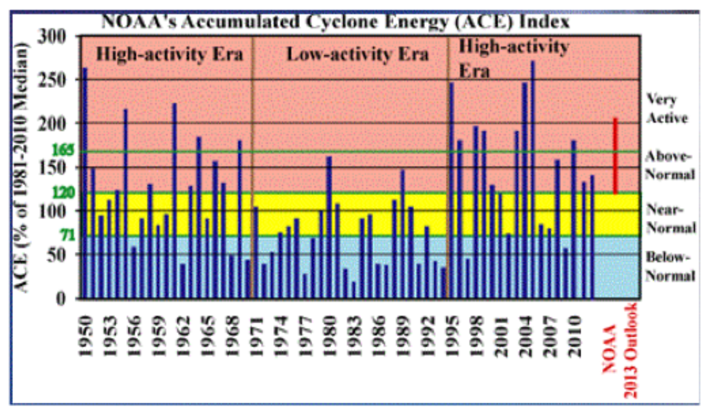


Figure 9. (left) PR SSTs from 2013-2015 (note close to the 30 degree threshold for bleaching) vs. historic mean (NOAA Coral Watch); (right) Atlantic NOAA Hurricane/Cyclone Intensity Index from 1950-2012 with 2013 predictions (NOAA, 2013)

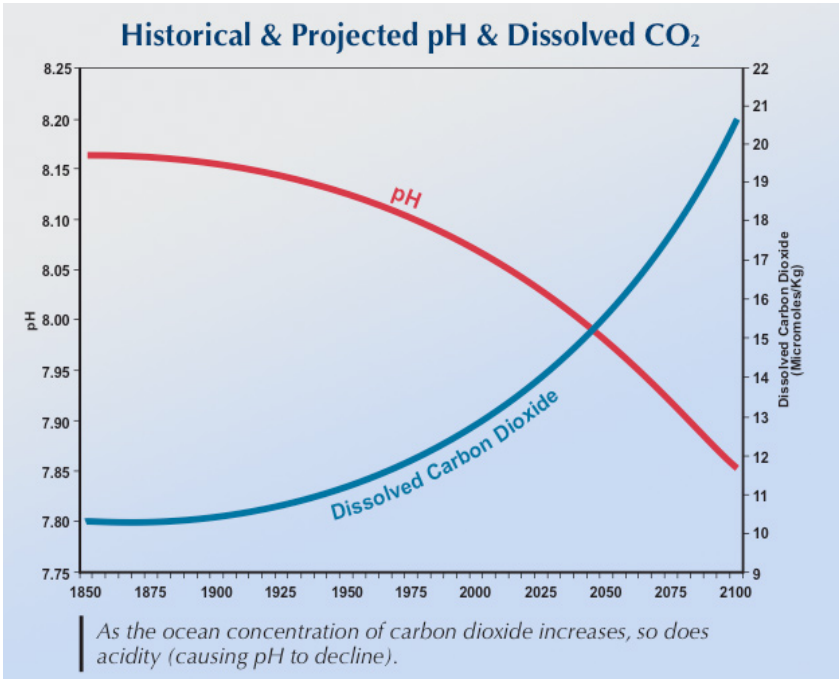


Figure 10. Current and Future Ocean Acidification Estimates (Feeley et al. 2006)

Section 3. Existing Conditions

Introduction

The Cabo Rojo municipality is located in the Southwestern corner of Puerto Rico. Its watersheds drain to both the western and southern Puerto Rico (Figure 1). To the west the major source of fresh water is the Guanajibo river and to the south it can be subdivided into several small watersheds with fairly limited export of freshwater to the coast. Cabo Rojo is one of the most important tourist destinations in Puerto Rico due to its vast marine resources and outdoor attractions. According to census data (1990-2010) its population has increased steadily from 38,521 to 50,917 inhabitants (USCB 2010). It is estimated that Cabo Rojo receives between 250,000 -500,00 visitors annually. This combination of high visitation with intense resource-dependent activities and an increasing urban development has created huge pressure over the fragile coastal ecosystems. Aside from these local factors, it is important to acknowledge global stressors to marine and coral reefs ecosystems. These are distributed over a great spectrum from the burning of fossil fuels to the increase in ocean acidity due to the increased released of CO2 being absorbed by the world's oceans.

Generally, there is a peak in local stressors such as overfishing, sediment, nutrients, stormwater runoff and sewage contamination with peak population and peak usage in the summer time. Fortunately, these stressors are also reversible through direct action and most stressors can be kept at bay through effective protective measures and policies. The NPDES permits provide an opportunity for municipalities with water and recreational dependent economies to integrate these requirements into local efforts to effectively control existing and future pollution sources and preserve the resources that serve as tenants for their economy for the long-term and effectively guard against additional impacts with climate change and sea level rise.

3.1 History

Cabo Rojo is the municipality with the most linear coastline in Puerto Rico (45 km approximately). It houses a rich history and is the birthplace of several iconic figures of the Puerto Rican political history. There is archaeological evidence that suggests that the territory was occupied by native settlements as far as 1,200 years ago. After the Spanish invasion of the islands of Puerto Rico in 1492, some Iberian settlements started to grow in the region known as "Los Morillos" by 1512. These communities took advantage of the salt mines in the area leading to one of the most antique industries of the hemisphere that still produces salt today. The name Cabo Rojo or "Red Cape" in English is derived from the reddish color of the salt flats. These salt mines were the setting for various battles; a fleeting British invasion in 1585, and consecutive failed invasions from groups from Aguada and San Germán in 1769. After this chain of events, the adjacent beach began to be called "El Combate" (the combat) and the local people "los mata con hacha" (those who kill with axes).

3.2 Governance

Governance in the watershed is provided by several municipalities including Cabo Rojo, San German and Hormigueros as well as portions of Lajas and Sabana Grande. Each of the municipalities has its own governance structure usually a Mayor and municipal government. Some functions remain at the Commonwealth level including erosion and sediment control regulations and enforcement though the other NPDES regulations are delegated to the Municipality. Each of these Municipalities does have NPDES responsibilities – though in each instance implementation of NPDES permits to the extent that it starts to improve water quality have proceeded very slowly as in the rest of Puerto Rico. This is also a significant opportunity to engage the implementation of the watershed plan as a method of reaching compliance with the NPDES requirements and improving water quality conditions for beaches and nearshore coral reefs.

3.3 Cabo Rojo Subwatersheds

Cabo Rojo is approximately 204 square miles and was be subdivided into 8 subwatersheds to heighten our focus on the resources in different areas (Figure 1). This helps highlight specific management efforts needed in specific subwatersheds as well as identify the existing and future threats and stressors to these systems. The estimated rainfall for modeling purposes as well as the size in acres and square miles is reported in Table 4.

Table 4. Subwatershed Characteristics

Subwatershed	Rainfall	Acres	Square Miles
Guanajibo	60	82984	129.7
Joyuda	50	3394	5.3
Puerto Real	50	5040	7.9
Buye	50	953	1.5
Boquerón	45	22747	35.5
Combate	45	2530	4.0
Corozo	45	4563	7.1
Pitahaya	40	9182	14.3

Guanajibo

Guanajibo is the largest subwatershed at almost 130 square miles, it is the most northern subwatershed draining the town of Cabo Rojo, Hormingueros and points to the east including much of Sabana Grande and San German. The river runs parallel to Rt. 2 after coming down from the mountains – and the subwatershed extends to the north to portions of Maricao. The Guanajibo valley is an important area for agricultural production as are the headwaters where there are important coffee farms closer to Maricao. This subwatershed includes urban drainage from the aforementioned towns and a concentration of quarry and extraction operations, as well as agriculture in the valley and in the headwaters around Maricao. The Guanajibo is one of the major discharge points on the West Coast of Puerto Rico and is the major discharge point in the larger Cabo Rojo watershed area.

Key recommendations include: minimizing impacts from quarry and mining operations, reducing sediment losses from coffee farms through conversion to sun coffee, addressing runoff from dirt roads and bare soils and illicit discharges from the existing towns. Also in particular, the town of Cabo Rojo had significant issues with illicit discharges with high levels of bacteria and ammonia (indicators of sewage contamination as did at least one tributary from Hormigueros. These likely contribute to the high levels of bacteria transported to the Guanajibo where Norat and Mattei (2006) measured consistently elevated levels.

Joyuda

The Joyuda subwatershed is composed of drainages that outlet to both Joyuda lagoon and directly to coastal waters. The land use is primarily low-density residential and non-intensive agriculture away from the coast and residential and commercial development along the coast including seafood restaurants, houses and condominiums. Also included in the drainage area are a small portion of Rt. 100 and nearby housing subdivisions and coastal road Rt.102. The town of Joyuda itself was historically a fishing village and now is a popular weekend destination with seafood restaurants and small bars. The area still has a fishing community and is also a popular embarkation point for scuba diving and snorkeling trips

Key recommendations include connections to sewer or tertiary treatment of on-site septic systems, tracking and fixing illicit discharge and working with local restaurants and homes to implement effective tertiary treatment systems, address stormwater runoff and illicit discharges.

Puerto Real

Puerto Real is further down the coast from Joyuda and is home to a small bay and harbor as well extensive mangrove areas. It contains a small town and related suburban development and some low intensity agriculture out to Rt. 100 – historically this area was a small fishing and boating village with small seafood restaurants, working marinas and fish markets (pescaderias) – many of which are still there today. Water quality in Puerto Real has been historically problematic with suburban development and waterfront development; sporadic homes and businesses (Figure 7) are not connected to sewer due to the challenges associated with connecting or lack of interest (Norat and Mattei, 2006). In many instances, particularly along the coast the connection points are located right at sea level or are lower than the sewer line itself – requiring pumps and tricky logistics.

The major issues in Puerto Real are the sewage connection issues/septic systems and stormwater runoff. Each individual connection to sewer helps to keep roughly 36,000 gallons of wastewater out of the coastal waters of Puerto Real and it is estimated that there are roughly the equivalent of 100 -300 poorly or non-functioning septics (restaurants would count for more as they would have higher discharges).

Buyé

Buyé is the smallest subwatershed in the Cabo Rojo municipality. It is mostly composed of rural residential development, some low-intensity agriculture and a nature reserve along the coast as well as a small area of intense coastal development along an important local beach and coral reef recreational area. Wastewater disposal in this coastal buffer area is though on-site wastewater facilities which can loose a high percentage of their nitrogen to nearshore waters impacting coral reefs. Improved understanding of the groundwater movement of nitrogen and other contaminants to coastal waters within this watershed is critical to properly siting management practices to address these issues.

Boquerón

Boquerón is a larger subwatershed (35.5 square miles) that contains Boquerón Bay and a watershed that extends into the Lajas Valley and includes Laguna Cartegena and the urbanized town of Lajas. Flow is derived from the Lajas irrigation channel, flow coming out of Laguna Cartegena and a tributary that picks up effluent from the Lajas sewage treatment plant. In addition, there are still several small sewage treatment plants operating in the Balenario beach area in Boquerón which discharge effluent into mangrove areas within the Boquerón reserve. Boquerón also contains a small resort town that boasts restaurants, bars and lodging and is known for its raw seafood kiosks. It is also home to many sailboats and some small marinas. Land use is rural residential, town areas in Boquerón and Lajas as well as a fair amount of mostly low intensity agriculture. Challenges include preserving good water quality conditions for swimming at the beaches and for fresh seafood which is stored off of docks in the small town area.

Key issues in Boquerón are issues associated with nutrients, bacteria and sediment. Bacteria and nutrients are components of stormwater as well as illicit discharges that may be occurring in the developed town area as there are a number of businesses and structures located adjacent or over the water. Elevated Enterococci levels were present here in our survey especially around the town area where shellfish are also kept for small kiosks that specialize in shellfish and other fresh seafood. These same areas have been documented as having elevated bacteria in the past by CECIA which is part of Interamerican University, San German campus. Other opportunities in Boquerón include capturing and filtering stormwater runoff as part of the streetscape to reduce bacteria that flow into the water during rain events. In addition, there are several empty lots and parking lots with bare soil as well as a nursery run by DNER that has issues with runoff from the bare soil areas which are visibly impacting the nearby mangroves. Lastly there are several small streams that are flowing in light agriculture/rural development areas that had indicators of sewage contamination – likely from failing septic systems – but these sources should be investigated and addressed. In these same areas, there is the potential for treatment wetlands to help treat runoff before it flows into the mangrove and nearshore waters.

Combate

The sub-basin Combate is approximately 4 square miles and is a coastal area dominated by tourism development and commercial areas. It contains one of the important beach areas of the greater Cabo Rojo area as well as guesthouses and hotels as well as commercial fishing. Coastal development dominates much of the coastline though several open space areas exist at the end of the town much of this area is dominated by red clays which give Cabo Rojo its namesake. Combate remains on septic systems despite having a high density of development consequently the Chlorophyll A levels here were very high and pose a threat to coral reefs in the area. Unpaved roads and exposed sediment from development and 4 track all-terrain vehicles also create sediment impacts which increase the loading to the coastal areas.

Corozo

Corozo is a small town adjacent to Rt. 301 on the way to the Cabo Rojo lighthouse (El Faro) it also contains the salt flats that are part of the Cabo Rojo National Wildlife Refuge and Bahia Sucia. This area is subject to flooding from runoff generated from higher in the watershed due to poor natural drainage and low-lying areas in town. There is opportunity to use green infrastructure stormwater practices to capture and even re-route some of the runoff helping reduce the level of flooding in the town. In addition, there are several opportunities to treat and detain stormwater runoff in the upper portion of the watershed which also may be a good target for reforestation. Dirt roads to Playa Sucia and around Corozo would also benefit from runoff controls.

Pitahaya

The Pitahaya subwatershed is 14.3 square miles and is the least populated and developed subwatershed with significant preserved land including portions of the Sierra Bermeja, the oldest rock formation on the island of Puerto Rico which is also an important area for birds and wildlife. Much of the land is low-intensity farmland for livestock or small areas of row crops. Another wildlife reserve along the coast protects extensive areas of mangrove which with sea level rise may need space to migrate inland. The low amount of rainfall in Corozo and Pitahaya also mean streams here are dry and only carry water intermittently during rain events.

Particular issues in this subwatershed are mainly confined to improved management of dirt roads and which can bring sediment to the coast particularly as many of these roads run directly perpendicular to the coast and have steep or moderate slopes which make them effectively at carrying sediment to the coast this can be seen with sediment deposition within some of the mangrove areas and salt flats.

3.4 Population and Land Use

According to census data (1990-2010) Cabo Rojo's population has increased steadily from 38,521 to 50,917 habitants (USCB 2010). It is estimated that Cabo Rojo receives roughly 500,000 visitors each year. Land Use in the greater Cabo Rojo watershed areas is dominated by forest and grassland and there is significant protected land (Appendix A-2), however much of the development is clustered on the coast which accentuates its impact. In addition, the MRLC (multi-resolution land cover) product (Appendix A-1) of the NLCD (national land cover dataset) appears to under represent agricultural tree crops such as coffee or plantains as cultivated crops are primarily represented in the Guanajibo Valley and not in the mountain areas (MRLC, 2001). These national data products need to better account for the land uses within Puerto Rico. According to the NLCD, the land use in the larger Cabo Rojo watershed is as follows:

Table 5. Subwatershed Characteristics

Land Cover	Acres	%
Evergreen Forest	56222	43.09%
Grassland/Herbaceous	41178	31.56%
Developed, Low Intensity	7523	5.77%
Scrub/Shrub	5454	4.18%
Developed, Medium Intensity	3716	2.85%
Pasture/Hay	3602	2.76%
Cultivated Crops	3487	2.67%
Developed, Open Space	2157	1.65%
Estuarine Forested Wetland	1936	1.48%
Open Water	1658	1.27%
Palustrine Emergent Wetland	1513	1.16%
Developed, High Intensity	501	0.38%
Bare Land	499	0.38%
Unclassified	465	0.36%
Estuarine Emergent Wetland	301	0.23%
Palustrine Forested Wetland	130	0.10%
Unconsolidated Shore	122	0.09%
Estuarine Aquatic Bed	16	0.01%
Total Acres	**130,481**	**203.8sq/mi**

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** – a number of projects have been identified for the Cabo Rojo area. These projects are important as these areas produce sediment at 10-100x the rate of natural forest or field areas (Ramos-Scharron, 2009). It should also be noted that new clearing and new developments continue to occur in Cabo Rojo and very few if any have effective erosion control measures.
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) **Improved policies –** improved policies, enforcement and local control over the development and protection process is critical to effectively safeguard the natural resources of Cabo Rojo.
8) **Outreach and restoration plans for quarries and extraction operations --** A special program particularly for the Guanajibo watershed needs to be developed and implemented for quarries to minimize runoff and sediment losses from these operations. This will also help quarries meet industrial stormwater permits that should be mandated by the Clean Water Act.

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 bare soil and road stabilization projects and potential source areas for pollution that were monitored.

Green Infrastructure and Treatment of Stormwater Runoff

Green infrastructure (GI) project are 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 re-creating wetlands and natural processes to reduce pollution. Figure 11 shows several examples of green infrastructure projects.

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 Cabo Rojo (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 Cabo Rojo watershed area. 10 being the highest impact and 0 being the lowest impact.

Figure 11. 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 removal of marine debris and trash cleanups as well as water quality monitoring at the beaches in Cabo Rojo. An important component of pollution prevention is improving erosion and sediment control at construction sites. In addition, engaging businesses, students and residents in green infrastructure projects in various towns and schools including in Boquerón, Combate, Joyuda, and Corozo is particularly important.

Road and Bare Soil Stabilization

Stabilization of bare soils (Figure 12) 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 6, maps are found toward the end of the section in Figure 16.

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 five dirt road sections in the same week).

The bare soil and dirt roads can be prioritized using 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-Scharron (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 12. Clockwise from top left: Dirt roads in Los Pozos near Combate, a significant source of sediment to coastal waters, (right) example of surface rills conveyance over the road surface creating erosion and resulting in fine sediment losses, bottom right sediment reaching coastal waters; bottom left: recently constructed sediment trap in Cabo Rojo to capture sediment before it enters Boquerón **Bay**

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 and bare soil areas 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 into the groundwater and maximizing nutrient removal via vegetation and uptake or by promoting de-nitrification. Examples of a pump and treat system are found in Figure 13 - the effluent can be pumped to a constructed wetland such as is shown in the figure. These efforts should be focused in areas where space is limited between the septic system and the coast and where septic failures are occurring and connecting to the sewer system is not an option. Examples would be to use these practices at small hotels and restaurants in places like Joyuda and Combate. Other more passive systems are also possible particularly where space is limited such as structures located on the beach itself – in this example from Combate septic systems are located in the beach berm. Restoring the beach buffer with native plants and vetiver (which can grow its roots to 3-4 meters deep) to attempt to intercept contaminated groundwater before it enters the nearshore waters with a dual benefit of also helping protect the shoreline from erosion by allowing the beach berm to aggregate sediment.

Figure 13. Top (Pump and treat system where effluent is pumped from homes to a constructed wetland or landscaped area (right); Bottom: (left) sewage effluent enters a septic system in the beach berm in Combate, (Bottom left) a passive low cost approach to addressing this issue is to restore a vegetated beach berm to include the use of vetiver and native species such as sea grape (uva playa) as has been done in Tamarindo Beach in Culebra

Coral Restoration

Coral restoration involves the propagation of corals, in this case Staghorn coral (*Acropora cervicornis)* (Figure 14), 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. Coral Restoration could be pursued in the greater Cabo Rojo area particularly in combination with implementation to control land based sources of pollution. Similar efforts have taken place in other reef areas in Puerto Rico including the first nursery site in Culebra. The goal of coral restoration efforts and out planting of corals has been to re-establish *Acropora* populations. The community project of Coral Reef Rehabilitation and Aquaculture in Culebra 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).

Figure 14. Coral restoration efforts in Tamarindo (Photo credit: CESAM)

Improved Policies

Improved policies, enforcement and local control over the development and protection process is critical to effectively safeguard the natural resources of Cabo Rojo.

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

1. Decrease the disturbance on new construction sites and provide local training and enforcement by Municipal police and Rangers including the issuing of stop work orders and fines. Create an erosion and sediment control committee in the municipality.
2. Create guidelines for the construction and maintenance of dirt roads in order to reduce their impact. This should include the specific options for BMP's to reduce sediment losses. These standards would be endorsed by Municipality, DNER and EPA and would be mandatory and subject to enforcement. Provide training for local contractors and agency staff.

3. Increased enforcement and education of contractors and local oversight from the municipal inspectors. Currently inspectors are housed out of Environmental Quality Board and serve the whole commonwealth – each development site would be fortunate to be visited just once during what is often several years of construction for most large sites or subdivisions. It is not realistic that such a program would be effective.

4. When sewer is extended into areas not previously sewered – connections should be mandatory and waivers granted for those who cannot afford to pay based on annual earnings etc. – in addition, where homes are lower than the sewer lines – cost-share should be granted to ensure connections as these areas are typically missed or result in fewer connections due to the optional nature of the program and the extra cost of pumps or other retrofits. This is a common occurrence in Puerto Real, Joyuda, and to a lesser extent Boquerón and to many waterfront communities across Puerto Rico. These areas will also be impacted the greatest by sea level rise, more frequent storms and other impacts of climate change – making effective, lasting solutions here particularly important.

Outreach and restoration plans for quarries and extraction operations

At least 12 quarries and extraction operations are present in the Guanajibo watershed of Cabo Rojo – most of these operations have limited best management practices based on field visits to sites as well as local testimonials. Proposed is a project that would work with quarries to minimize runoff and impacts to downstream waters including sediment and stormwater controls, pollution prevention plans and outreach and education. EPA, EQB should be involved in providing oversight and regulatory encouragement of quarries to minimize their impact as well as funding to help initiate the program and support for helping quarries achieve higher levels of treatment and pollution prevention. Figure 15 shows a typical quarry occurring on slopes with no visible sediment control basins or ponds.

Figure 15. Quarry located on a slope close to the Guanajibo River with few visible runoff controls

Cabo Rojo Restoration Project Map

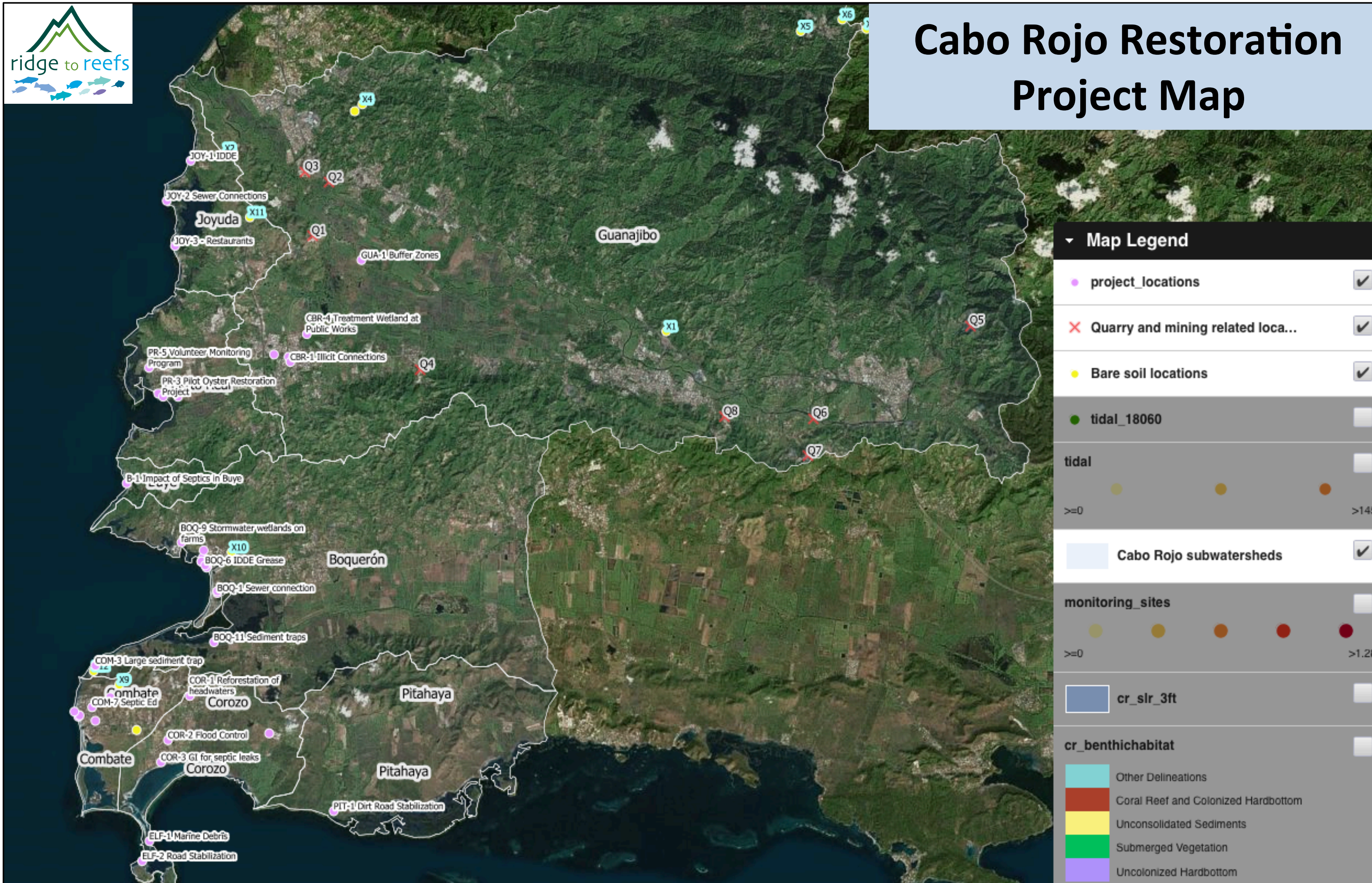


Table 6. Quarry and Bare soils sites

Quarry Sites

Sites	Acres	Subwatershed	Notes
Q1	18.4	Guanajibo	Quarry
Q2	3.19	Guanajibo	Distribution Equipment
Q3	17.8	Guanajibo	Storage yard/ distribution center for Quarry
Q4	9.51	Guanajibo	Quarry
Q5	34.9	Guanajibo	Quarry
Q6	11.6	Guanajibo	Main complex and two smaller complexes -- high probability for discharge to stream/river
Q7	30.5	Guanajibo	Large quarry operation
Q8	17.4	Guanajibo	Quarry operation
Q9	14.3	Guanajibo	Quarry operation

Bare soils sites

Sites	Acres	Subwatershed	Notes
X1	17.2	Guanajibo	Construction site
X2	10.7	Guanajibo	Construction site
X3	4	Guanajibo	Construction site/ landfil?l
X4	3	Guanajibo	Construction site
X5	3	Guanajibo	Maricao construction site
X6	3	Guanajibo	Maricao
X7	4	Guanajibo	Maricao farm
X8	1	Combate	Combate clearing/LU
X9	3	Combate	Combate clearing
X10	0.5	Boquerón	Small site likely impacts turbidity in BOQ
X11	0.5	Joyuda	Hydroseeding/vetiver sites along Rt. 100
X12	1.5	Combate	ATV roads/ trails-- direct flow to coastal waters
X13	55.4	Pitahaya	Large clearing -- ag/urban?
X14	9.95	Guanajibo	Landfill

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. Both freshwater and saline coastal areas are sometimes contaminated by discharges from wastewater treatment plant discharges, illicit discharges, washwater, and failing septic systems. Determining sources of contamination to the nearshore and marine ecosystems is a critical component of watershed management. Potential pollution locations were monitored on land and in the nearshore marine environment through the assistance of Surfrider Rincon as well as one of the local marinas in Puerto Real who provided boat support.

Initial findings based on our monitoring of bacteria, ammonia, optical brighteners, and Chlorophyll A at freshwater sites include: 11/31 sites with >.35 mg/l of ammonia (this level is often used on a threshold for suspected sewage contamination). 12/31 sites were highly elevated for enterococcus bacteria > 2000 col/100ml and most were far above the 33col/100ml which is the EPA threshold for water contact recreation. In the saltwater sites: 5/15 sites were elevated for multiple parameters which included: enterococci, turbidity, optical brighteners and chlorophyll A.

Key conclusions from the freshwater sampling: 1) intermittent contamination across all the sites sampled; 2) septic systems have a high degree of failure in coastal communities due to poor soils, high water table and poor standards for septic construction; 3) sources of contamination should be further investigated and tracked to their sources and remediated; 4) a high proportion of contaminated samples were identified in the main town of Cabo Rojo; 5) Additional information is needed from PRASA and EPA about the sanitary sewer system to determine which homes and businesses are connected to the sanitary sewer and which are not.

Table 7. Summary of freshwater Illicit discharge concerns

Station	Description and Contamination Source
JOY-1, JOY-2, JOY-3	Likely illicit discharge – these are likely the result of failing septic systems or an direct discharge
BQ-1	Illicit discharge
PR-4, PR-10	Likely discharges from failing septic systems (note: sewer connections are available here – so many problems could be addressed)
CRT-4, CRT-5, CRT-6	Likely sewage discharges from failing pipes or direct discharges
CB-1, CB-3	Surface water contamination in Combate, likely due to failing septic systems

Key conclusions from the tidal monitoring include:

1) elevated enterococci levels were found in Boquerón Bay next to the town – this is particularly important since shellfish are harvested and also stored in nearshore waters before they are served to the public. In addition, Boquerón Bay is an important area for sunbathing at the beaches and water recreation such as sailing, paddleboarding etc
2) consistently high concentrations for chlorophyll A were found in Combate across a number of station -- these concentrations also coincided with high turbidity and optical brighteners. This is likely due to on-site septic systems being the dominant form of wastewater disposal in the subwatershed despite the high density of development and relatively poor soils in many areas.

Table 9. Cabo Rojo Saltwater Pollution Tracking Water Quality Sample Sites

Site	Date	Lat	Long	Temp (°C)	pH	Cond (mS)	Sal (mg/L)	Turb (NTU)	Op. Br.	Chlor a	Amm	ENT
BQ-7	17-May	18.018377	-67.172261	*	*	*	36	*	0.182	3.65	*	0
BQ-6	17-May	18.009949	-67.176097	*	*	*	36	*	0.188	3.461	*	0
BQ-5	17-May	18.007905	-67.177695	*	*	*	36	*	0.222	14.8	*	0
BQ-8	17-May	18.024986	-67.174196	*	*	*	36	*	0.23	2.012	*	145
BQ-4	17-May	18.030424	-67.175268	*	*	*	36	*	1.071	14.23	*	309
PRM-3	3-Apr	18.1183167	-67.18445	27.3	8.15	53.96	35.9	3.18	0.078	3.001	*	20
PRM-9	3-Apr	18.069433	-67.1860667	28.2	8.21	54.41	36.17	8.58	*	*	*	0
CB-4	2-Apr	17.981315	-67.214752	29.6	8.19	54.38	36.21	10	0.878	19.77	*	0
PRM-10	3-Apr	18.07345	-67.1869333	28.6	8.12	54.44	36.23	16	*	*	*	0
PRM-6	3-Apr	18.094716	-67.19935	28	8.22	54.53	36.26	3.06	*	*	*	0
PRM-1	3-Apr	18.1292667	-67.1848833	26.9	8.07	54.57	36.27	1.95	0.436	0.193	*	0
PRM-2	3-Apr	18.1231167	-67.1842	27.4	8.12	54.57	36.28	2.23	0.25	*	*	0
CB-5	2-Apr	17.982637	-67.214789	29.8	8.12	54.54	36.32	27.1	2.216	53.13	*	20
PRM-5	3-Apr	18.0995667	-67.1909	27.7	8.17	54.61	36.33	1.66	*	*	*	0
PRM-4	3-Apr	18.1106333	-67.1821001	27.5	8.23	54.63	36.34	2.15	*	*	*	0
PRM-12	3-Apr	18.0748333	-67.1890833	28.5	8.18	54.61	36.36	14.6	*	*	*	0
PRM-7	3-Apr	18.04905	-67.19935	27.9	8.1	54.7	36.4	9.68	*	*	*	0
PRM-8	3-Apr	18.063217	-67.197652	27.8	8.21	54.67	36.43	6.1	*	*	*	0
PRM-11	3-Apr	18.07795	-67.1955	28.4	7.76	54.85	36.59	8.24	*	*	*	0
CB-2	2-Apr	17.978433	-67.213162	30.4	8.12	54.6	37.27	21.8	2.246	48.96	*	0

Elevated turbidity >10 NTUs
Elevated Optical Brighteners
Elevated Chloro A >10 ug/l
Enterococci above water contact standard of 33 col/100ml
Station with Elevated Concentrations
*test not available

Section 5. Implementation and Monitoring Strategy

The restoration and monitoring strategy and timeframe are presented in this section. The implementation schedule balances priority projects that are straightforward and easier to implement (e.g., addressing sediment from dirt roads, identifying illicit discharges and treating stormwater using green infrastructure) into the first three years. Projects that are more intensive connecting new areas to sewer and larger capital projects which require design and permitting 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 10 provides a preliminary implementation strategy over a 5-10-year timeframe. The restoration timeline and anticipated nutrient load reductions are also shown. An estimate of the type and quantity of restoration and the resulting sediment and nitrogen reduction associated with each of the recommendations is also shown in Table 10.

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 40 baseline stations/ source areas were assessed at discharge points on land, in small streams, in the Guanajibo watershed and in nearshore waters particularly around Ensenada Honda. In addition, 11 baseline sites for coral, habitat and fish have been established by Edwin Hernández-Delgado (UPR/CREST) and Sociedad Ambiente Marino (SAM). These sites are in a gradient from the nearshore coral reefs to those much further offshore. The extensive report is located in Appendix A-7. A mix of long-term coral monitoring sites and fixed water quality stations close to shore as well as near current sources of contamination in the watershed are critical in order to establish baselines and measure watershed restoration success over time.

Table 10. Anticipated load reductions and proposed schedule

Recommendation	Locations and Quantity Estimates	Estimated Annual Load Reduction	
		Total Nitrogen (TN)	Total Suspend. Sediment (TSS)
Short-term 0-3 Years			
1. Continued identification and remediation plans for illicit discharges	PR-4, BOQ 5-6, GUA-3, COM-6, JOY-1 Estimate is based on population and estimated number of homes and businesses with discharges including the better management of sewage and waste oil and grease (Based on the reduction of 60 illicit typical discharges)	6,000lbs N	3,600lbs
2. Reduce erosion and sediment runoff from roads	Approximately 10 miles of roads are high priorities for stabilization these include areas in the Combate/Boquerón watersheds as well as coffee farms in the Guanajibo watershed - based on a 50% load reduction efficiency for sediment with a multiple BMP approach to load reduction. (COM-2, GUA-4)	320lbs N	640,000 lbs.
3. Large sediment trap and stabilization of soils in Los Pozos	Creation of a large sediment trap to address runoff from ATV, ORV trails near Combate and Boquerón (COM-3), BOQ-3, BOQ – 11	87.5 lbs N	175,000 lbs
4. Green Infrastructure in Urban Areas	CBR 2-3, COM 4-5, BOQ 2-4, 7-8, COR 2-3 Green infrastructure stormwater management projects within existing developed areas including the Town of Cabo Rojo, Combate, Boquerón, Joyuda and locals schools	793 lbs N	116,000 lbs
5. Volunteer monitoring program to track existing conditions at beaches and nearshore WQ	PR-5, COM-6 Volunteer monitoring for bacteria and other indicators such as Chlorophyll A, nutrients and sediment particularly in impacted areas	NA-Prevention, education and early warning	NA- Prevention, education and early warning
6. Determine the impacts of septics in Buyé	Install test wells in Buyé to determine the concentration of nutrients flowing through the groundwater	NA - Prevention	NA - Prevention
7. Connection of Boquerón plants to Lajas Plant	Based on existing levels of treatment vs tertiary treatment at Lajas	21,880 lbs N	Minimal
Short-term longer duration to implement (1-5 years)			
8. Connection of businesses and homes to sewer	Work with homes and businesses that are not connected to sewer to get connected – possible to work with the municipality on grant efforts to secure funds for connections (300 homes/businesses connected)	18,000lbs N	10,800 lbs
9. Development of a program to address mining and extraction sites in Guanajibo watershed	GUA-2 Creation of a program to address runoff from Quarry and aggregate plants and related distribution centers – estimated between 110-120 acres	1,000 lbs N	366,120 lbs.
10. Establish Buffer Zones and upland forest areas in critical areas to reduce stormwater runoff and provide for infiltration and pollutant uptake	Buffer and re-forestation areas would include locations in Guanajibo and Corozo (GUA-1, COR-1) 6400ft * 100 = 640,000ft2, + 43560 = 683,560 ft2 (use WTM buffer est)	78 lbs N	8,000 lbs

Table 10. Anticipated load reductions and proposed schedule

Recommendation	Locations and Quantity Estimates	Estimated Annual Load Reduction	
		Total Nitrogen (TN)	Total Suspend. Sediment (TSS)
Mid-term 3-5 years			
10. Pilot oyster restoration projects	Pilot project to grow oysters at docks to increase the filtering capacity in impacted embayments (PR-3) Education and outreach project with Boquerón Oysterias to insure high standards of shellfish by educating and improving WQ in Boquerón.	No standard for calculation	Minimal
Summary Load Reductions **68,540 lbs N/yr** **1,320,000 lbs/TSS/yr**			

Monitoring Metrics

Monitoring in Cabo Rojo is critical to establish a baseline with which to measure future improvements and to also allow for adaptive management. Most of the stressors are a threat to other coastal habitats including seagrasses, human health (bacteria) as well as aesthetics at beaches (sediment) etc. 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 15 to 20 sites including some of the contaminated sites were water quality was measured in the initial water quality investigations. In addition, coastal and beach monitoring sites were suggested by the watershed stakeholders. Also at a practice monitoring should be implemented at typical restoration practices, new practices and especially large and important practices such as sewage treatment plant improvements around Boquerón Bay and implementation of sediment projects in Los Pozos area near Combate. 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); Long-term tracking of reef health and to occur every 1-3 years)
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) **In-situ monitoring buoy** (purple): At least one in-situ real-time monitoring buoy is needed 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.

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 11. Recommended Monitoring Metrics for the Cabo Rojo Watershed Plan

Metric	Type	Response	Source/Data collection	BMPs that address
Baseline WQ info (In-shore, watershed)	Stressor	Fast	CATEC, UPR RM, RTR/PDC, SAM, CESAM, DNER	Sewage connection, IDDE, Septics, Sediment
At a practice monitoring	Stressor	Fastest	CESAM, SAM, RTR/RDC, DNER, NOAA	Erosion/sediment traps, constructed wetland, sewage connections where they had drained to one tributary, IDDE
Nearshore reef nutrients, Chl(a)	Stressor	Fast	CATEC/ NOAA	IDDE, large septics, connections
Nearhore reefs Turbidity, clarity	Stressor	Fast	CATEC/CESAM/NASA/ NOAA	ESC, sediment traps, dirt roads, stormwater runoff
RS CDOM	Stressor	Fast	NASA/USEPA/NOAA	
RS TSS	Stressor	Fast	NASA/USEPA/NOAA	ESC, dirt roads, traps, stormwater runoff
RS Chl(a)	Response	fast	NASA/NOAA/USEPA	IDDE, connections
Algal cover/ biomass	Response	Moderate	CATEC/NOAA/ DNER/SAM/ CESAM	IDDE, connections, large septics
Coral cover	Response	Slow	CATEC/NOAA/ DNER/SAM/ CESAM	IDDE, large septics, sewer connections
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	

Table 11. Recommended Monitoring Metrics for the Cabo Rojo Watershed Plan

Metric	Type	Response	Source/Data collection	BMPs that address
Turbidity, Nutrients, current/ direction, Temp	Response and ancillary	Real-time in situ data	NOAA/USEPA/DNER	
RS= remote sensing, RTR/PDC - 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				

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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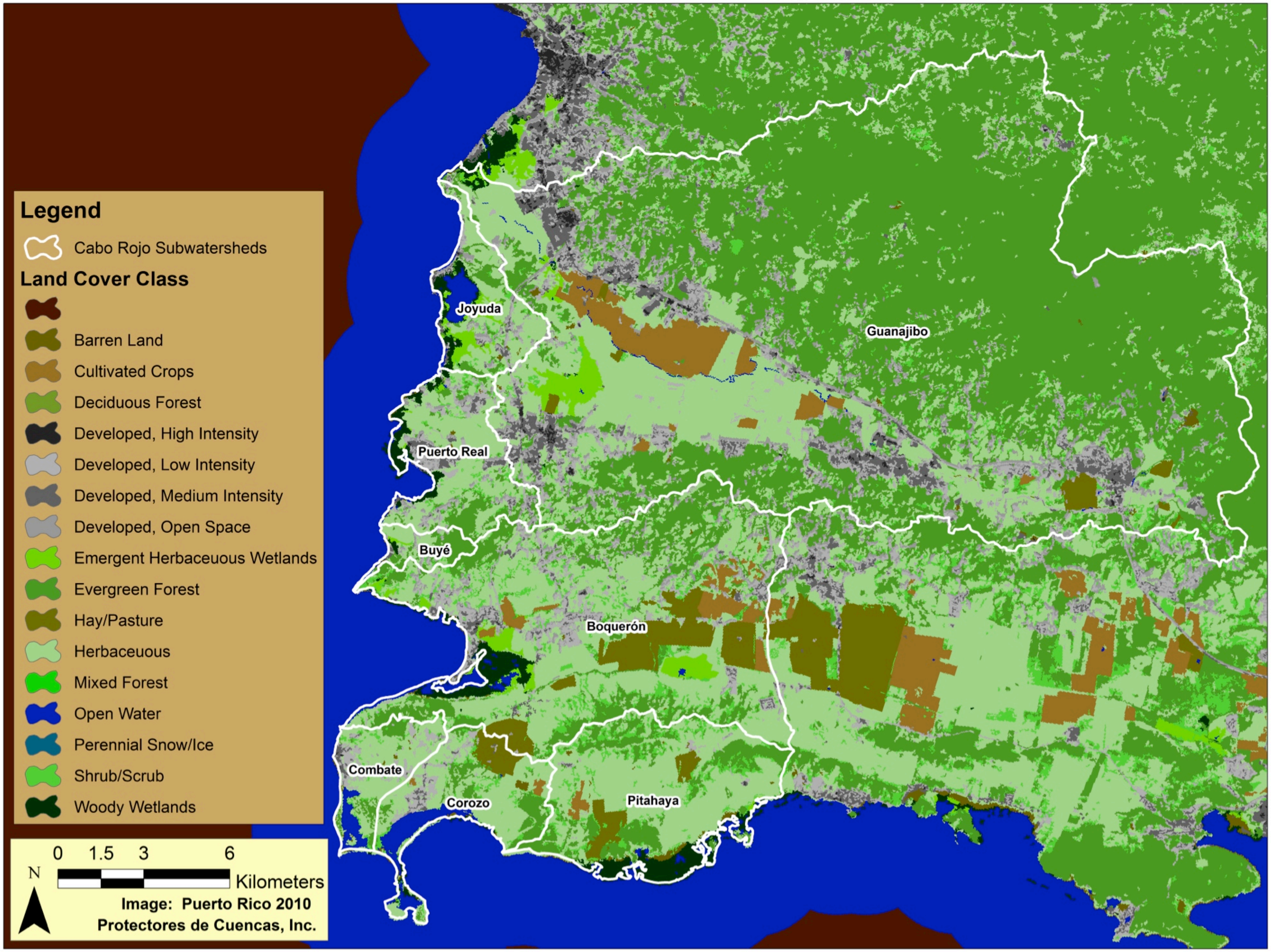
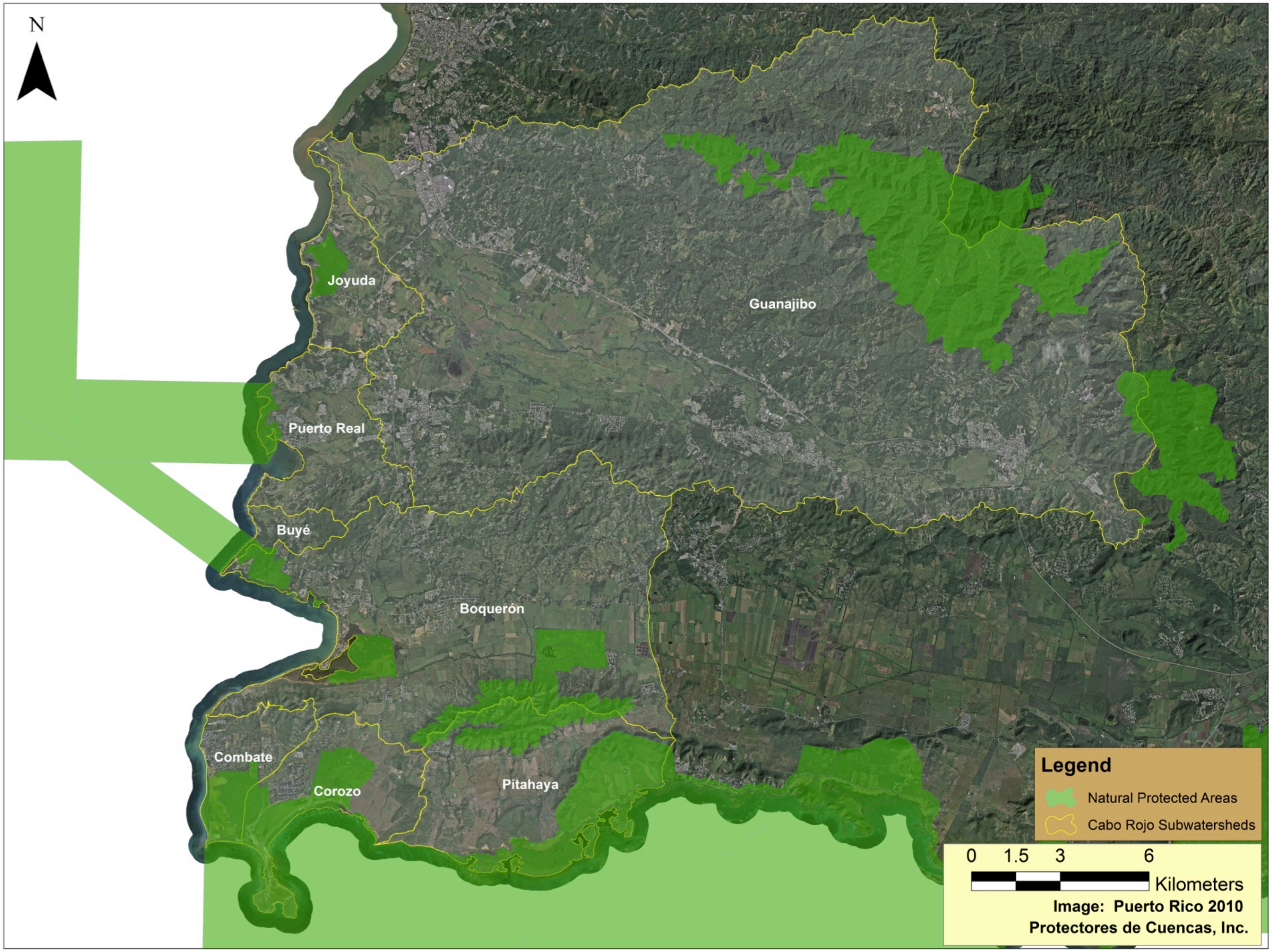
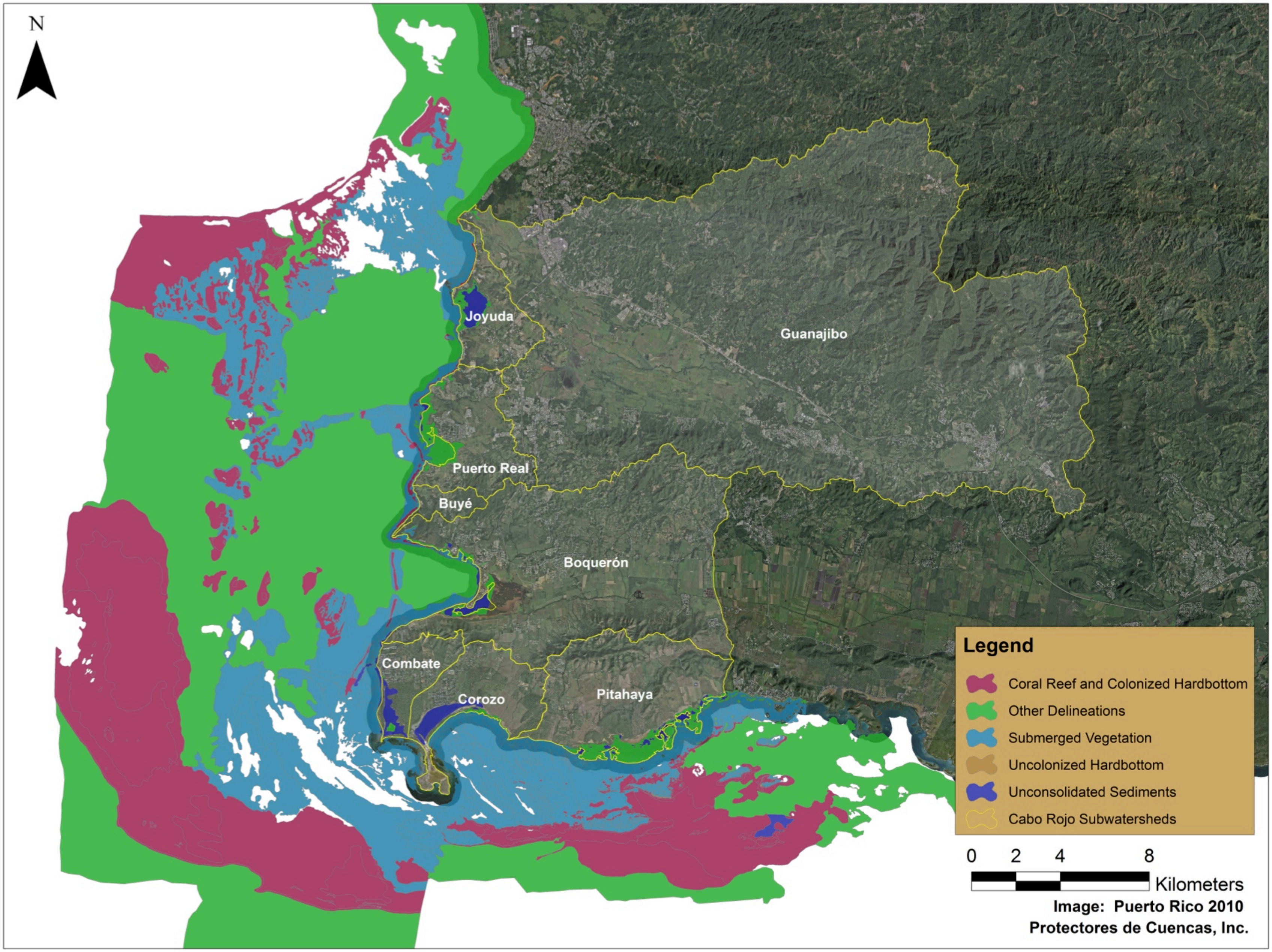
Appendices



Appendix A-1. Land Use Based on the 2001 National Land Cover Dataset (NLCD)



Appendix A-2. SW Puerto Rico Protected Natural Areas (DNER, 2015)



Appendix A-3. NOAA Coastal Habitat Map

Appendix A-4 Cabo Rojo 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	50	2.2	0.4	100	20000	11.2	2.0	509
	MDR	35	2.2	0.4	100	20000	8.2	1.5	371
	Low	21	2.2	0.4	100	20000	4.3	0.8	194
Grass/Parks		8	2.0	0.4	70	20000	2.0	0.4	69
Mining and Quarries		50	2.0	0.4	1000	5000	12.2	1.2	6102
Cleared land		50	2	0.2	**1000**	5000	12.2	1.2	6102
Cropland							4.6	0.7	500
Pasture/Hay Scrub/Shrub							4.6	0.7	100
Forest and wetlands		1					2.0	0.2	100
Open water							10.0	0.5	100

Other Assumptions

- Homes per subwatershed were estimate based on reported population estimates and number of housing units (where housing units were not available -- we used ave household size to estimate units size of households)
- Sediment estimates in bold are based on averages in Ramos-Scharron, 2009

Appendix A-5 Cabo Rojo soils

Soils in the Cabo Rojo municipality is composed mainly of 9 soil associations (1975 soil survey); 1)Coloso-Toa; 2)Voladora-Múcara; 3)Fraternidad-Aguirre-Cartagena; 4)Bahía-Guayabo-Sosa; 5)Caguabo-Múcara; 6)Nipe-Rosario; 7)Descalabrado-Jacana-San Germán; 8)Aguilita-Amelia; and 9)Descalabrado.

Coloso-Toa: this soil type consists of mostly leveled soils along rivers and streams. The physiography is leveled plains, low areas and occasional puddles. The three main parts of this association are located along the three major flood plains of rivers. Most of the areas are susceptible to flooding and sedimentation.

Voladora-Múcara: This association consists of different geomorphic forms, including slightly inclined to steep elongated skirts slopes, low ridged and steep hills, which have narrow peaks soils. Numerous intermittent streams intersect the area. The majority of soils in this association are acid and fine textured. Voladora soils are well drained and dark red-brown.

Caguabo-Múcara: This association occupies the land with steep slopes bearable in rounded ridges and steep mountains with narrow peaks. It is interspersed with many intermittent streams. Most of these soils are present in moderately steep hills with V-shaped drains. The majority of the soils in this association are well drained and moderately permeable

Nipe-Rosario: This association occupies sloping plateaus and slopes ranging from steep to moderately steep. These soils are characterized by their extremely weathered profile and uniform dark color. They are rich in iron oxides, which can stain hands and clothing.

Descalabrado: This association occupies skirts, tops and slopes in the driest part of the land area. The area is sectioned by many intermittent streams. The association is characterized by a large number of steep mountain slopes such as those found in forests or pastures. There are also some strongly sloping hillsides and some narrow skirts. To the South it borders with the Lajas Valley area.

Fraternidad-Aguirre-Cartagena: This association is in a long, wide area extending almost entirely across the northern part of the Lajas Valley area. The broad alluvial plains of this association have a slight slope from the base of the mountains to the middle of the valley. The association crosses many streams of intermittent stream flowing into the main drainage channels traversing the lower part of the valley. Most soils are calcareous and the surface layer and the underlying are sticky clay.

A-6 Restoration Concepts for Green Infrastructure

A-7 Baseline Coral Reef habitat, chemical and biological assessments