Culebra LBSP Ridge to Reef Monitoring Program

Standardized work plans to monitor changes in land-based sources of pollution stressors, exposure, and habitat responses on Culebra Island, Puerto Rico

1. Introduction and Background

Land-based sources of pollution (LBSP), namely, terrigenous siltation, turbidity, and increased nutrient inputs remain the main threat to coral reef habitats worldwide, including the Caribbean and the island of Culebra, Puerto Rico (Rogers 1990; Bégin et al. 2016; Otaño-Cruz et al. 2017, 2019; Rogers & Ramos-Scharrón 2022). Coastal development and tourism are the primary source of pollutant stressors on Culebra (Hernandez-Delgado et al. 2012; Ramos-Scharrón et al. 2012; Sturm et al. 2014). In particular, coastal development on the island alters the natural land cover and promotes the construction of unpaved roads which are particularly vulnerable to erosion. In addition, undertreated sewage from the Culebra Wastewater Treatment Plant, septic systems, and vessels are sources of pathogens and nutrients which is exacerbated with increased population densities during tourist seasons. These alterations result in increases in stormwater runoff and sewage discharge, and consequently increased sediment and nutrient loads into receiving coastal waters bodies. Increases in stressors from the land, generate increased pollutant exposure in the coastal environment causing physical and chemical changes. In Culebra, these changes include impairments to water quality, such as increases in nutrient and contaminant concentrations, increases in light attenuation, and decreases in water clarity. In addition, increases in terrigenous sediment discharged into coastal waters alters benthic substrate and can physically smother benthic habitats. Once the pollutant exposure reaches a certain point, it will elicit a habitat and/or resource response. Oftentimes these pollutant thresholds are mediated by site specific conditions such as residence time, legacy contamination, and other external factors. However, once these exposure levels are exceeded, ecosystems responses such as algal blooms, and decreases in seagrass and coral health and abundance, can be expected (Figure 1).

STRESSOR (Coastal Development) →	EXPOSURE (Physical / Chemical Changes) →	RESPONSE (Habitat and Resource Changes)
Increased population density	Impaired nearshore water quality ● < Water clarity ● > Light attenuation ● > Suspended Solids ● > Turbidity ● > Nutrients (N, P) ● > Microbial contamination	Increased chlorophyll a
Altered land cover ● > Bare soils ● > Unpaved Roads		Decreased seagrass health and abundance ● > Epiphytic growth on seagrass ● > Macroalgal cover ● < Seagrass cover ● < Shoot density ● < Deep edge of seagrass bed ● < Habitat area
Undertreated sewage ● WWTP ● Septic ● Vessels		
Increased pollutant (sediment, nutrient, microbial) load ● > stormwater runoff ● > sewage discharge	Increased terrigenous sedimentation	Decreased coral health and abundance ● < Live coral cover ● > Macroalgal cover ● < Coral recruitment ● < Coral biodiversity ● > Colony mortality?

Figure 1. Conceptual model of land-based sources of pollution impacts on Culebra.

Since 2010, NOAA has worked with federal, jurisdictional, and local partners and stakeholders to develop watershed management strategies and actions to reduce the impacts of LBSP to the nearshore marine habitats of Culebra, including: 1.) stabilization of unpaved roads through the construction of best management practices (BMPs) (e.g., check dams, cross drains, and sediment retention ponds) to slow and divert runoff, prevent road scouring, and capture sediments to promote infiltration and reduce total runoff volume; and 2.) installation of floating treatment wetlands at the WWTP to promote removal of nutrient flux from the wastewater treatment plant through evapotranspiration, nutrient sequestration, and nutrient transformation (e.g., nitrification).

This Monitoring Program implements a *ridge to reef* approach to evaluate performance of LBSP management actions using a **Multiple Lines of Evidence** approach (Lenwood and Giddings 2000) consisting of: 1.) Monitoring of **LBSP stressors** that are being managed through NOAA funding including sediment accumulation at unpaved road stabilization projects, water quality monitoring at key points throughout the watershed, and watershed modeling to estimate pollutant loads into the nearshore coastal environment. 2.) Monitoring of **LBSP exposure** through nearshore water quality and sediment trap monitoring at nearshore fixed stations. 3.) Monitoring of nearshore **habitat response** that is co-located with the aforementioned nearshore water quality fixed stations and includes data collection via seagrass monitoring transects. These studies are spatially and temporally coordinated and represent the basis of Culebra's Integrated

LBSP Monitoring and Evaluation Framework with which to assess changes in LBSP stressors, LBSP exposures, and coastal habitat response. These are key elements to successfully evaluate progress and effectiveness toward achieving NOAA LBSP management goals and outcomes on Culebra (Table 1).

2. Monitoring Objectives

This document provides coastal resource managers and practitioners with a suite of recommended metrics and techniques to support the collection of robust monitoring data of LBSP **stressors**, **exposure**, and **habitat responses** to assess changes in LBSP impacts on Culebra. The NOAA Restoration Center's Strategy for LBSP management addresses the following evaluation questions:

(Q1) Did restoration actions reduce the amount of target pollutants (i.e., sediment, nutrients, and/or contaminants) discharged from a restoration site after 1, 3, and/or 5 years after implementation?

(Q2) Did restoration actions reduce target pollutant loads into the marine environment after 1, 3, and/or 5 years post- implementation (depending on the site this would be best measured at a stream mouth before entering coastal waters)?

This is achieved by the use of physical and biological indicator metrics that provide a measurable proxy for quantifying changes in stressors, exposures, and responses over time. The monitoring metrics adopted in this Ridge to Reef LBSP Program are robust indicators recommended by the US Coral Reef Task Force Watershed Working Group Metrics Subcommittee (Table 1).

Table 1. Summary of NOAA LBSP management goals, outcomes, and evaluation questions aligned with components of the risk assessment model (stressor, exposure, response). Priority indicators are used to evaluate change between pre- and post-restoration as well as progress toward reference conditions. This information will provide the evidence needed to evaluate change over time.

RISK COMPONENT	GOALS	OUTCOMES	EVALUATION QUESTIONS	PRIORITY INDICATORS
STRESSOR	By 2025, 100% implementation of NOAA priorities AND reduction in sediment and nutrient loads from the site	Stabilize unpaved roads and bare soils in priority subwatersheds	What area has been stabilized?	Area stabilized
		Stabilize and protect the coastal zone in priority locations	What percent of the BMPs are functioning as designed?	Percent function
		Install tertiary treatment at the Culebra WWTP	Has pollutant transport - from priority BMPs - been reduced?	Nutrient (TN, TP) and/or sediment load
		Enhance stormwater treatment in priority locations		
	By 2025, reduction in sediment and nutrient loads from priority subwatersheds	Reduce sediment and nutrient delivery from priority subwatersheds	Has pollutant transport - from priority subwatersheds - been reduced?	Nutrient (TN, TP) and/or sediment load
EXPOSURE	By 2030, improvements to Culebra's nearshore water quality and sedimentation	Improve nearshore water quality	Have nearshore water quality conditions improved?	Water clarity (Light attenuation, turbidity, SSC, TSS, Chl-a, CDOM, PAR), Nutrient concentration (TN, TP, Ammonia, Nitrate + Nitrite, Orthophosphate)
		Reduce terrigenous sedimentation rates	Has nearshore terrigenous sedimentation decreased?	Sediment constituent accumulation (Percent terrigenous, Sediment accumulation rate)
RESPONSE	By 2035, improvements to Culebra's nearshore seagrass and coral reef condition	Improve nearshore seagrass and coral reef habitat condition	Have seagrass habitat conditions improved?	Benthic cover, Shoot density Epiphyte load, Deep edge of bed,

Stressor changes are quantified by comparing site-specific measurements of indicators between pre- and post-restoration. Changes in pollutant exposure and corresponding changes in habitat response will be assessed through comparisons of site-specific measurements of indicators at ‘restored’ sites to ‘reference’ sites. If measures of indicators at ‘restored’ sites are trending toward ‘reference’ sites this would suggest that pollutant exposures and habitat responses are improving as a result of management actions. Therefore, establishing baseline conditions of stressors, exposures, and habitat responses, together with systematic and periodic monitoring are key to successfully evaluate management success over time.

3. Monitoring Locations and Frequency

Monitoring for LBSP stressors

<u>Altered land cover monitoring</u>: will be conducted across the island where BMPs and road stabilization projects have been implemented. Monitoring is prioritized in the Fulladosa, Culebra/Punta Aloe, and Puerto del Manglar watersheds because these are areas where restoration projects have been completed to date with no expected major changes in the near future, and are the focus of future watershed modeling efforts (Figure 2).

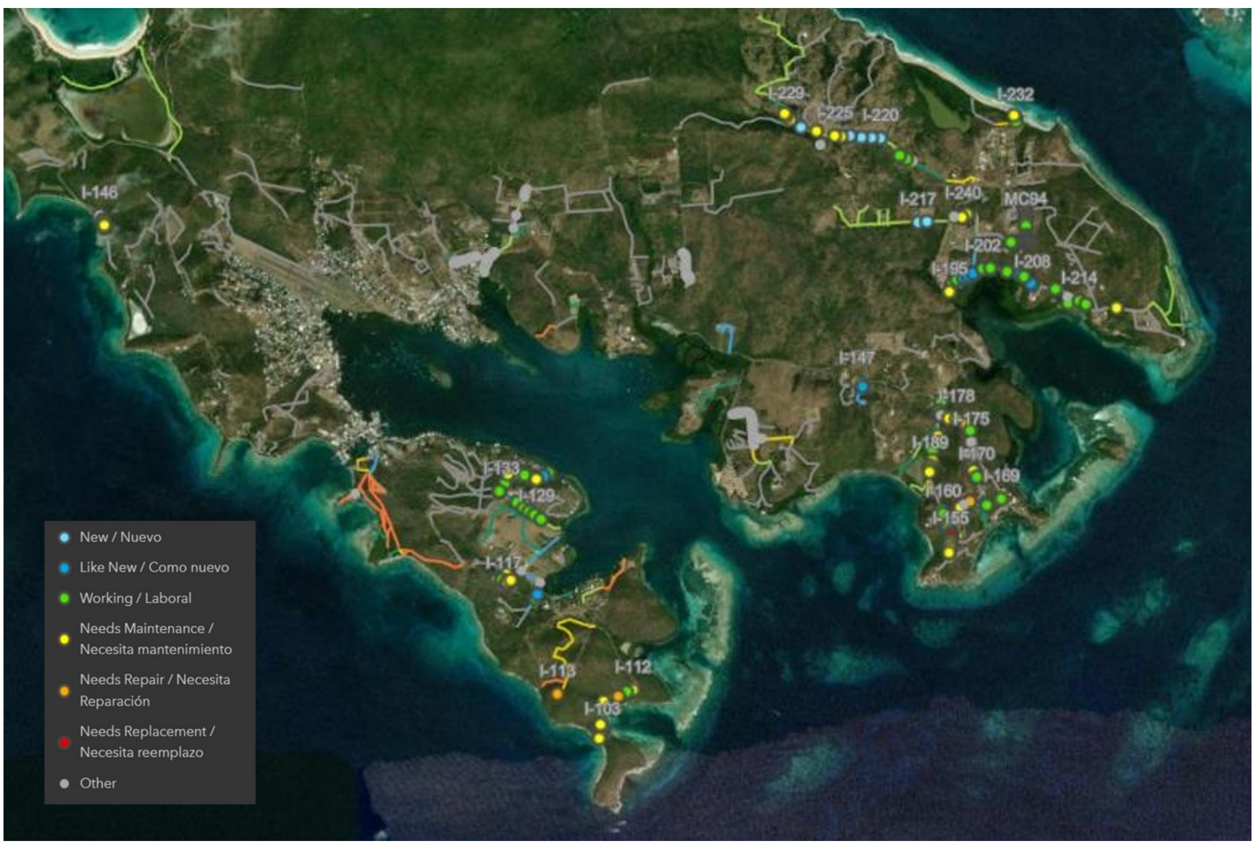

Figure 2. Location and condition record snapshot of NOAA’s BMPs and road stabilization projects on Culebra.

<u>Increased watershed pollutant loads from stormwater and undertreated sewage monitoring:</u> will take place at nine locations. Four within Culebra’s Wastewater Treatment Plant (WWTP), two WWTP downstream locations prior to discharge to Ensenada Honda, and three additional urban

sites in the Coronel and Aeropuerto watersheds to assess point and nonpoint sources entering Ensenada Honda (Figure 3). Monitoring at all nine stations will be conducted on a monthly basis for at least one full year. This dataset will build on the existing water quality monitoring to establish pre- and post-restoration pollutant load baselines.

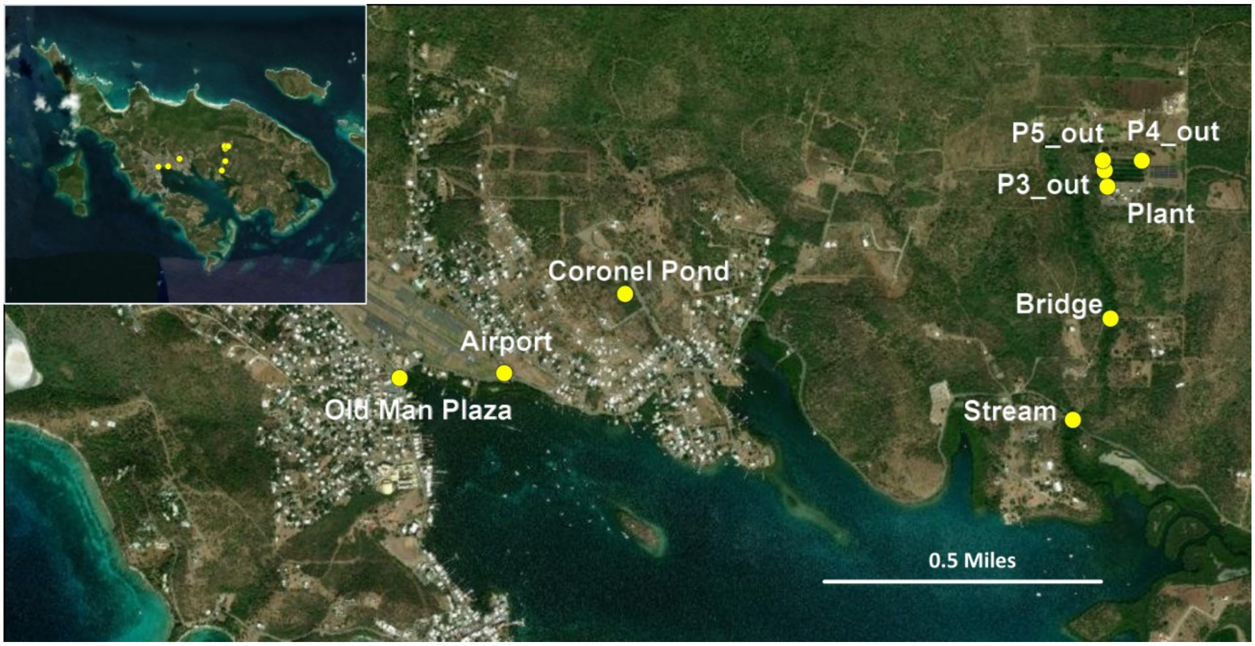

Figure 3. Location of the watershed water quality fixed monitoring stations for increased pollutant loads from stormwater and untreated sewage on Culebra.

Monitoring for LBSP Exposure

Impaired nearshore water quality monitoring: will occur at 13 fixed stations (Figure 4) selected following a rigorous analysis of watershed hydrology and coastal hydrodynamics, as well as the existing level of LBSP exposure and anticipated changes to LBSP exposure due to management actions Appendix A: Identifying Priority Fixed-Site Monitoring Locations), representative of: 1.) locations where LBSP BMPs have been implemented; 2.) a range of LBSP impairment, including areas which have no known direct discharge of LBSP but are characteristic of physical environmental conditions that are encountered at the BMP sites; and 3) repeat locations previously sampled in 2014 for water quality and baseline seagrass community assessments. For at least one full year water quality monitoring will be conducted on a monthly basis and sediment trap monitoring on a quarterly basis at these locations. This dataset will build on the existing water quality monitoring to establish pre- and post-restoration pollutant load baselines.

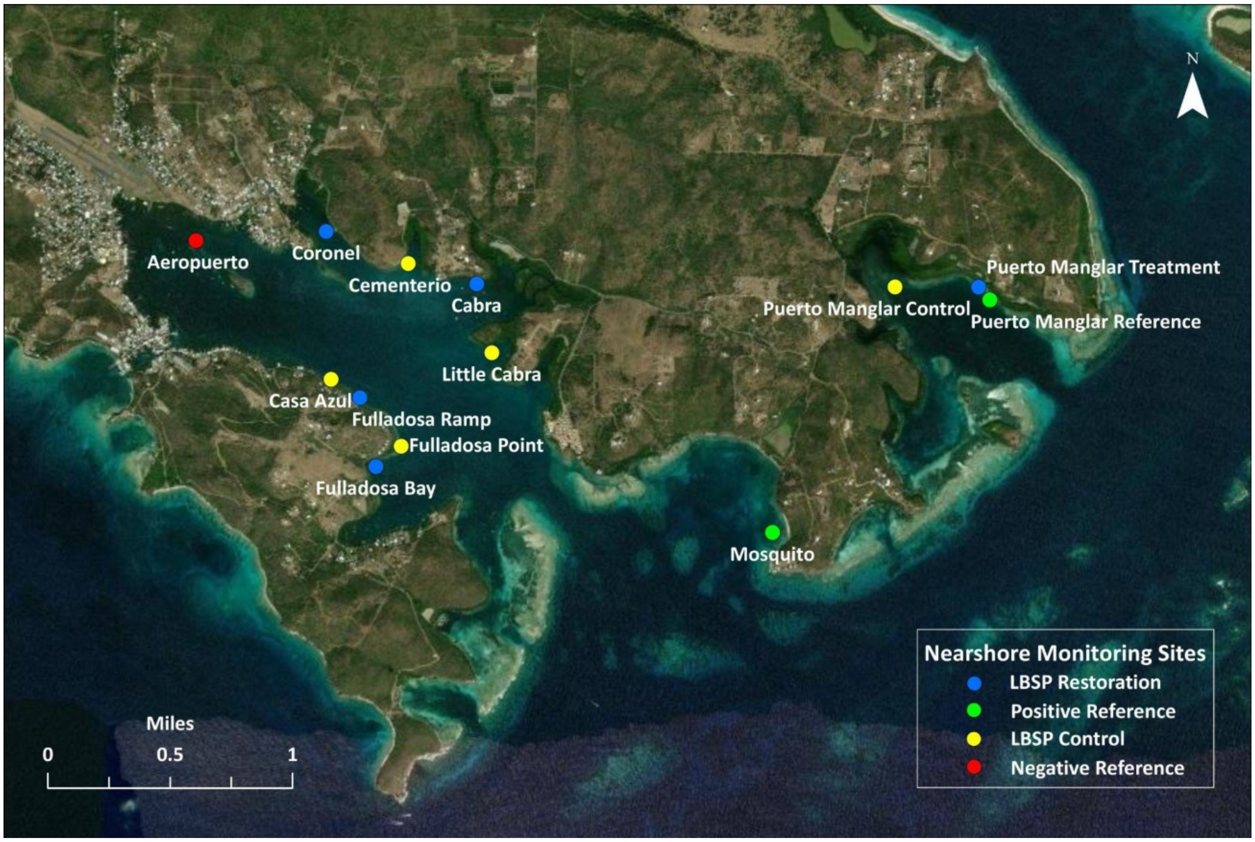

Figure 4: Exposure monitoring; nearshore water quality and sediment trap monitoring stations on Culebra

Monitoring for LBSP Habitat Response

Altered nearshore habitat and resource monitoring: will occur along seagrass transects co-located with the fixed nearshore water quality and sediment trap monitoring stations identified in Figure 4.

4. Monitoring Activities and Work Plans

Standardized work plans for each individual monitoring component outlined above can be accessed by clicking on hyperlinks below.

Monitoring for LBSP stressors

Altered land cover: Culebra LBSP Best Management Practices Implementation Inventory and Condition Monitoring Work Plan

Increased watershed pollutant loads from stormwater and untreated sewage: Culebra Cabra Watershed Water Quality Monitoring Work Plan

Monitoring for LBSP Exposure

Impaired nearshore water quality: Culebra Nearshore Water Quality Monitoring Program Work Plan, Culebra Sediment Trap Monitoring Work Plan

Monitoring for LBSP Habitat Response

Altered nearshore habitat and resource: Culebra Seagrass Monitoring Work Plan

5. Budget

A high-level operational budget is presented in Table 2. Detailed, annotated expenditures for each individual monitoring activity, including the development and implementation of data management tools can be accessed in the work plans for each monitoring individual component outlined above. In addition, an itemized list of equipment, instruments, and supplies needed for each monitoring component can be accessed by clicking on this link (Appendix 1: Culebra LBSP Ridge-to-reef monitoring; equipment, instrument, and supply budget list). Cost sharing, namely labor, is achieved through the spatial and temporal coordination of the different monitoring components. Additional cost savings are derived from lodging at the Protectores de Cuencas Culebra field station, as well as by sharing equipment, supplies, and instrumentation.

Table 2. Culebra Ridge-to-Reef monitoring operational budget. Itemized expenditures for each individual monitoring component are presented in the corresponding individual work plans.

Monitoring Component	**Descriptor**	**Annual frequency**	**Sample size**	**Labor**	**Travel**	**Services**	**Equipment / supplies**	**Subtotal**	**Cost savings***	**Total**
Unpaved Road	Assumes 6 events are needed per year, with 5 work days and 2 travel days per event. This work can be prioritized for certain watersheds and significantly reduce cost.	6	Prioirty watersheds	$28,400.00	$12,645.00	$8,300.00	$600.00	$49,945.00	$4,770.00	$45,175.00
Watershed Monitoring	Assumes 12 sampling events per year and sample processing using PDC equipment.	12	9 sites	$21,000.00	$17,382.00	$13,140.00	$13,740.00	$65,262.00	$25,797.00	$39,465.00
Nearshore Water Quality	Assumes 12 sampling events per year and sample processing using PDC equipment.	12	13 sites	$25,200.00	$23,088.00	$57,474.00	$15,600.00	$121,362.00	$11,448.00	$109,914.00
Nearshore Sediment Traps	Assumes 4 sampling events per year.	4	13 sites	$21,600.00	$12,374.00	$8,400.00	$9,100.00	$51,474.00	$18,914.00	$32,560.00
Nutrient & Tracer Monitoring	Asumes 12 sampling events per year and sample processing. Sample analysis conducted by NCCOS contract Lab at Texas A&M University	12		$1,830.00		$60,199.20	$4,760.00	$66,789.20		$66,789.20
Seagrass Monitoring	Assumes 1 sampling event per year - likelihood of annual monitoring is uncertain	1	13 sites x 3 transects)	$10,800.00	$8,695.50	$2,400.00	$6,210.00	$28,105.50	$3,339.00	$24,766.50
Data Management								$65,000.00		$65,000.00
TOTAL								$447,937.70	$64,268.00	$383,669.70

*Significant cost savings is achieved by the temporal coordination of monitoring activities as well as lodging at the Protectores de Cuencas field station on Culebra.

6. Data Management and Visualization

Several resources have been developed and implemented to collect, QA/AC, store, and visualize raw data. Data Management instructions and tools for each monitoring component can be found in the corresponding individual monitoring work plans.

Data Collection and Entry Tools:

- Nearshore & Watershed Water Quality
    - Data entry
- Culebra Ridge-to-Reef Monitoring
    -
    - https://fieldmaps.arcgis.app/?itemID=6c9d647f1e944adeaa95dc80b05c5305&referenceContext=open&portalURL=https%3A%2F%2FHorsleyWitten.maps.arcgis.com

Data QA/QC Tools

- Nearshore & Watershed Water Quality
    - Nearshore Water Quality QC
    - Watershed Water Quality QC Field
    - Watershed Water Quality QC Lab
- Culebra Ridge to Reef Monitoring
    - Desktop EDITOR

Data Storage and visualization

- Nearshore & Watershed Water Quality
    - Culebra Water Quality Dashboard
- The Culebra Project
    - Resources Hub

7. Literature Cited

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