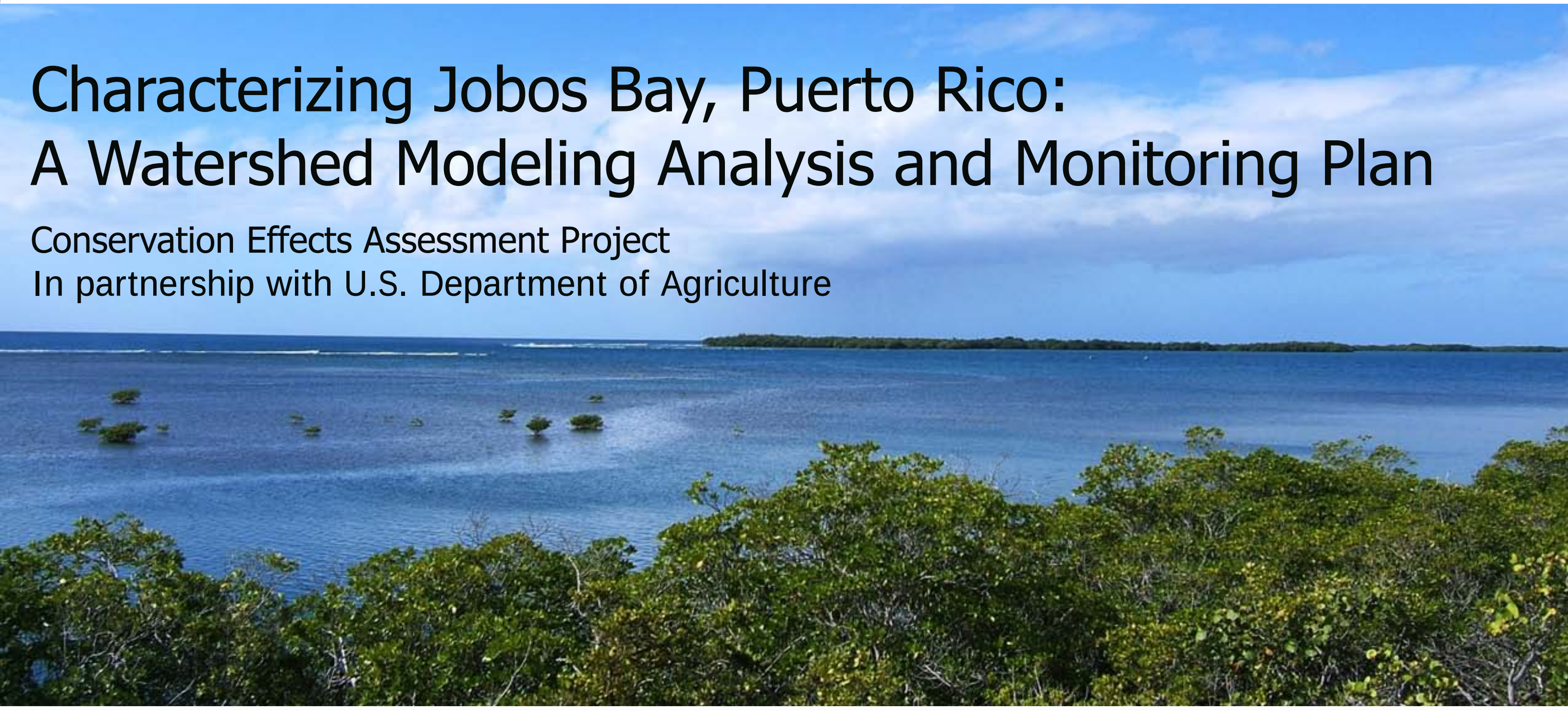
Characterizing Jobos Bay, Puerto Rico: A Watershed Modeling Analysis and Monitoring Plan

Conservation Effects Assessment Project
In partnership with U.S. Department of Agriculture



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A Watershed Modeling Analysis and Monitoring Plan

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ABOUT THIS DOCUMENT

This characterization of Jobos Bay, Puerto Rico represents a progress report on an ongoing partnership between the U.S. Department of Agriculture (USDA) and the National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment (CCMA). The Conservation Effects Assessment Project (CEAP) Special Emphasis Watershed at Jobos Bay originated from a long-standing collaboration between NOAA and USDA on the U.S. Coral Reef Task Force. The objective of this cooperative effort is to quantify the environmental effects of agricultural conservation practices on coral reef ecosystems. The Jobos Bay watershed was chosen because it has a large percentage of agricultural land use and is host to a NOAA National Estuarine Research Reserve (NERR). With the assistance of Jobos Bay NERR staff, USDA and NOAA continue to conduct *in situ* monitoring efforts on the watershed and in the estuary that will enhance the understanding of ecosystem responses to conservation practices.

The report consists of two components: a discussion of sediment and pollutant predictions in the Jobos Bay watershed from a spatially-explicit modeling approach; and a description of the monitoring efforts conducted by NOAA in the estuary. The watershed modeling analysis provides an initial screening of areas on the landscape that may exert the greatest stress on the coral reef ecosystem from sedimentation and pollution. The monitoring plans described in this report will be carried out before and after conservation practices are implemented on the watershed. The results will allow USDA and NOAA to assess the effectiveness of selected conservation practices and make recommendations for other agricultural operations in tropical regions. For more information on this effort please visit the NCCOS/CCMA webpage dedicated to this project at http://ccma.nos.noaa.gov/ecosystems/coralreef/CEAP.html or direct questions or comments to:

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EXECUTIVE SUMMARY

Land-based pollution is commonly identified as a major contributor to the observed deterioration of shallow-water coral reef ecosystem health. Human activity on the coastal landscape often induces nutrient enrichment, hypoxia, harmful algal blooms, toxic contamination and other stressors that have degraded the quality of coastal waters. Coral reef ecosystems throughout Puerto Rico, including Jobos Bay, are under threat from coastal land uses such as urban development, industry and agriculture. The objectives of this report were two-fold:

1. To identify potentially harmful land use activities to the benthic habitats of Jobos Bay, and
2. To describe a monitoring plan for Jobos Bay designed to assess the impacts of conservation practices implemented on the watershed.

Image 1. A recent crop planting in Salinas, Puerto Rico. (Photo Credit: T. Potter, USDA-ARS)

This characterization is a component of the partnership between the U.S. Department of Agriculture (USDA) and the National Oceanic and Atmospheric Administration (NOAA) established by the Conservation Effects Assessment Project (CEAP) in Jobos Bay. CEAP is a multi-agency effort to quantify the environmental benefits of conservation practices used by private landowners participating in USDA programs. The Jobos Bay watershed, located in southeastern Puerto Rico, was selected as the first tropical CEAP Special Emphasis Watershed (SEW). Both USDA and NOAA use their respective expertise in terrestrial and marine environments to model and monitor Jobos Bay resources.

This report documents NOAA activities conducted in the first year of the three-year CEAP effort in Jobos Bay. Chapter 1 provides a brief overview of the project and background information on Jobos Bay and its watershed. Chapter 2 implements NOAA's Summit to Sea approach to summarize the existing resource conditions on the watershed and in the estuary. Summit to Sea uses a GIS-based procedure that links patterns of land use in coastal watersheds to sediment and pollutant loading predictions at the interface between terrestrial and marine environments. The outcome of Summit to Sea analysis is an inventory of coastal land use and predicted pollution threats, consisting of spatial data and descriptive statistics, which allows for better management of coral reef ecosystems. Chapters 3 and 4 describe the monitoring plan to assess the ecological response to conservation practices established by USDA on the watershed.

Jobos Bay is the second largest estuary in Puerto Rico, but has more than three times the shoreline of any other estuarine area on the island. It is a natural harbor protected from offshore wind and waves by a series of mangrove islands and the Punta Pozuelo peninsula. The Jobos Bay marine ecosystem includes 48 km^2 of mangrove, seagrass, coral reef and other habitat types that span both intertidal and subtidal areas. Mapping of Jobos Bay revealed 10 different benthic habitats of varying prevalence, and a large area of unknown bottom type covering 38% of the entire bay. Of the known benthic habitats, submerged aquatic vegetation, primarily seagrass, is the most common bottom type, covering slightly less than 30% of the bay. Mangroves are the dominant shoreline feature, while coral reefs comprise only 4% of the total benthic habitat. However, coral reefs are some of the most productive habitats found in Jobos Bay, and provide important habitat and nursery grounds for fish and invertebrates of commercial and recreational value.

The Jobos Bay watershed covers 137 km^2 of the South Coastal Plain of Puerto Rico, and drains surface water runoff and groundwater directly to Jobos Bay. From Spanish Colonial times up to the 1970's, almost the entire coastal plain of the Jobos Bay watershed was under sugarcane cultivation. Over the past 35 years, sugarcane lands have been steadily converted to fruit and vegetable cultivation or entirely removed from agricultural cultivation. Today, cultivated lands in the Jobos Bay watershed only comprise 11% of the area's total land cover. The watershed is overwhelmingly rural with vegetated lands, including grassland, forest and shrub, covering 70% of the landscape. The 32,000 residents of the Jobos Bay watershed live in low density residential communities that are located throughout the area. Among other industries, Jobos Bay hosts two electric power generation plants, a petroleum refinery, and several major chemical and pharmaceutical facilities.

Image 2. NOAA diver descending to ocean floor. (Photo Credit: NOAA Biogeography Branch)

For the purposes of this analysis, the Jobos Bay watershed was divided into nine hydrologically discrete subwatersheds. An evaluation of each subwatershed's contribution to predicted sediment and pollutant loading to Jobos Bay is included in this report. Three subwatersheds of Jobos Bay account for over 75% of the predicted annual sediment discharged to Jobos Bay. They include the Río Seco and Quebrada Coquí waterways as well as several diffuse sources near the Barrio Jobos district. These same three subwatersheds, with the addition of the Upper Salinas subwatershed, are responsible for 85% of both the predicted annual total nitrogen and total phosphorus loads to Jobos Bay. The Upper Salinas subwatershed contributed the largest predicted loads of total nitrogen, total phosphorus and total suspended solids compared to all other subwatersheds in the study area. As expected from these pollutant load predictions, the Upper Salinas subwatershed contains the highest population and most agricultural lands in Jobos Bay.

In order to assess the benefits of conservation practices to the health of near-shore coral reef ecosystems, a comprehensive monitoring approach must be implemented in Jobos Bay. Two distinct monitoring efforts have been designed to characterize the ecology of Jobos Bay and its surrounding waters; one measuring water quality and sediment, and the other surveying reef fish and benthic habitat. Water column samples are taken monthly at each of the four NOAA System-Wide Monitoring Program (SWMP) sites, in order to leverage the existing nutrient and water quality data at these locations. In addition, a stratified random sample design has been implemented for sediment sampling throughout the bay. Sediment grabs (n=44) have been taken across four sampling strata, 10 in each zone, and again at the four existing SWMP sites. Sediment sampling will be carried out before and after conservation practices are implemented on the watershed to detect potential concentration changes in pesticides and metals of agricultural concern.

As part of the comprehensive monitoring plan, NOAA proposes a reef fish and habitat monitoring effort for Jobos Bay. A stratified random sample design will be employed to investigate 100 sites inside and outside of the bay. NOAA dive teams will collect several types of fundamental, *in situ*, data on reef fishes and benthic habitats at each site. Visual surveys are conducted along 25 m long by 4 m wide (100 m^2) belt transects and include data on abundance and size-frequency of fish species as well as benthic floral and faunal composition. NOAA expects to conduct yearly surveys to characterize Jobos Bay's living marine resources and describe species distribution changes over time in Jobos Bay.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

The Conservation Effects Assessment Project (CEAP) is a multi-agency effort to quantify the environmental benefits of conservation practices used by private landowners participating in selected U.S. Department of Agriculture (USDA) conservation programs. The Jobos Bay Watershed, located in south-central Puerto Rico (PR), was selected by CEAP partners as the first tropical CEAP Special Emphasis Watershed. Special Emphasis Watersheds (SEW) are strategically located watersheds in which researchers quantify and demonstrate water quality and other environmental effects of conservation programs. Investigations in Jobos Bay characterize terrestrial and marine ecosystems at varying spatial scales in order to evaluate the relationship between agricultural practices and the health of near-shore coral reef ecosystems.

Image 3. CEAP partners boarding a JBNERR boat in Jobos Bay. (Photo Credit: T. Potter, USDA-ARS)

Current partners in the CEAP Jobos Bay SEW include USDA's Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS), National Oceanic and Atmospheric Administration (NOAA) and the Government of Puerto Rico. The project originated from an on-going collaboration between USDA and NOAA on the U.S. Coral Reef Task Force. The Jobos Bay watershed was chosen because the predominant land use is agriculture, most of which is adjacent to one of NOAA's 26 National Estuarine Research Reserves. CEAP research involves Jobos Bay National Estuarine Research Reserve (JBNERR) staff throughout the assessment.

Funds to support the work come from multiple sources including ARS, NRCS and NOAA. The Coral Reef Conservation Program (CRCP) within NOAA provides funding to the Center for Coastal Monitoring and Assessment (CCMA) which conducts and manages monitoring of the biological, physical and chemical characteristics of U.S. tropical marine ecosystems. Characterization, habitat mapping, monitoring and assessment of coral reef ecosystems by CCMA and its partners is conducted via the CRCP National Coral Reef Ecosystem Monitoring and Coral Ecosystem Mapping Programs.

In 2002, the U.S. Coral Reef Task Force identified the need for action at the local level to reduce key threats to coral reefs in each of the seven states and territories which possess significant coral reef resources. Local Action Strategies (LAS) were developed by Puerto Rico's local and federal agency representatives in 2003. The CEAP work in Jobos Bay directly addresses a LAS goal related to land-based sources of pollution by "reducing loss of live coral reef cover through the promotion and implementation of integrated watershed and land use management practices." This effort highlights the interaction between upland and coastal ecosystems and involves a collaborative partnership between USDA and NOAA to address spatially complex natural resource issues.

1.2 OBJECTIVES

The primary objective of the Jobos Bay CEAP study is to determine the environmental effects that agricultural conservation practices implemented by farmers on the upland may have on coastal waters and the associated coral reef ecosystem.

Specific objectives to be addressed in Jobos Bay by CEAP partners include:

1. Estimate benefits of conservation practices currently present on the landscape.
2. Estimate effects of conservation practices in terrestrial and aquatic species and habitat.
3. Quantify changes in water quality, sediment chemistry, and coral ecosystem response from implementation of conservation management practices.
4. Estimate the need for additional conservation practices and the benefits that could be realized if appropriate conservation practices were implemented on all cropland and poultry farms.
5. Simulate alternative options for implementing conservation programs on croplands and poultry farms in the future.

An initial plan of work has been created that defines the responsibilities of CEAP partners in order to address these specific objectives. Responsibilities were assigned based on each agency's traditional area of expertise and can be summarized by the following:

- ARS leads research to quantify the effects of specific conservation practices on the delivery of water, sediment, and chemicals from agricultural lands to surface and shallow ground waters.
- NRCS serves as the lead coordinating agency for the project and conducts outreach activities with the conservation partnership. NRCS also assists the Puerto Rico Land Authority in development and implementation of innovative conservation practices with farmers.
- NOAA leads efforts to define the state of Jobos Bay water quality, benthic habitats and living marine resources. In addition, NOAA collaborates with the JBNERR to monitor changes in these ecosystem components to assess the effects of implemented conservation practices.

1.3 STUDY AREA DESCRIPTION

Jobos Bay is located on the south-central coast of PR centered at 17º 56'N and 66º 13'W, between the municipalities of Salinas and Guayama (Figure 1.1). The second largest estuary in PR, Jobos Bay has a total surface

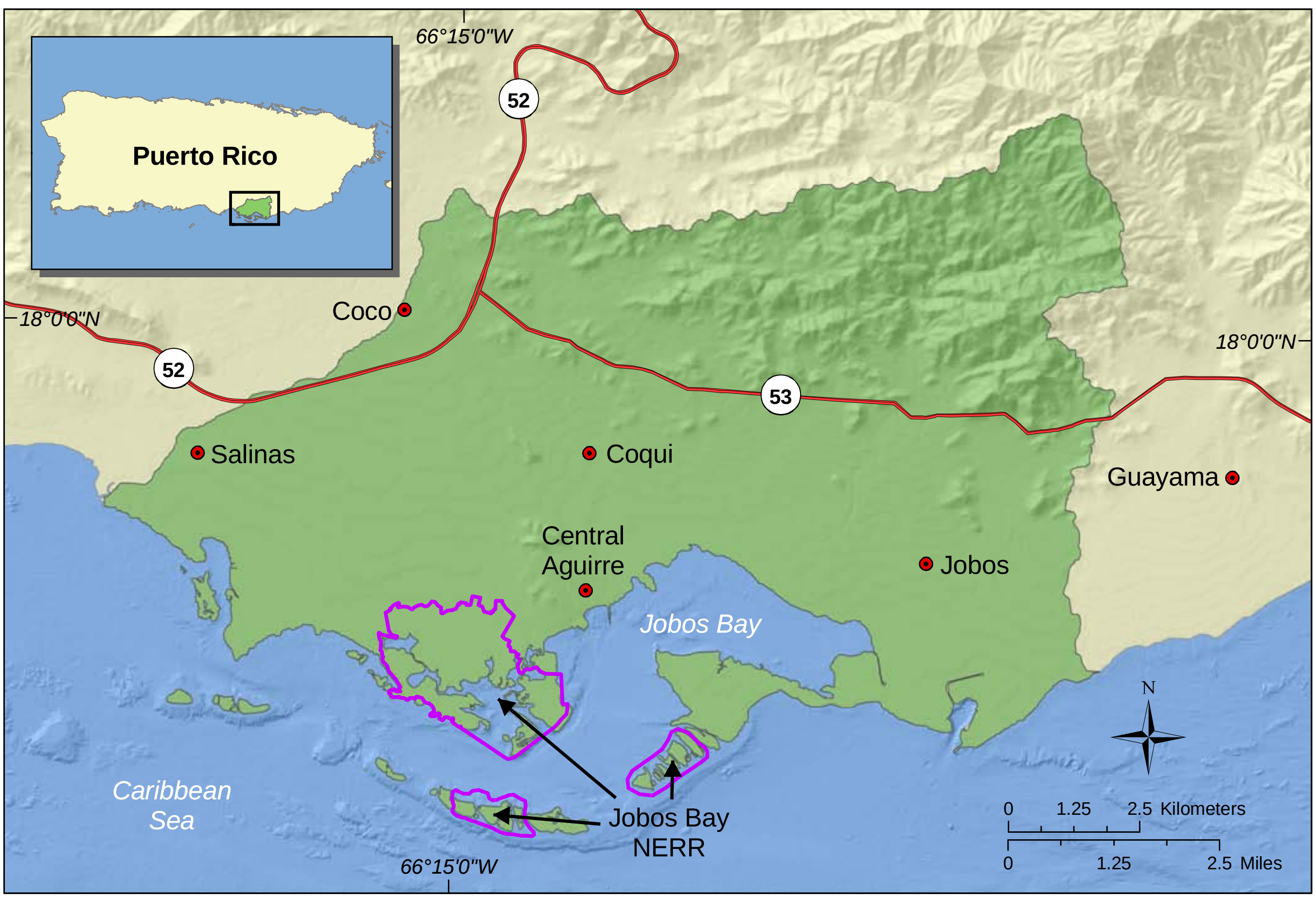

Figure 1.1. Location of Jobos Bay, Puerto Rico and its watershed area.

area of just over 25 km². Jobos Bay is classified as a coastal plain estuary that was formed by rising sea levels at the end of the last ice age. The rising seas invaded the low-lying coastal river valley and created the shallow embayment that is now Jobos Bay. It is a natural harbor protected from offshore wind and waves by a series of mangrove islands in the southwest and Punta Pozuelo in the southeast. Jobos Bay features diverse marine habitats, including mangroves, salt marshes, seagrasses and coral reefs.

Image 4. View between crop rows of a banana plantation in Salinas, PR. (Photo Credit: T. Potter, USDA-ARS)

The Jobos Bay watershed reaches as far as 11 km inland and has a total catchment area of 137 km². The watershed contains several centers of low density urban development and hosts an estimated total population of 32,000 people (U.S. Bureau of the Census, 2001). The predominant land use is agriculture, including diversified production of agricultural commodities such as plantains, bananas, papayas, sorghum, corn and hay, and animal operations with poultry and some beef cattle.

Water quality and conservation concerns related to agricultural practices are important in the Jobos Bay watershed and may influence coral reef ecosystem health. Preliminary studies reported that pesticides and fertilizers applied in agricultural fields were being transported to the bay (Field *et al.*, 2002). Increasing industrial and commercial growth in the watershed has also been recognized as a concern to Jobos Bay's ecosystem health. There are two landfill operations within the watershed. The regional landfill, operated by BFI, is located in the middle of the watershed and is expected to broaden to twice the size of its original plans; while the other is on the eastern edge of the watershed in Guayama. Other major industries such as Chevron Phillips, Ayerst-Wyeth, IPR Pharmaceuticals, Colgate-Palmolive and ProChem maintain operations in the watershed (Field *et al.*, 2002). Two of Puerto Rico's five power production plants operate within the Jobos Bay watershed.

1.4 DOCUMENT ORGANIZATION

This report addresses the three main contributions of NOAA/CCMA's involvement in the CEAP study of Jobos Bay:

- **Chapter 2. Summit to Sea Characterization**
  CCMA Biogeography Branch's Summit to Sea characterization uses a Geographic Information Systems (GIS) based approach that links patterns of land use in coastal watersheds to sediment and pollutant discharge predictions at the receiving waters of adjacent coral reef ecosystems. Chapter 2 summarizes the methods used to characterize the study area and describe the subwatersheds of Jobos Bay as well as the marine environment.
- **Chapter 3. Sediment and Water Quality Sampling Plan**
  CCMA's Coastal and Oceanographic Assessment, Status and Trends (COAST) Branch has initiated a baseline assessment of estuarine water and sediment quality. This chapter outlines the sampling plan being implemented before and after conservation practices are applied in the watershed.
- **Chapter 4. Reef Fish and Habitat Monitoring Plan**
  The last chapter of this document describes the Biogeography Branch's proposed plan to monitor reef fish and benthic habitats in Jobos Bay.

This document was generated in fulfillment of NOAA's Year 1 Tasks as described in the Plan of Work agreed upon by CEAP partners (NOAA, 2007a).

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CHAPTER 2 SUMMIT TO SEA CHARACTERIZATION

Land based pollution is commonly identified as a major contributor to the observed deterioration of shallow-water coral reef ecosystem health. Human activity in coastal areas is a major cause of nutrient enrichment, hypoxia, harmful algal blooms, toxic contamination, sedimentation and other stressors that have degraded the quality of coastal waters (Waddell, 2005). NOAA's Biogeography Branch has developed a process, known as Summit to Sea, to better understand the threats to coral ecosystems imposed by coastal land use.

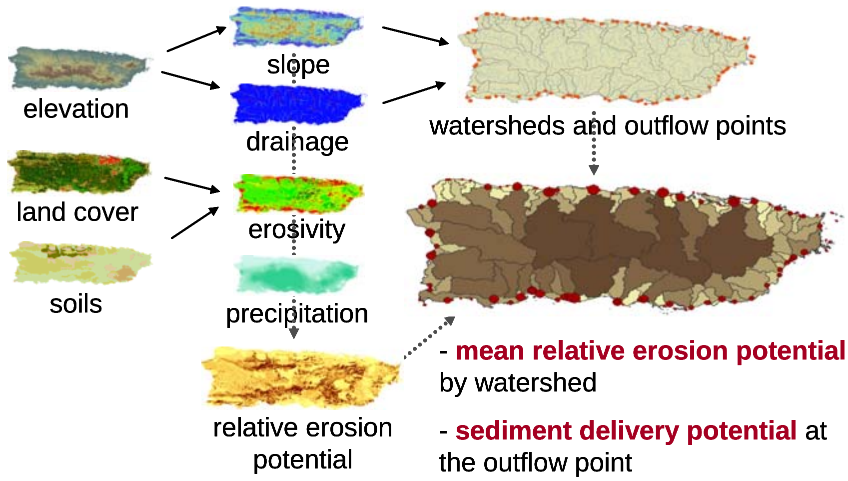

Image 5. This cartographic model depicts the process to map soil erosion threats (by watershed) to coral reefs from mainland Puerto Rico. The original inputs are elevation, land cover, soils and precipitation.

Fundamentally, Summit to Sea is the process of synthesizing the best available data on the resource conditions of a study area and using predictive models that are most appropriate for that data. It is an adaptive scheme that can be applied to any geographic location at varying scales. Summit to Sea is not an exhaustive modeling effort, but instead should be utilized as an initial screening tool to build more refined models and field studies upon.

Summit to Sea uses a GIS-based approach that links patterns of landscape use in coastal watersheds to sediment and pollutant loading predictions at the interface between terrestrial and marine environments. Widely accepted water resource models are employed to estimate sediment and pollutant loads for land use and other activities on the watershed. Summit to Sea analysis highlights specific watersheds and terrestrial areas that are most likely to contribute sediment and pollutant loads to nearshore coral reef ecosystems. As a result, terrestrial areas that are particularly threatening to marine habitats are identified. The outcome of Summit to Sea analysis is an inventory of coastal land use and predicted pollution threats, consisting of spatial data and descriptive statistics, which allows for better management of coral reef ecosystems. The analysis described in this report uses the evolving Summit to Sea application for the characterization of coastal watersheds and implements its approach in the Jobos Bay watershed.

2.1. METHODS

Summit to Sea analysis of Jobos Bay was conducted using a variety of spatial data generated by U.S. government agencies including U.S. Geological Survey (USGS), USDA and NOAA. The general workflow to completion is outlined by two primary processing steps:

- Watershed Delineation
- Runoff and Pollutant Modeling

A majority of the Summit to Sea GIS processing techniques were completed with the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT). N-SPECT is a GIS application developed by NOAA's Coastal Services Center to predict water quality impacts from nonpoint source pollution and erosion in watersheds. N-SPECT is an extension to Environmental Systems Research Institute's (ESRI) ArcGIS software package that relies on functionality in ESRI's Spatial Analyst extension. Spatial data on land cover, topography, precipitation and soil characteristics are ingested into the watershed characterization tool. Water resource models and terrain analysis are applied with the aid of a GIS to derive watershed boundaries, estimates of runoff, sediment and pollutant loadings, and sources across the landscape. The following sections are a summary of the primary processing steps completed during the Summit to Sea analysis of Jobos Bay.

Watershed Delineation

Watersheds are the fundamental unit of Summit to Sea analysis because they link all locations on the landscape with a surface water network and ultimately a point of discharge to Jobos Bay. Watershed delineation is a flexible process in which larger areas may be successively divided into smaller entities, known as subwatersheds, depending upon the desired scale of analysis. Drainage basins in Jobos Bay were described at two levels of delineation: 1) the entire area draining to Jobos Bay, which will be referred to as the Jobos Bay watershed for the remainder of this document; and 2) the subwatersheds of the Jobos Bay watershed. Each subwatershed is linked to a single point of discharge, while the Jobos Bay watershed is an aggregation of all points of discharge to Jobos Bay.

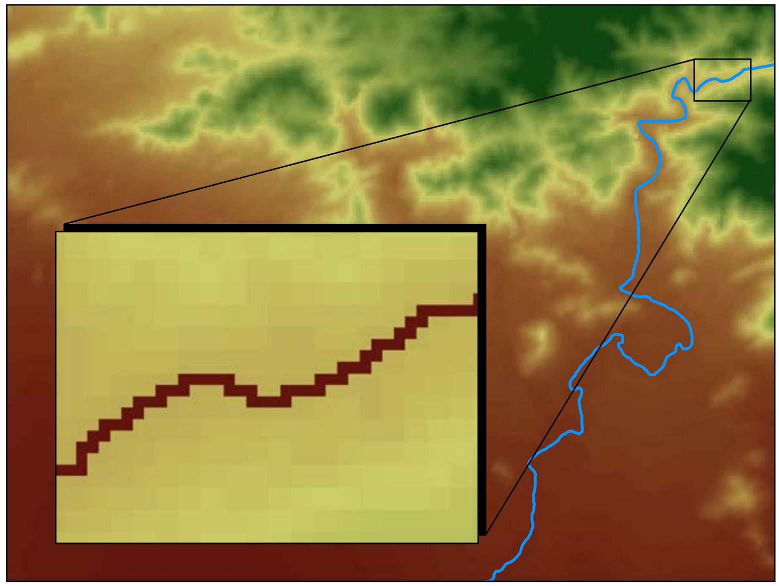

Figure 2.1. An example of "stream burning" to ensure that modeled surface water networks correspond to mapped stream lines. Río Seco (blue line) was manually embedded into the elevation grid (inset) before surface water runoff simulation.

A collection of four 12-digit USGS Hydrologic Unit Codes (HUC) was identified as the Jobos Bay watershed and the HUCs were merged to define the terrestrial boundaries of the study. Subwatersheds were delineated for this area from a hydrologically corrected 30 m (1 arc-second) digital elevation model (DEM) using N-SPECT. The DEM was acquired from the National Elevation Dataset (USGS, 1999) and represents filtered bare ground readings. Before implementing N-SPECT's delineation module, the locations of National Hydrography Dataset streams were manually embedded into the DEM using analysis tools provided in ArcGIS. Elevation grid cells that corresponded with stream lines were reduced by 2 m less than the minimum value in that area (Figure 2.1). This process, referred to as "stream burning", made certain that predicted drainage water flowed continuously across the landscape through mapped river beds. In addition, HUC watershed boundaries were artificially raised in the DEM to ensure agreement between HUCs and the subsequent N-SPECT generated subwatersheds.

The prepared DEM was then ingested into N-SPECT's watershed delineation module to derive Jobos Bay subwatersheds. N-SPECT relied upon several traditional ArcGIS hydrology functions. For each grid cell in the DEM, the direction of overland flow (FlowDirection) and the number of cells flowing into each adjacent downstream cell (FlowAccumulation) were defined. Using this flow network, all cells that flowed to a common point were aggregated as a subwatershed (Basin) and the maximum cell within each basin was identified as the point of discharge. Refer to the *N-SPECT Technical Guide* (NOAA, 2004) for more detail.

Runoff and Pollutant Modeling

A component of Summit to Sea analysis is evaluation of the threat to coral reef ecosystems from land-based sources of sediment and nutrients. N-SPECT was employed to combine spatial information on the terrestrial environment, such as elevation, slope, soils, precipitation and land cover, to derive estimates of stormwater runoff and nonpoint source pollution. Two types of estimates were calculated for the watershed:

1. Local Contribution – amount of runoff or pollutant contributed by each individual grid cell.
2. Accumulated – total amount of runoff or pollutant accumulated at each grid cell when considering cells upstream as well.

Jobos Bay watershed runoff and pollutants were evaluated on an annual basis, so all calculations reflect yearly estimates. N-SPECT was executed on 30 x 30 m grid cells; as a result, landscape features or land use activities smaller than 900 m² may not be accounted for in this analysis.

Runoff and sediment modeling of the Jobos Bay watershed was achieved with a series of water resource models. N-SPECT defined the equation's parameters from spatial data on the physical environment using a cell-by-cell approach. N-SPECT utilized the Soil Conservation Service Runoff Curve Number (SCS-CN) method described in *Urban Hydrology for Small Watersheds: Technical Release 55* (USDA, 1986) as the basis for its runoff estimates. The Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997) was used to evaluate annual erosion in the watershed. RUSLE provided gross erosion estimates that were used to describe the local effects of soil erosion at each grid cell. However, Williams' (1977) sediment delivery ratio equation was necessary to evaluate how much eroded soil was actually transported downstream. The calculated sediment delivery ratios were then applied to the previous RUSLE estimates for each grid cell and a final sediment yield grid was derived for the Jobos Bay watershed. See the Runoff and Sediment Models inset for a more detailed description of the equations and input parameters.

Runoff and Sediment Models

The Soil Conservation Service Runoff Curve Number (SCS-CN) method (USDA, 1986) described surface runoff:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Equation 1

Where:
Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in)
I_a = initial abstraction (in)

The Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997) was used to evaluate annual erosion in the watershed:

$$A = R * K * L * S * C * P$$

Equation 2

Where:
A = average annual soil loss (tons/acre)
R = rainfall-runoff erosivity factor
K = soil erodibility factor
L * S = length slope factor
C = cover-management factor
P = support practice factor

Sediment delivery ratio (Williams, 1977) was necessary to evaluate how much eroded soil was actually transported downstream:

$$SDR = 1.366 * 10^{-11} * DA^{-0.0998} * ZL^{0.3629} * CN^{5.444}$$

Equation 3

Where:
SDR = sediment delivery ratio
DA = drainage area (km^2) (at the cell level rather than the watershed)
ZL = relief-length ratio (m/km)
CN = SCS curve number

N-SPECT was also employed to estimate loads of total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) for the Jobos Bay watershed. With land cover as a proxy, pollutant loadings were determined by applying pollutant contribution coefficients, also known as unit loads, to land cover classes. In other words, the total areas of each land cover class within a subwatershed were scaled by coefficients that corresponded to expected pollutant loads per unit area. Analysis was based on a land cover grid generated by the Puerto Rico GAP Analysis Project (PRGAP, 2006) through classification of enhanced Landsat Thematic Mapper imagery. The PRGAP land cover's exhaustive classification categories were aggregated to 10 general classes that are used in NOAA's Coastal Change Analysis Program (C-CAP). This aggregation allowed for the use of default pollutant coefficients provided in the N-SPECT documentation (NOAA, 2004). One exception was the reduction of the grassland class's coefficients for TN, TP and TSS in order to reflect the unmanaged nature of grasslands common in the Jobos Bay watershed. See Table 2.1 for the land cover classes and corresponding pollutant coefficients used in this analysis.

Table 2.1. Aggregated Puerto Rico GAP Analysis Project (PRGAP, 2006) land cover classes with pollutant contribution coefficients (NOAA, 2004). All coefficients were provided by N-SPECT as default values for NOAA Coastal Change Analysis Program (C-CAP) land cover data, with the exception of reduced coefficients for grassland.

Classification		Coefficients		
Code	Name	Nitrogen	Phosphorus	TSS
2	High Intensity Developed	2.22	0.47	71
3	Low Intensity Developed	1.77	0.18	19.1
4	Cultivated Land	2.68	0.42	55.3
5	Grassland	1.875	0.075	16.65
7	Forest	1.25	0.05	11.1
9	Scrub/Shrub	1.25	0.05	11.1
10	Wetland	1.1	0.2	19
16	Unconsolidated Shore	0.97	0.12	70
17	Bare Land	0.97	0.12	70
18	Water	0.0	0.0	0.0

This procedure does not account for duration or intensity of rainfall, but instead uses annual mean rainfall. The *N-SPECT Technical Guide* (NOAA, 2004) describes a procedure that improves estimate accuracies by deriving local pollutant coefficients from water quality sampling data. Similar to Burke and Sugg (2006), the N-SPECT default coefficients were accepted due to a lack of water quality sampling data required to derive local pollutant coefficients for the Jobos Bay watershed.

The maximum accumulated loads of sediment, TP, TN and TSS were associated with each subwatershed's point of discharge. These discharge points, with accompanying pollutant loads, acted as summary statistics for all the activities occurring on the watershed. The points of discharge were assumed to be the only interface between terrestrial runoff and the waters of Jobos Bay. Although this is a simplification of the mechanisms of non-point source pollution, these point values were considered to be reasonable approximations of land-based sources of pollution to marine waters.

Without an understanding of the margin of error in the prediction estimates, using exact values is discouraged. It has been shown that N-SPECT over-estimates loads due to an inability to model sediment and nutrient attenuation within the watershed (Burke and Sugg, 2006). The watershed discharge values are not absolute. Instead, values of runoff, sediment, TN, TP and TSS are relative and can be compared to each other, but not with estimates derived from other techniques. For this reason, predicted pollutant loads in this report are regularly reported as a percentage of the total loadings rather than mass values or concentrations.

2.2 WATERSHED CHARACTERIZATION

Environmental Setting

The Jobos Bay watershed is primarily comprised of the low-relief South Coastal Plain of Puerto Rico, but reaches elevations of greater than 700 m (2,297 ft) at its landward boundary. Many of Jobos Bay watershed's physical characteristics are attributed to the presence of two of Puerto Rico's Central Interior Mountain Ranges to the north, La Cordillera Central and La Sierra de Cayey. These mountains serve as a barrier to the moisture-laden northeast trade winds and give rise to a zone of low precipitation throughout the southern coast of Puerto Rico. Mean annual rainfall between 1990 and 2006 was 958 mm (37.7 in.) at the Aguirre rain gauge station located in the watershed (NCDC, 2007). For this same time period and station, September was recorded as the wettest month, with an average rainfall of 152 mm (6 in.), while March was the driest month, with an average rainfall of 30 mm (1.18 in.) (Figure 2.2).

The Jobos Bay watershed is located in the Subtropical Dry Forest Zone, the most arid ecological life zone in Puerto Rico (Ewel and Whitmore, 1973). The parched vegetation is almost entirely deciduous and forms a complete ground cover on most soils. Past land uses, especially abandoned sugar cane fields, support man-modified vegetation that is characterized by a complete grass cover and sparsely distributed tall trees with flattened spreading crowns.

Temperatures in the Jobos Bay watershed are high throughout the year and show little seasonal fluctuation. The mean annual temperature is 26º C (78.8º F), with a maximum of 27.5º C (81.6º F) in August and a minimum of 24.3º C (75.7º F) in January (NCDC, 2007). The predominant wind comes from an easterly direction at mean speeds of 10 km/hr or less (McClymonds and Díaz, 1972). The regular daily wind pattern is for low velocity northeast winds to give way to a more brisk southeast wind as the day progresses (Field *et al.*, 2002).

Image 6. Puerto Rico's South Coastal Plain (foreground) and La Cordillera Central range (background). (Photo Credit: T. Potter, USDA-ARS)

Due to Jobos Bay's dry climate and relatively low seasonal rainfall, surface runoff usually only occurs during the wettest months of the year, September through November (Ewel and Whitmore, 1973). As a result, most of the watershed's natural stream beds are only intermittently flooded throughout the year. Río Seco, in the east, is the only major river that discharges into Jobos Bay during the entire year. Quiñones-Aponte *et al.* (1997) described that year-round streamflow downstream is limited by where most streams meet the highly porous fan delta deposits. At that point, the streamflow infiltration becomes the most important source of groundwater recharge to the underlying aquifer.

The Jobos Bay watershed is within the South Coastal Plain alluvial aquifer that extends from the bedrock hills near the watershed's northern boundary to the coast. According to Quiñones-Aponte *et al.* (1997), the aquifer can be divided into three hydrogeologic units: 1) a deep zone composed of weathered bedrock, 2) the principal groundwater flow zone of fan delta and alluvial deposits, and 3) an upper zone of sand and gravel. In the north, groundwater moves mostly unconfined through the upper zone; however, as the amount of fine-grained sediment increases coastward, the upper zone becomes confined from the principal groundwater flow zone (Rodríguez, 2006). These conditions create two discrete groundwater units in the coastal zone, a shallow aquifer between 3m and 23 m thick and a deep aquifer below. The shallow aquifer is believed to supply the mangrove complex at the watershed's coastal margins, while the deep aquifer may provide freshwater to the offshore mangrove islands that form Jobos Bay's southern boundary.

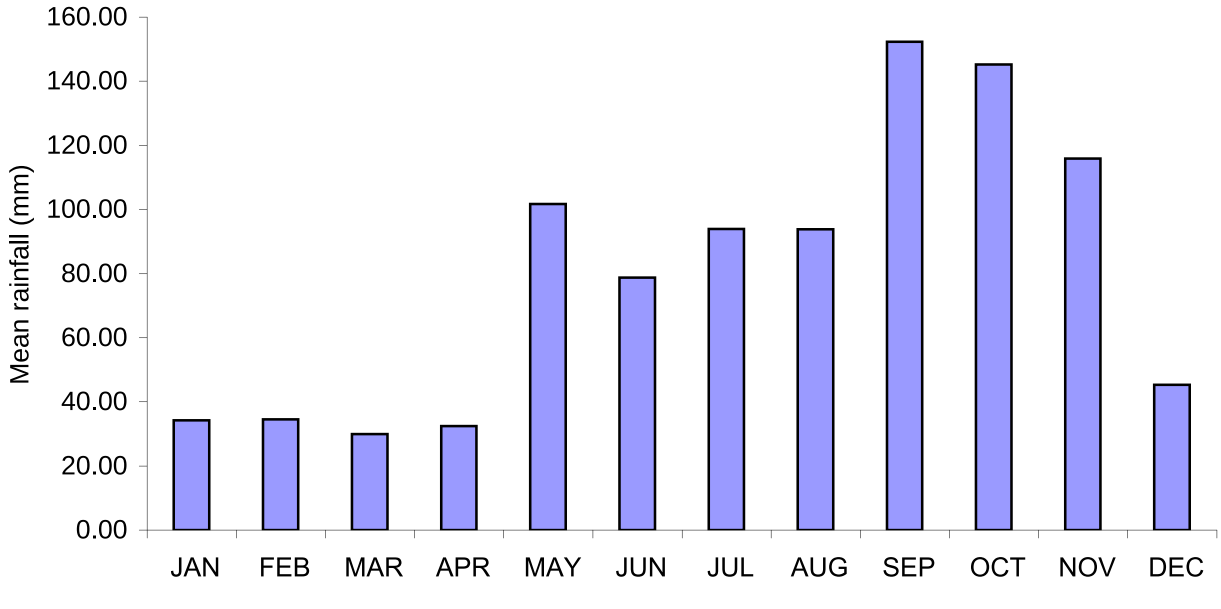

Figure 2.2. Monthly rainfall averages for 1990-2006 at the Aguirre rain gauge station in the center of the Jobos Bay watershed (NCDC, 2007).

Jobos Bay Watershed

The Jobos Bay watershed includes 137.3 km² of the South Coastal Plain of Puerto Rico and drains surface runoff directly to Jobos Bay (Figure 2.4). Jobos Bay and its associated watershed is framed by two perennial stream networks; Río Nigua to the west and Río Guamaní to the east. The watershed's northern boundary, beginning in the foothills of the Central Interior Mountain Range, extends about 6 km to 11 km landward from the shoreline of Jobos Bay. Although Jobos Bay's shoreline represents a straight-line distance of under 20 km, the meandering Bay's mainland coast stretches a total distance of over 45 km.

Image 7. Cultivation of papaya at farm near Salinas, Puerto Rico. (Photo Credit: T. Potter, USDA-ARS)

The Jobos Bay watershed does not contain one single river network that accumulates surface water flow throughout the basin. Instead, the watershed contains a variety of distinct pathways by which surface waters are contributed to Jobos Bay. These include perennial stream discharges, intermittent stream discharges and diffuse overland runoff to Jobos Bay. A unique composite of land cover, topography and underlying geology dictate the type of surface water contribution found in the different areas of the Jobos Bay watershed. These will be discussed later in this report.

The Jobos Bay watershed experienced several man-made water diversion projects since the start of the 20th century. Beginning in 1914, successful agricultural operations have been achieved by transferring surface water to the Jobos Bay watershed from reservoirs outside the basin through irrigation canals. As part of the Guayama

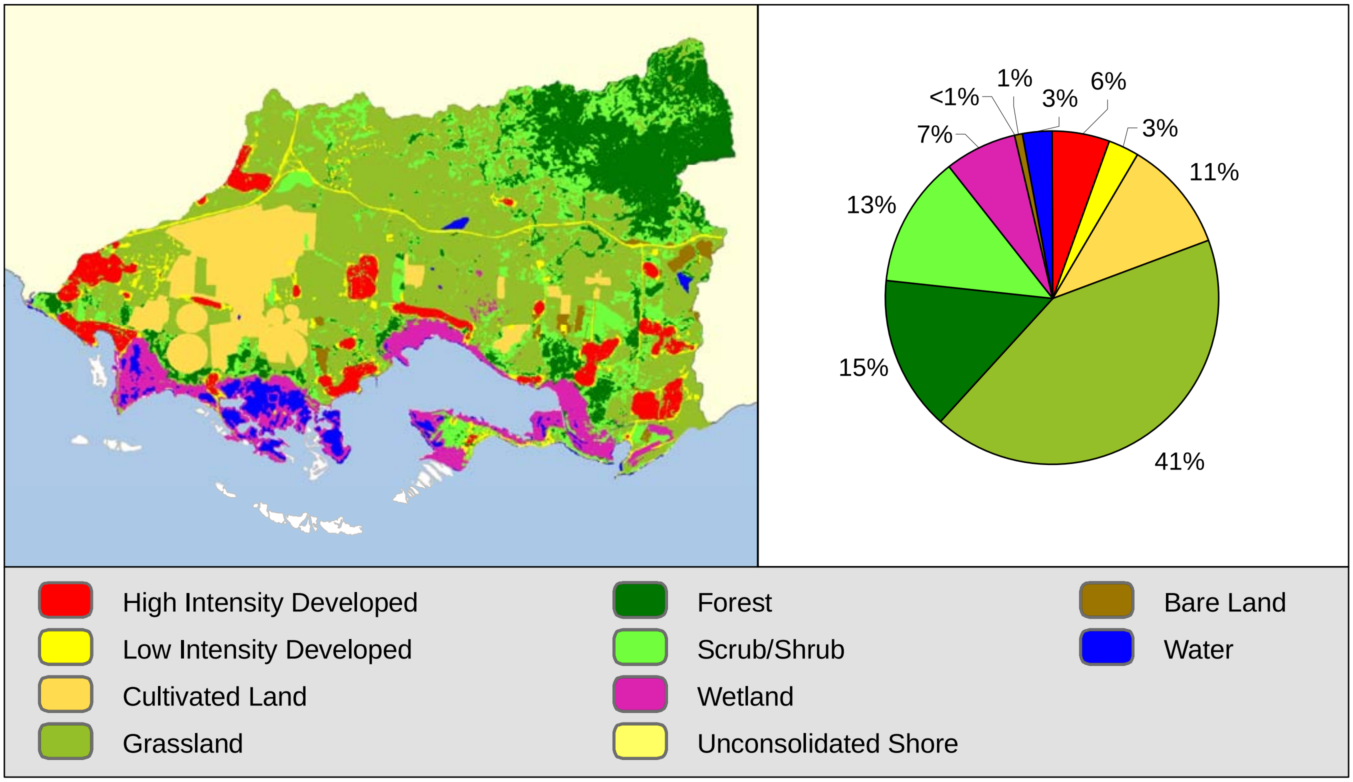

Figure 2.3. Spatial distribution and percent coverage of Jobos Bay land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

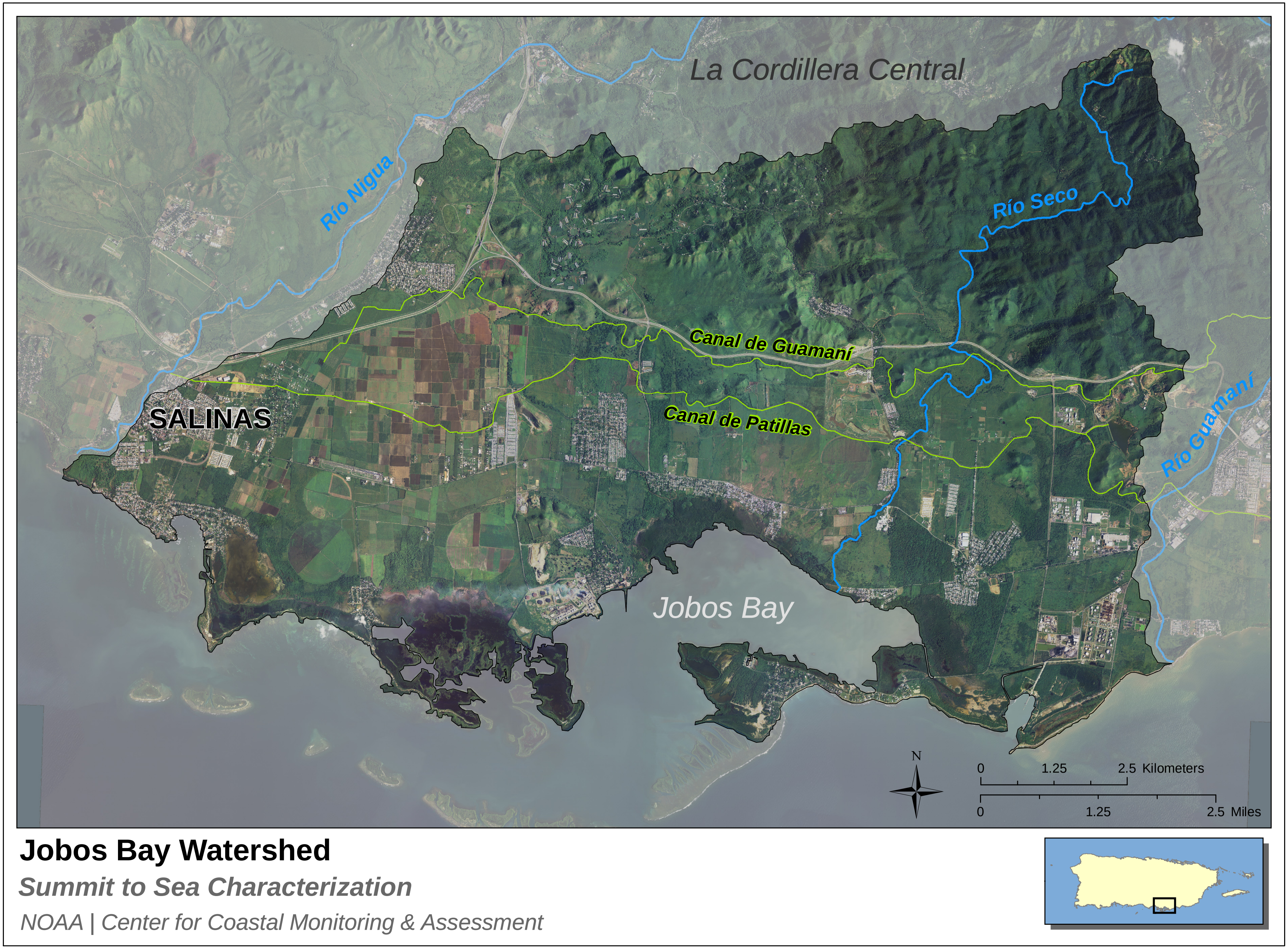

Figure 2.4. Jobos Bay watershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

Irrigation District, two primary irrigation canals distribute water from Patillas and Carite Reservoirs, northeast of Jobos Bay, to operations throughout the watershed. Both canals flow from east to west, with Canal de Guamaní in the north and Canal de Patillas in the south. Non-irrigation drainage canals were also constructed in order to reclaim wet areas for agriculture and to reduce mosquito breeding in response to the risk of malaria in the 1930's (Field *et al.*, 2002).

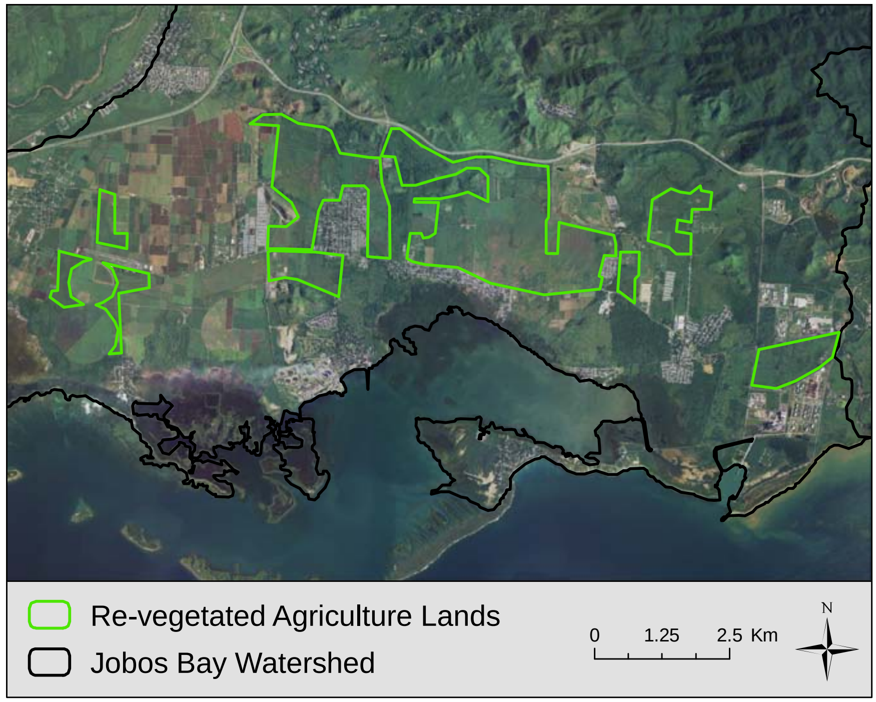

Figure 2.5. Location of 13.5 km² of former agriculture lands classified as grassland in the Puerto Rico GAP Analysis Project land cover dataset (PRGAP, 2006). Orthophotography reflects 2004 ground conditions (USDA, 2004).

From Spanish Colonial times up to the 1970's, the Jobos Bay watershed was primarily used for agricultural production (Field *et al.*, 2002). Almost the entire coastal plain of Jobos Bay was under sugarcane cultivation until the demise of Puerto Rico's sugarcane market during the 1960's. Over the past 35 years, sugarcane lands have been steadily converted to fruit and vegetable cultivation or entirely removed from agricultural cultivation. Today, cultivated lands in the Jobos Bay watershed only comprise 11% of the area's total land cover, which is 15 km². However, the extensive sugarcane cultivation of the past has had a lasting impact on the landscape of the Jobos Bay watershed.

Despite the historic prevalence of agriculture in the Jobos Bay watershed, existing land cover conditions are more indicative of an ecosystem in a natural state. Vegetated lands cover 70% of the landscape with grassland, forest and scrub/shrub accounting for 42%, 15% and 13%, respectively (Figure 2.3). The large amount of vegetated lands may lead to the inaccurate conclusion that the Jobos Bay watershed is a relatively pristine system. Inspection of aerial photography indicated that as much as 13.5 km² of the area classified as grassland is re-vegetated agriculture lands (Figure 2.5). In addition, an unspecified amount of classified grasslands are actually used for livestock pasture. If these areas were considered a separate land cover type the amount of naturally vegetated land cover would be reduced by 10% to 15%. Re-vegetated agriculture fields and pasture have a higher frequency of disturbance and serve fundamentally different ecosystem services than naturally vegetated grasslands. A majority of the disturbed grasslands exist south of the irrigation canals, while the naturally vegetated grasslands tend to lie north of the canals in the foothills of the Central Interior Mountain Range.

The 32,000 residents of the Jobos Bay watershed live in low density residential communities that are located throughout the area. Over two thirds of the population are residents of the municipality of Salinas in the western half of the watershed, while the remainder of the residents live in the municipality of Guayama in the east. The average population density in Jobos Bay is maintained at a comparatively low 234 people/km² by large areas of open space between communities. The primary transportation routes through the area are Highways 52 and 53, with Route 3 servicing local traffic. A variety of industrial activities are distributed throughout the Jobos Bay watershed. Among other industries, Jobos Bay hosts two electric power generation plants, a petroleum refinery, and several major chemical and pharmaceutical facilities.

For the purposes of this analysis, the Jobos Bay watershed was divided into nine hydrologically discrete subwatersheds. Each subwatershed has a unique set of surface water drainage, land cover and land use conditions that are described in the following individual sections. Moreover, an evaluation of each subwatershed's contribution to predicted sediment and pollutant loading to Jobos Bay is included in the following sections. Refer to Figure 2.6 for the subwatershed boundaries and an index of subwatershed codes and the corresponding page number of each section. Appendix A is a table describing summary statistics for each subwatershed assessed in this study. Appendix B displays the predicted values of surface water runoff, sediment, TN, TP and TSS in annual load (kg/yr) to Jobos Bay from individual subwatersheds.

For the remainder of this document, all statistics and assertions about land cover, predicted sediment and pollutant loadings, and benthic habitats are the result of Summit to Sea analysis, unless otherwise noted.

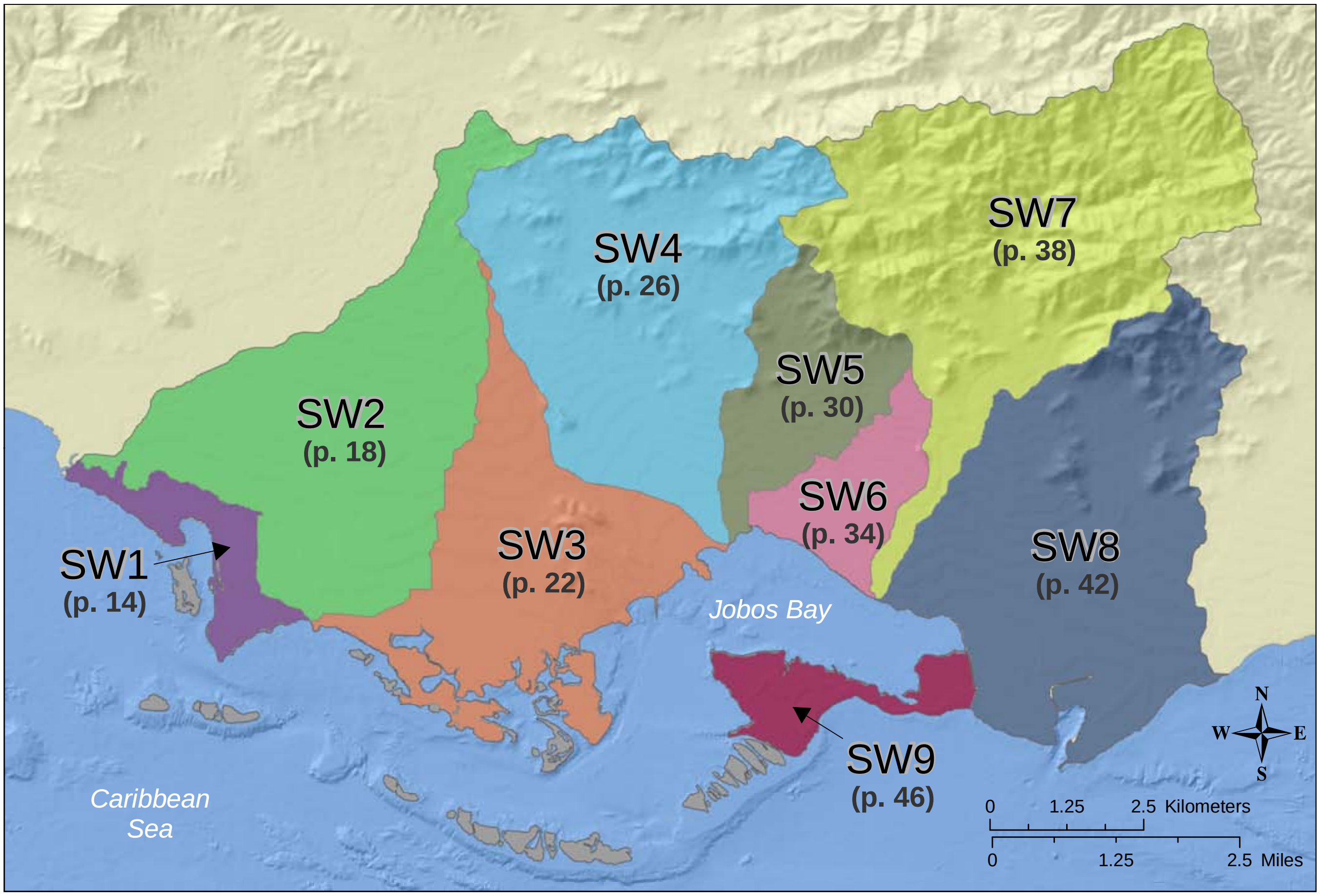

Figure 2.6. Index for subwatersheds of the Jobos Bay watershed. Each subwatershed is labeled with an ID code and a page number corresponding to the section on its detailed description.

SW 1 – Coastal Salinas

The Coastal Salinas subwatershed (SW1), with an area of 3.3 km², is the smallest drainage basin in the Jobos Bay watershed. It represents a narrow strip of coastal land that lies just east of Río Nigua's outflow and west of the Mar Negro wetland complex (Figure 2.8). The coastal basin lacks a defined stream network, and is instead characterized by several distributed discharges of overland flow to the western edge of Jobos Bay.

The Coastal Salinas subwatershed is dominated by two land cover types, wetland and high intensity urban development, 33% and 23% of the subwatershed respectively (Figure 2.7). The wetland complex at Punta Arenas, comprised of tidally flooded coastal lagoons and fringing mangrove, covers an area just under 1.5 km². It is possible that these wetlands provide some natural filtration of ground and surface waters that may enter from the agricultural operations conducted in the adjacent subwatershed.

Image 8. Above and below the surface view of prop roots at the edge of a red mangrove (*Rhizophora mangle*) forest. (Photo Credit: NOAA Biogeography Branch)

North of the Punta Arenas wetlands is a residential community situated around a protected cove with several active marinas. None of the urban development in this area is served by public sewer facilities, but as an alternative uses individual sewage disposal systems. Coastal Salinas supports a population density of 746 persons/ km²; the highest densities for any subwatershed in the study area. Additionally, the 2,461 permanent residents in the area all live within 500 m of the shoreline of Jobos Bay. As a result, the residential area of Coastal Salinas has the

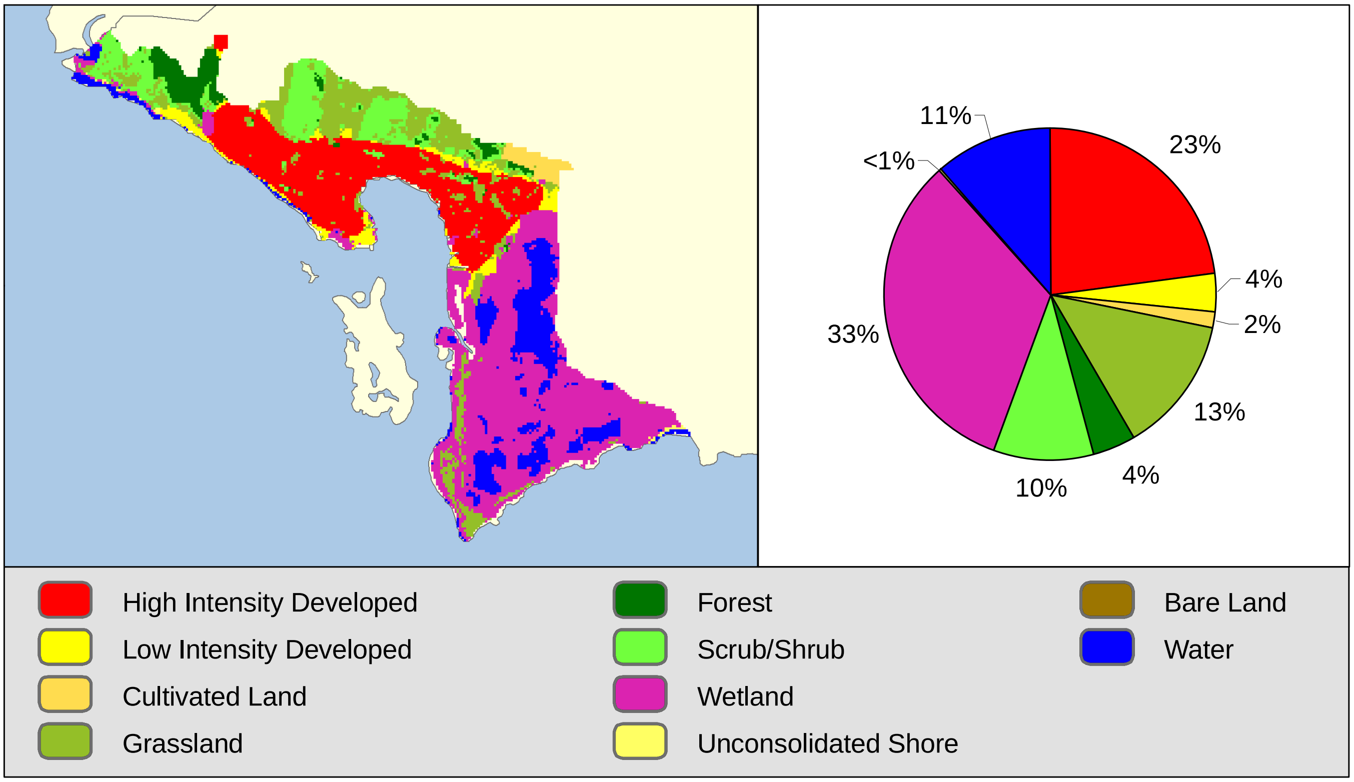

Figure 2.7. Spatial distribution and percent coverage of Coastal Salinas land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

Figure 2.8. Coastal Salinas subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

second highest road density (5.6 km/km²) of all the subwatersheds in this study.

Figure 2.9 displays the percent of watershed-wide total loads of sediment, TN, TP and TSS to Jobos Bay. Coastal Salinas only contributes around 1% of Jobos Bay's total load for each of the four pollutants assessed. Local contributions of pollutants from each 900 m² grid cell are represented in Figure 2.10. Pollutant loadings from this subwatershed are minimal in comparison to other subwatersheds in the study area because Coastal Salinas is only a fraction of the size. However, a large proportion of this watershed's pollutants are likely discharged directly into the estuary due to a lack of vegetated buffer between residential development and Jobos Bay. In addition, the impacts of the individual sewage disposal systems are not well understood for this community in Puerto Rico and may have a more deleterious effect than predicted in this analysis.

The eastern portion of the Coastal Salinas subwatershed in Figure 2.10 is depicted as having no local contribution to predicted pollutant loads. A shortcoming of N-SPECT is that coastal wetlands and standing water are not considered during pollutant modeling. As a result, local contribu-

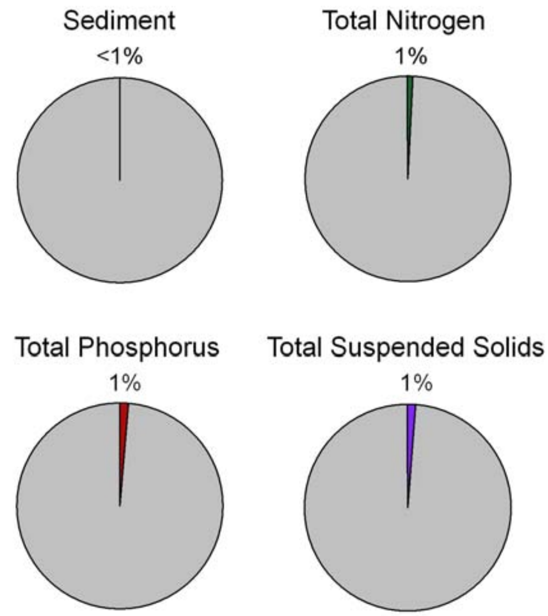

Figure 2.9. Coastal Salinas subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

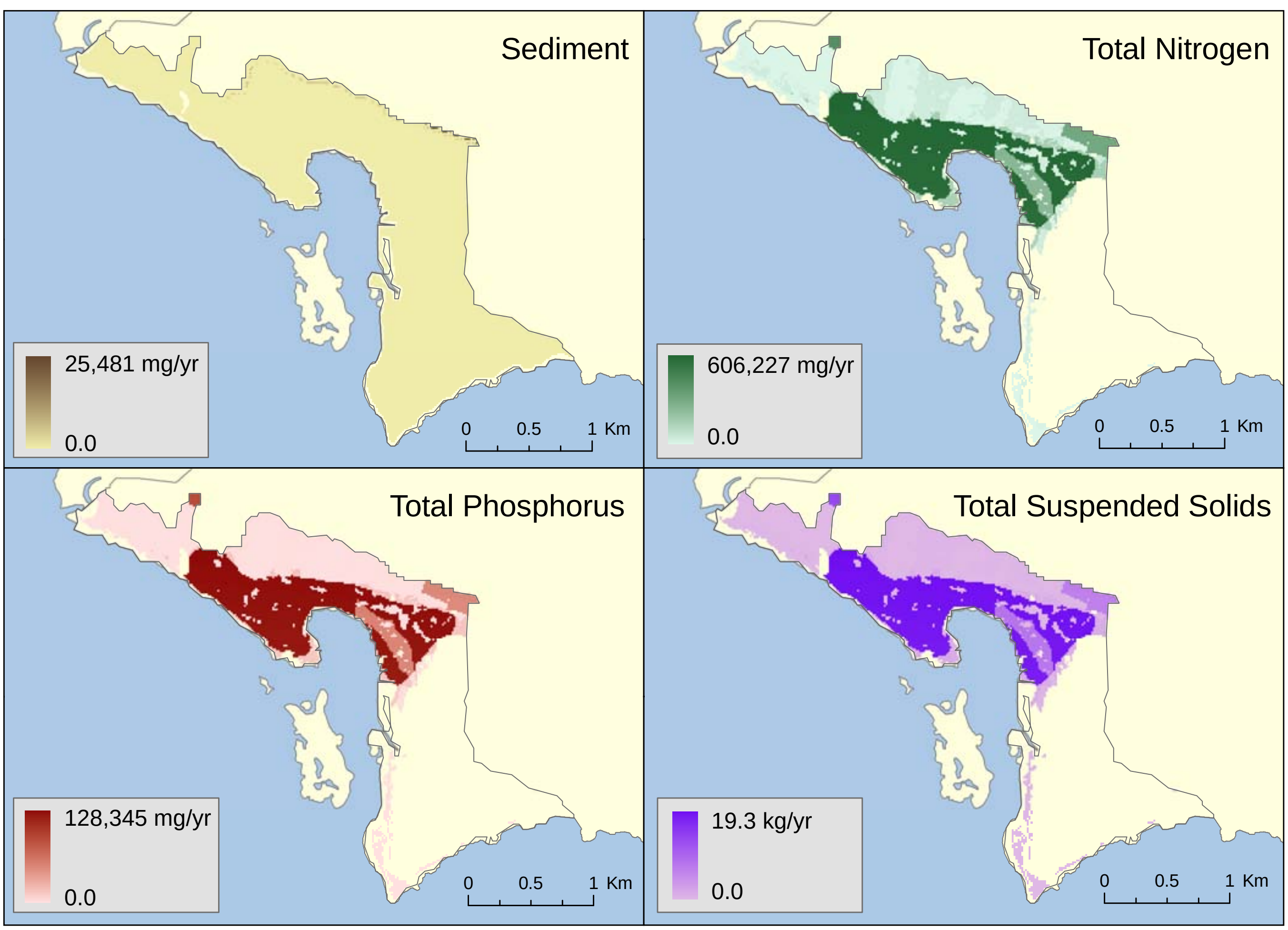

Figure 2.10. Localized annual pollutant contributions by grid cell in Coastal Salinas.

tion output surfaces lack data in these areas regardless of the specific characteristics of the wetland feature. Throughout this analysis, N-SPECT outputs indicate that coastal mangrove complexes contribute no pollutant loads. However, there has been no research in Jobos Bay to characterize the mangroves as either sources or sinks of pollutants.

SW 2 – Upper Salinas

The Upper Salinas subwatershed (SW2) covers 22.6 km² of the western Jobos Bay watershed. Its northern and western boundaries are defined by the drainage divide separating Río Nigua's catchment area from that of Jobos Bay's (Figure 2.12). The entire basin is located on the Salinas Fan Delta (Rodríguez, 2006) and has very little topographic relief. No natural stream channels exist, but a series of irrigation canals deliver surface waters to a single point of discharge in western Jobos Bay.

The Upper Salinas subwatershed contains the largest amount of human-altered landscape of all the other Jobos Bay subwatersheds. Cultivated land and urban developed land uses make up 56% of the subwatershed, while an additional 33% is grassland areas that have likely been re-vegetated after past agricultural usage (Figure 2.11). Upper Salinas is the location of 65% of the total cultivated land in the larger Jobos Bay watershed, comprising 9.5 km² of the 14.7 km² in the whole watershed.

The subwatershed encompasses two communities with significant urban land cover, Salinas in the west and Coco in the north. Salinas and Coco combine to account for over one third of the total population of the Jobos Bay watershed, 12,272 of the 32,096 permanent residents. As a result of these two population centers, Upper Salinas has a higher average road density (6.1 km/km²) than all of the other subwatersheds surrounding Jobos Bay. Unlike the residential areas of Coastal Salinas, urban development in this subwatershed is connected to the municipal sewer system.

The Salinas Speedway, an automobile racetrack located in the center of the subwatershed, is classified as high intensity urban development. It is not well understood what contribution the Speedway has to the overall pollutant loading in this watershed and may be a potential source of contaminants, such as polynuclear aromatic hydrocarbons (PAH).

Consistent with the trend described in USDA (1986), conversion of naturally vegetated lands to impervious or less pervious urban cover in Upper Salinas does contribute a larger volume of surface runoff to Jobos Bay. The subwatershed contributes a predicted average of 324 million L/km² of runoff each year, the most of any subwatershed in the study. Furthermore, Figure 2.13 provides several statistics about the proportion of pollutant loading that the Upper Salinas subwatershed is responsible for in Jobos Bay.

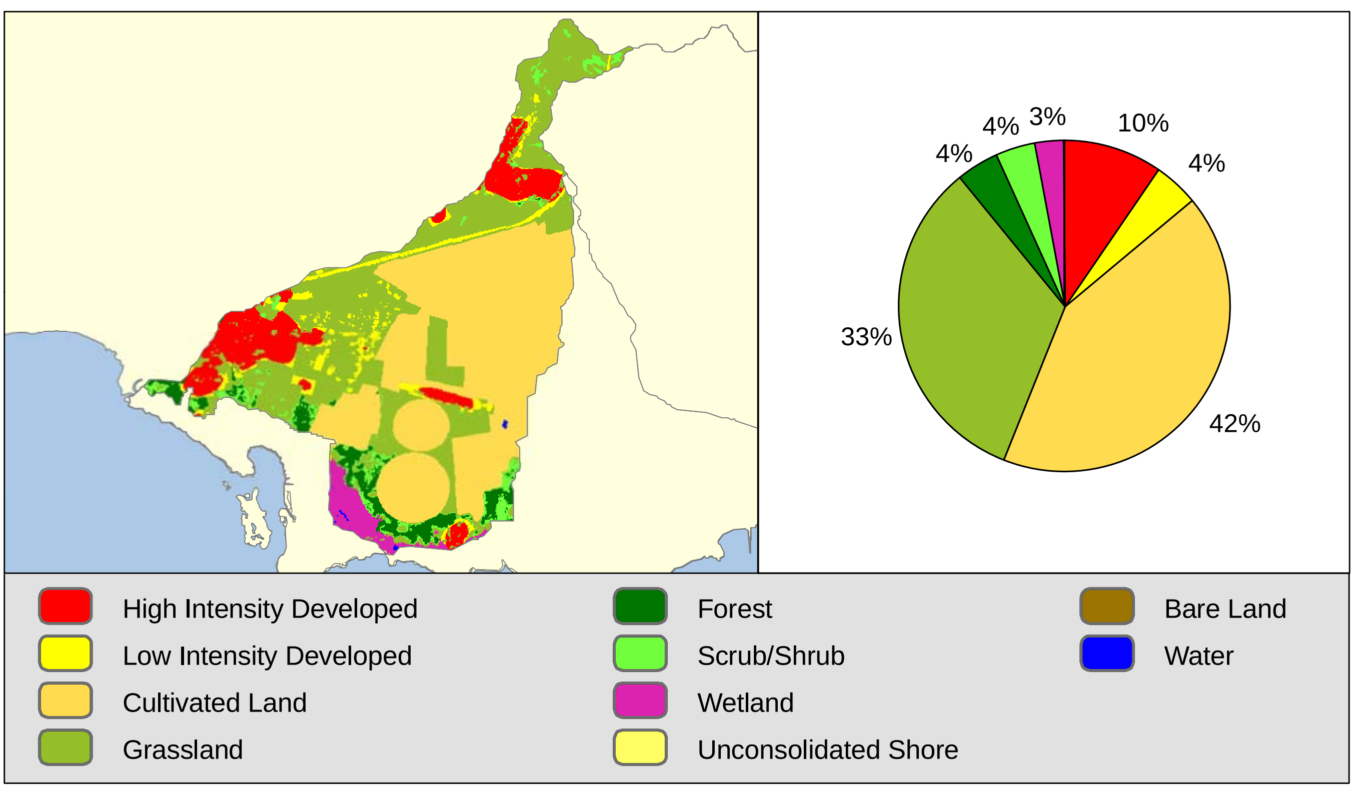

Figure 2.11. Spatial distribution and percent coverage of Upper Salinas land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

Figure 2.12. Spatial distribution and percent coverage of Upper Salinas land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

The Upper Salinas subwatershed had the largest predicted loading for TN, TP and TSS, with 19,000 kg/yr, 3,000 kg/yr, and 438,000 kg/yr, respectively. These predictions are again consistent with USDA (1986) findings that indicate urban and agricultural watersheds contribute most to pollutant loads. In contrast, the subwatershed was attributed with a much smaller proportion of the overall sediment load to Jobos Bay, at 8% of total load. This 8% is considerably less than the 24%, 25% and 26% contributions of three other subwatersheds of comparative size (SW4, SW7 and SW8) discussed later in this report. Larger amounts of cultivated lands regularly induce higher sediment loads due to reduced vegetative cover and soil tilling. One possible explanation for this discrepancy is the lack of topographic relief throughout the Upper Salinas subwatershed. With an average slope of less than 1º, the required energy to transport sediment in runoff may not be available. Figure 2.14 indicates the areas of greatest localized contributions of sediment, TN, TP and TSS.

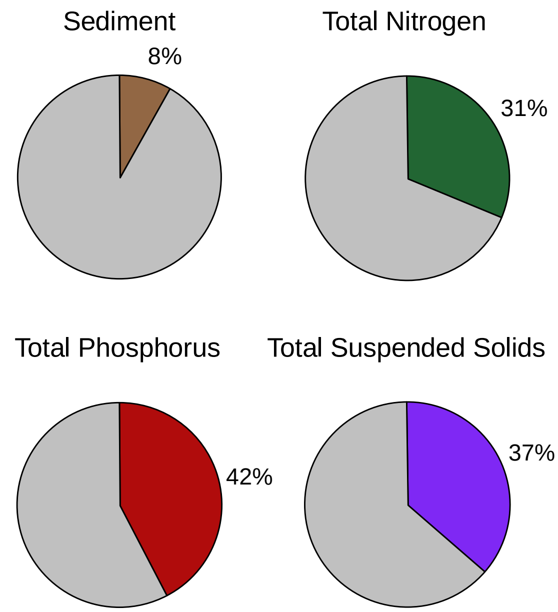

Figure 2.13. Upper Salinas subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

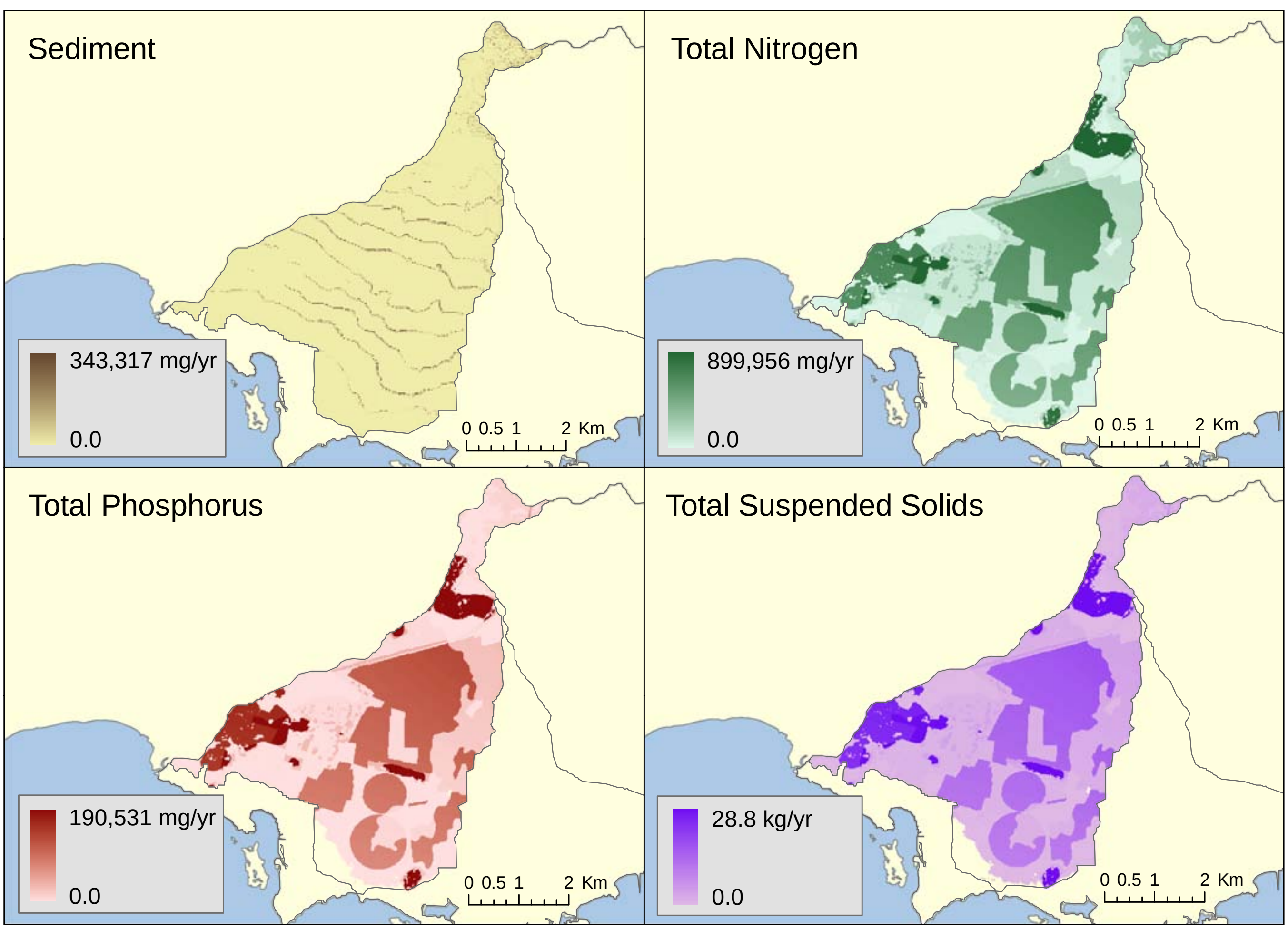

Figure 2.14. Localized annual pollutant contributions by grid cell in Upper Salinas. Sediment contributions are depicted along contour lines due to a failure in the digital elevation model's ability to describe this low relief coastal area as a continuous surface.

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SW 3 – Central Aguirre

The Central Aguirre subwatershed (SW3) has a total area of 16.5 km², one third of which is covered by intertidal lands. The northern reach of the basin begins just south of the convergence of Highways 52 and 53. It widens as it extends southward towards Jobos Bay until a long serpentine coastline of over 20 km forms the southern boundary of the watershed (Figure 2.16). Most of the coastline is formed by the Mar Negro wetland complex, but it also extends beyond the Central Aguirre waterfront and shipping port. Similar to many subwatersheds in Jobos Bay, the Central Aguirre subwatershed has no defined stream channels and as a result discharges surface waters to Jobos Bay at several locations.

A diversity of land cover types exist on the Central Aguirre subwatershed, including agriculture, industry, residential development, and natural forested and wetland areas. The dominant feature in the watershed is Mar Negro's mangrove forests and associated tidal waterways and mud flats. These wetlands are protected as part of the Jobos Bay National Estuarine Research Reserve. Mar Negro and another mangrove forest to its east comprise 32% of the subwatershed's land cover (Figure 2.15). Most of Central Aguirre subwatershed's 2,652 residents live in the coastal community adjacent to the industrial waterfront, however newer residential development exists in the northern portion of the watershed.

Central Aguirre has the second most cultivated land (3.2 km²) in the entire Jobos Bay watershed. Agriculture extends from the adjacent Upper Salinas subwatershed to cover a large portion of northern Central Aguirre subwatershed. USDA's ARS is conducting their 2007-2010 field studies with a cooperating farm site located directly north of Mar Negro. The farm, characterized by its circular shape due to its center pivot irrigation system, agreed to implement a series of agricultural conservation practices on their farm and facilitate ARS's monitoring of water quality on the farm.

The Central Aguirre waterfront and its surrounding lands host a variety of land use activities that may have significant impact on estuarine water quality. These activities are not adequately represented by a generalized land cover dataset, thus, warrant special mention. The Central Aguirre Golf Club is located 0.5 km from the Jobos Bay shoreline. Its land use classification as grassland may not sufficiently represent the load of nutrients and pesticides the golf course contributes to the watershed. In addition, a municipal landfill and deposit of dredge

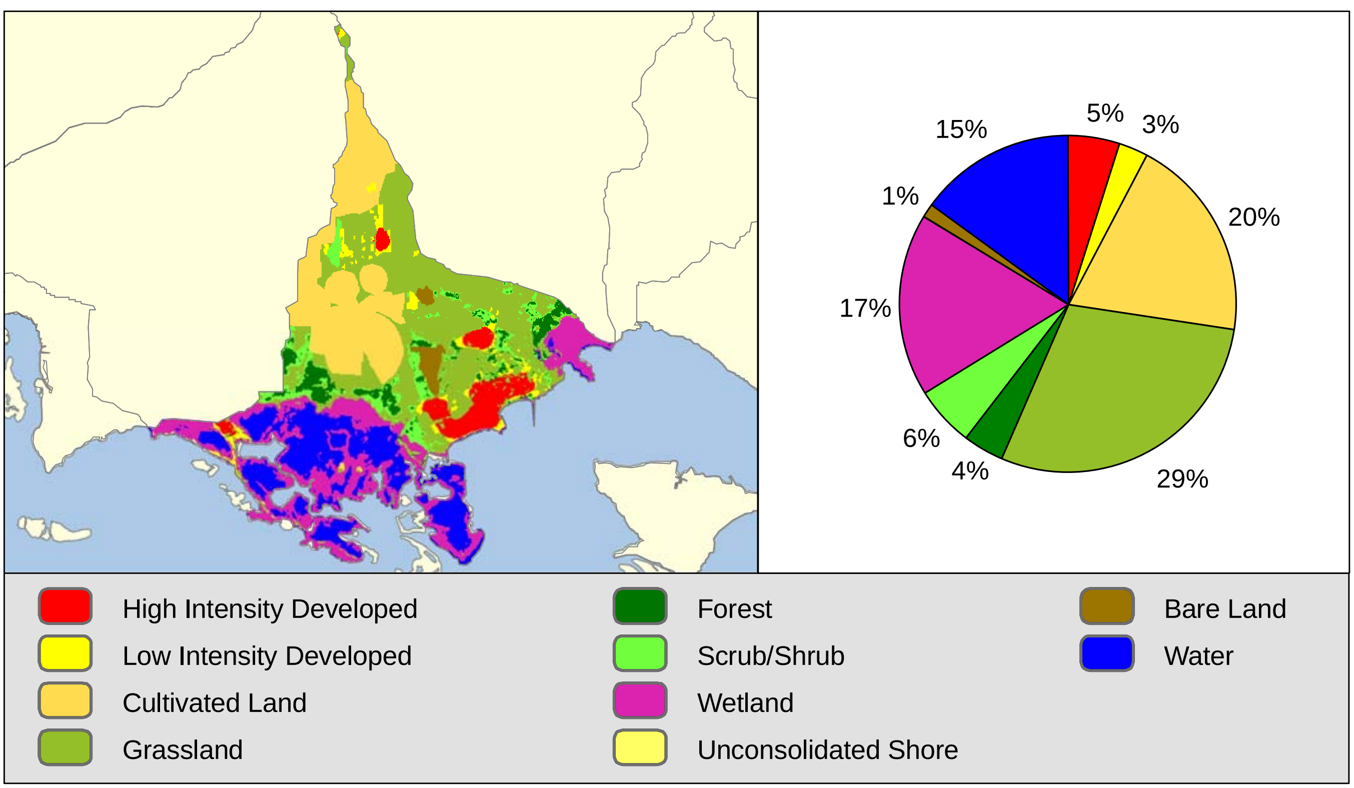

Figure 2.15. Spatial distribution and percent coverage of Central Aguirre land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

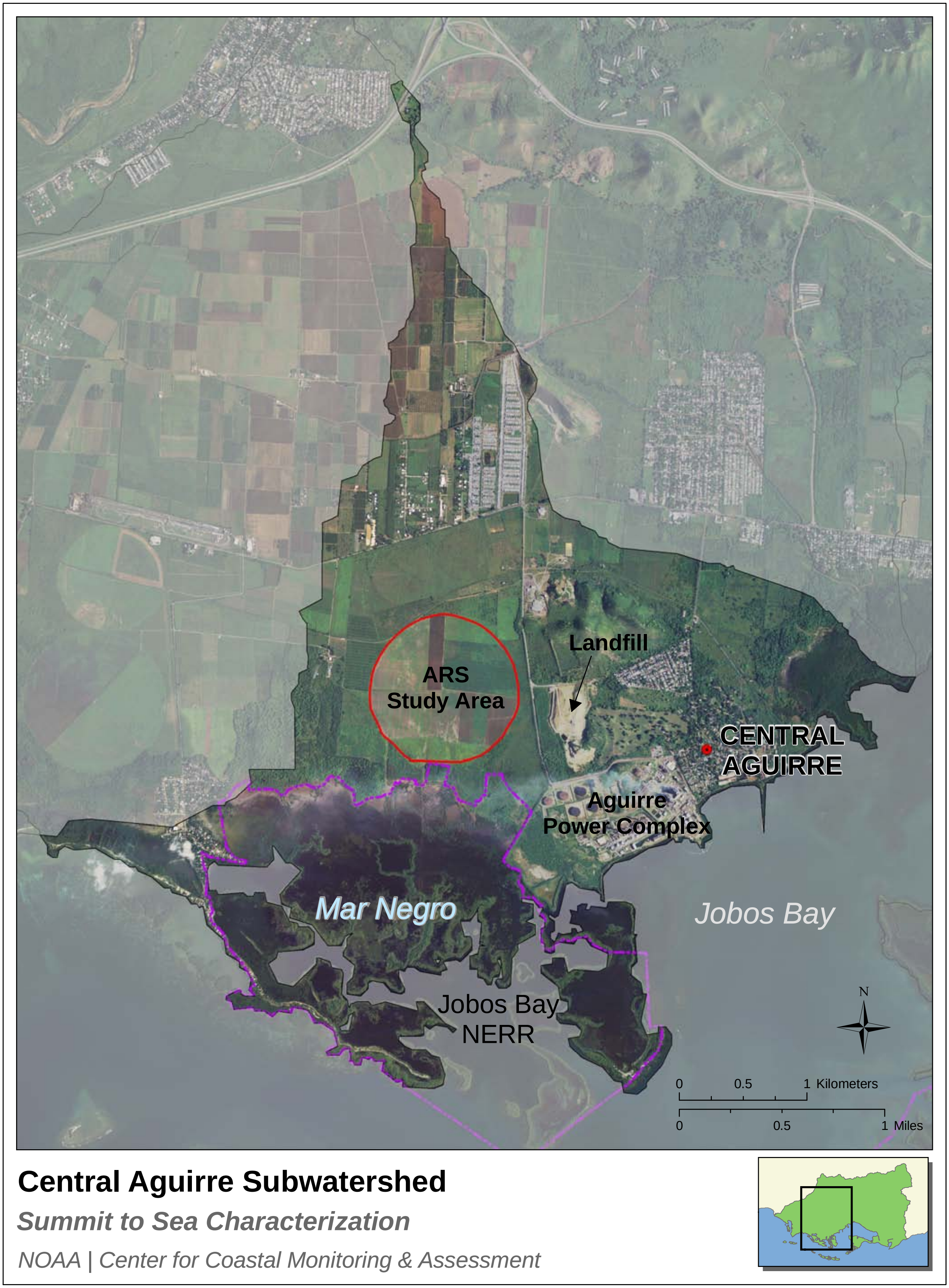

Figure 2.16. Central Aguirre subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

spoils from the Aguirre Navigational Channel are within 1.5 km of the shoreline. No information exists to describe what leaches from either of these bare soil features and how the pollutants interact with surface runoff or groundwater. The Puerto Rico Electric Power Authority's (PREPA) Aguirre Power Generating Complex is located just south of the landfill. This major industrial activity discharges cooling waters directly to Jobos Bay and has been the subject of extensive ecological research through the 1970's (PRWRA, 1972; PRNC, 1972; PREPA, 1983).

The Central Aguirre subwatershed had similar proportions of predicted loadings for sediment, TN, TP and TSS, but was not responsible for more than 10% of any pollutant discharged to Jobos Bay (Figure 2.17). The subwatershed was the fourth largest in area, but only a portion of its landscape was prone to pollutant-inducing land use types, such as agriculture and high intensity developed lands (Figure 2.18). Although this analysis did not account for the filtration capacity of wetlands, it should be noted that much of the watershed's agriculture occurred upstream of the Mar Negro wetland complex.

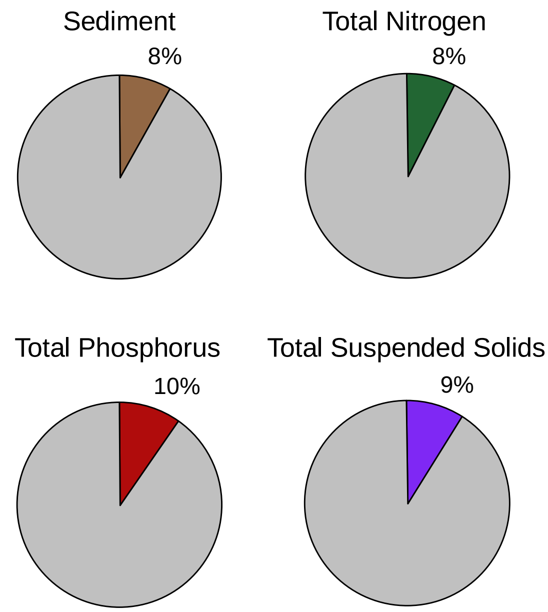

Figure 2.17. Central Aguirre subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

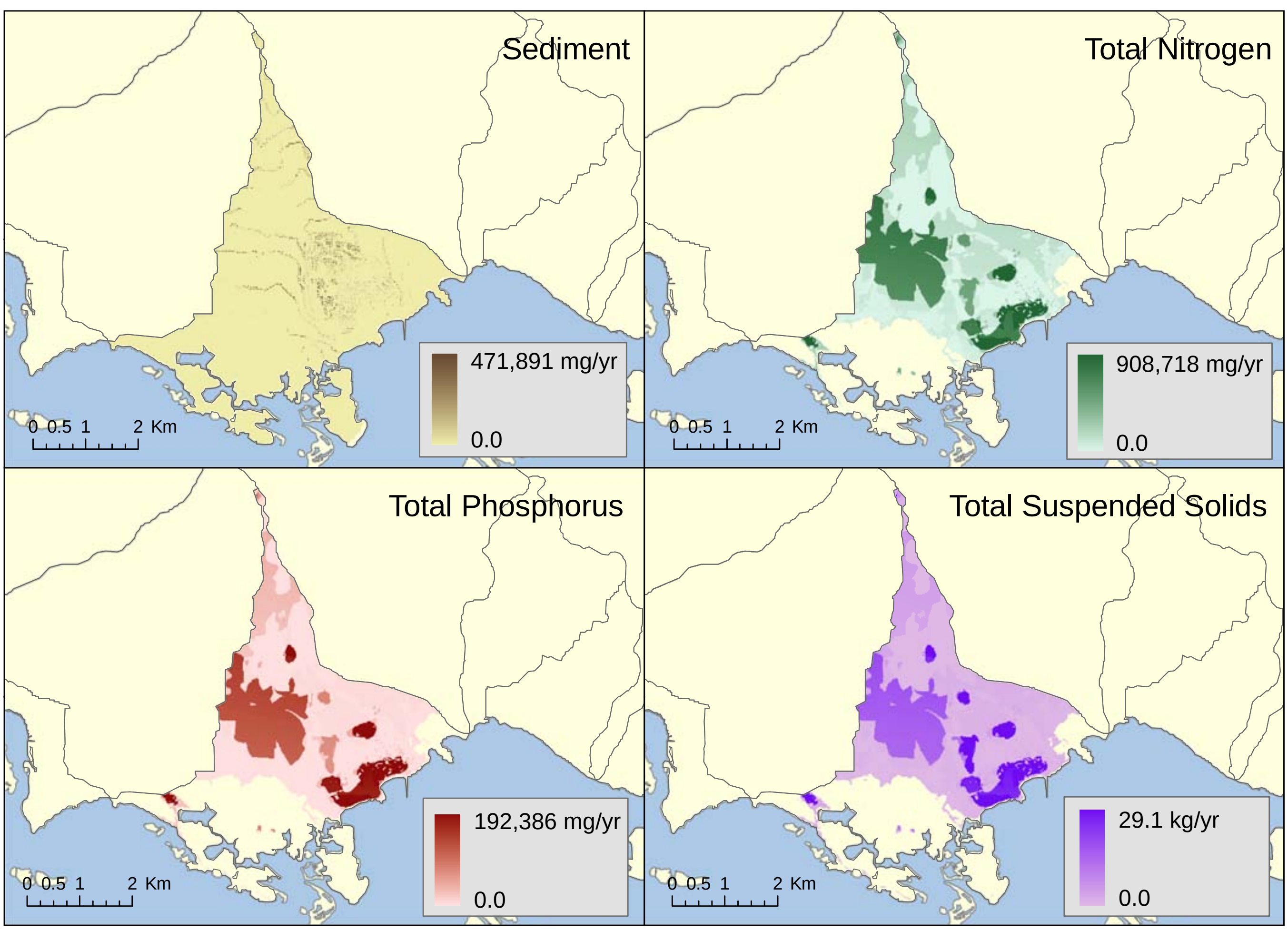

Figure 2.18. Localized annual pollutant contributions by grid cell in Central Aguirre.

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SW 4 – Quebrada Coquí

The Quebrada Coquí subwatershed (SW4) covers a total area of 24 km², making it the third largest subwatershed in the Jobos Bay watershed. Highway 53 divides the basin approximately in half and defines two distinct geographic and topographic areas within the subwatershed (Figure 2.20). The north is characterized by the foothills of La Cordillera Central mountain range, while the south is a continuation of the low-relief South Coastal plain.

Image 9. A typical sight line from the shore of Jobos Bay with mangroves in the foreground and mountains in the background. (Photo Credit: T. Potter, USDA-ARS)

The Quebrada Coquí subwatershed is distinguished from most other subwatersheds in the study area by the presence of two perennial streams. The primary stream channel, Quebrada Coquí, runs out of the mountain foothills and along the western side of the subwatershed. Quebrada Aguas Verdes drains a small area of the eastern subwatershed and joins Quebrada Coquí just before it discharges into Jobos Bay. A 1 km² mangrove basin forest, extending across several subwatersheds (SW3, SW4, SW5 and SW6), is formed by stream discharge at the subwatershed's southern edge.

The landscape of Quebrada Coquí subwatershed is dominated by grassland and scrub/shrub growth, 76% and 11% respectively (Figure 2.19). Much of the grassland in the north is presumed to be undisturbed natural vegetation around the foothills. However, the trend of historically cultivated land conversion to grassland is much more prevalent in the south of the watershed closer to the agricultural fields of Upper Salinas. Another type of cultivated land conversion in the Jobos Bay watershed is to residential development. Coquí, the only residential

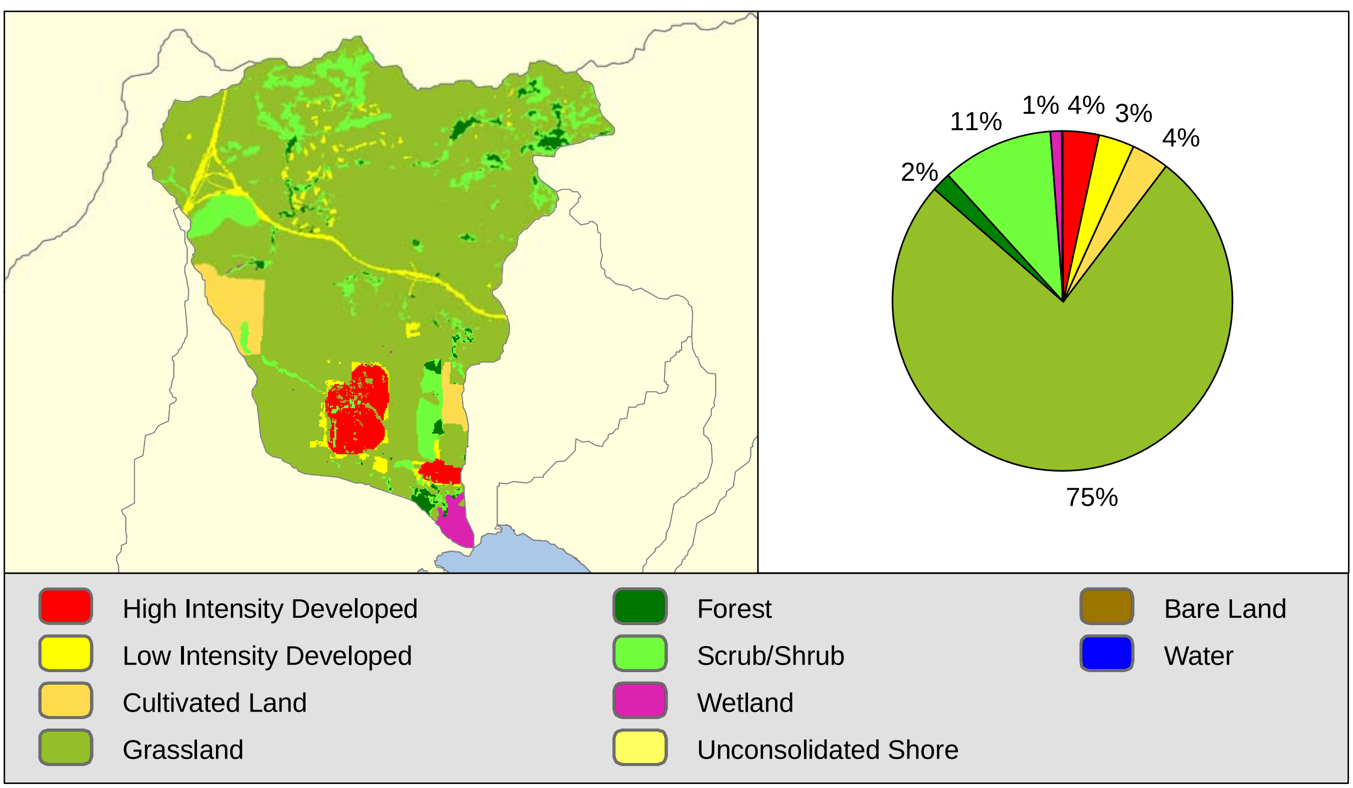

Figure 2.19. Spatial distribution and percent coverage of Quebrada Coquí land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

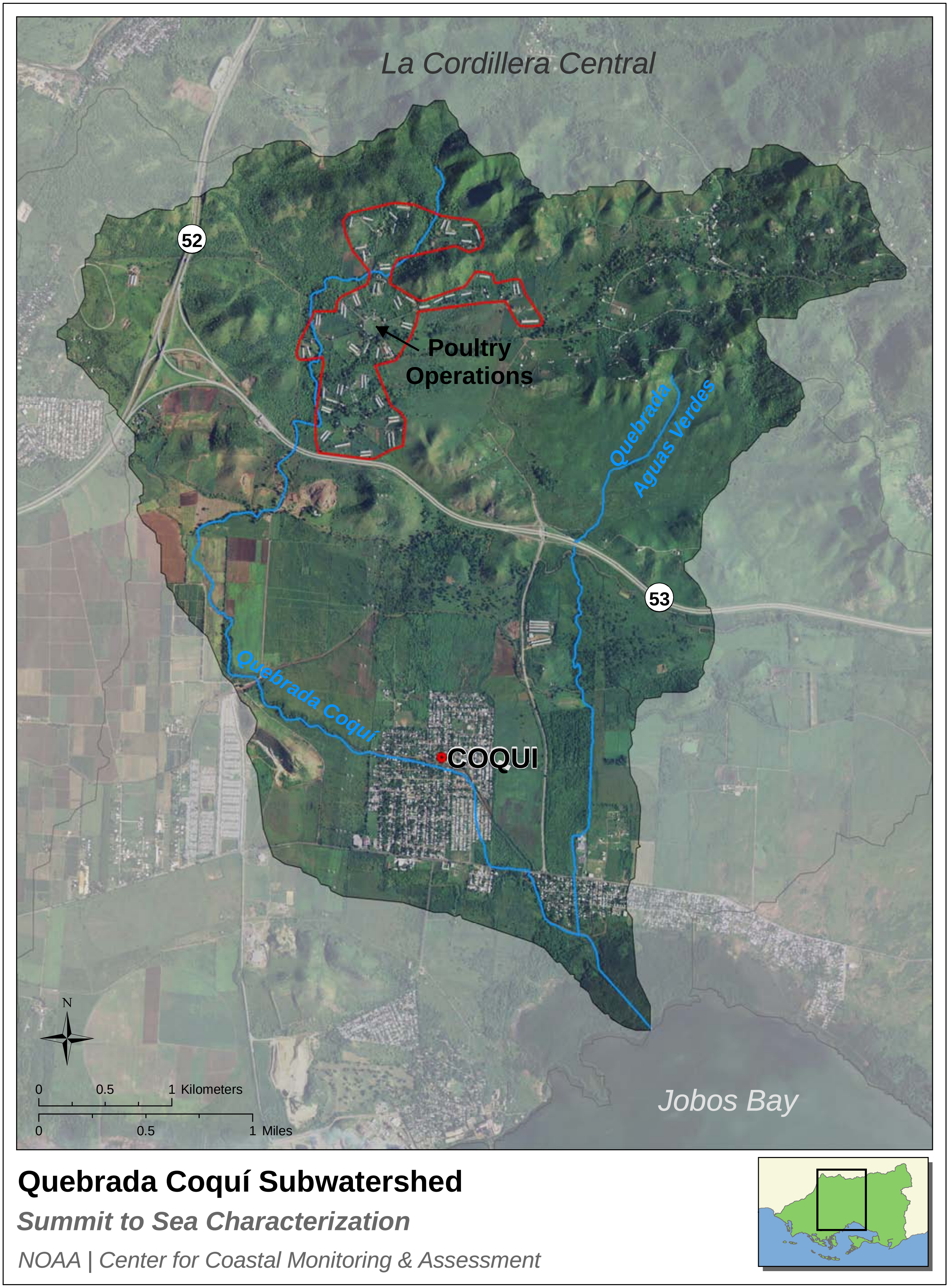

Figure 2.20. Quebrada Coquí subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

community in the subwatershed, hosts a population of just under 5,000 residents in a 1.2 km² area. The community is compactly developed with an average road density of 16 km/km² and is served by a public sewer system.

Although there is only limited cultivated land in the subwatershed, an extensive confined feeding operation exists in the foothills north of Highway 53. During 2002, an estimated 29 poultry farms, with 2 houses per farm, were concentrated in a 1.3 km² area. Roubert (2001) reported that this aggregation of poultry farms produced 1.8 million chickens per year. Additionally, a small cattle farm operates just north of Coquí.

The Quebrada Coquí subwatershed contributed substantial predicted loadings for all four pollutants assessed in this analysis. Figure 2.21 displays the predicted loading percentages and Figure 2.22 shows the source areas of pollutant contributions to Jobos Bay. Unlike any other subwatershed of Jobos Bay, SW4 contributed at least 15% of the total loadings for each pollutant.

Figure 2.21. Quebrada Coquí subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

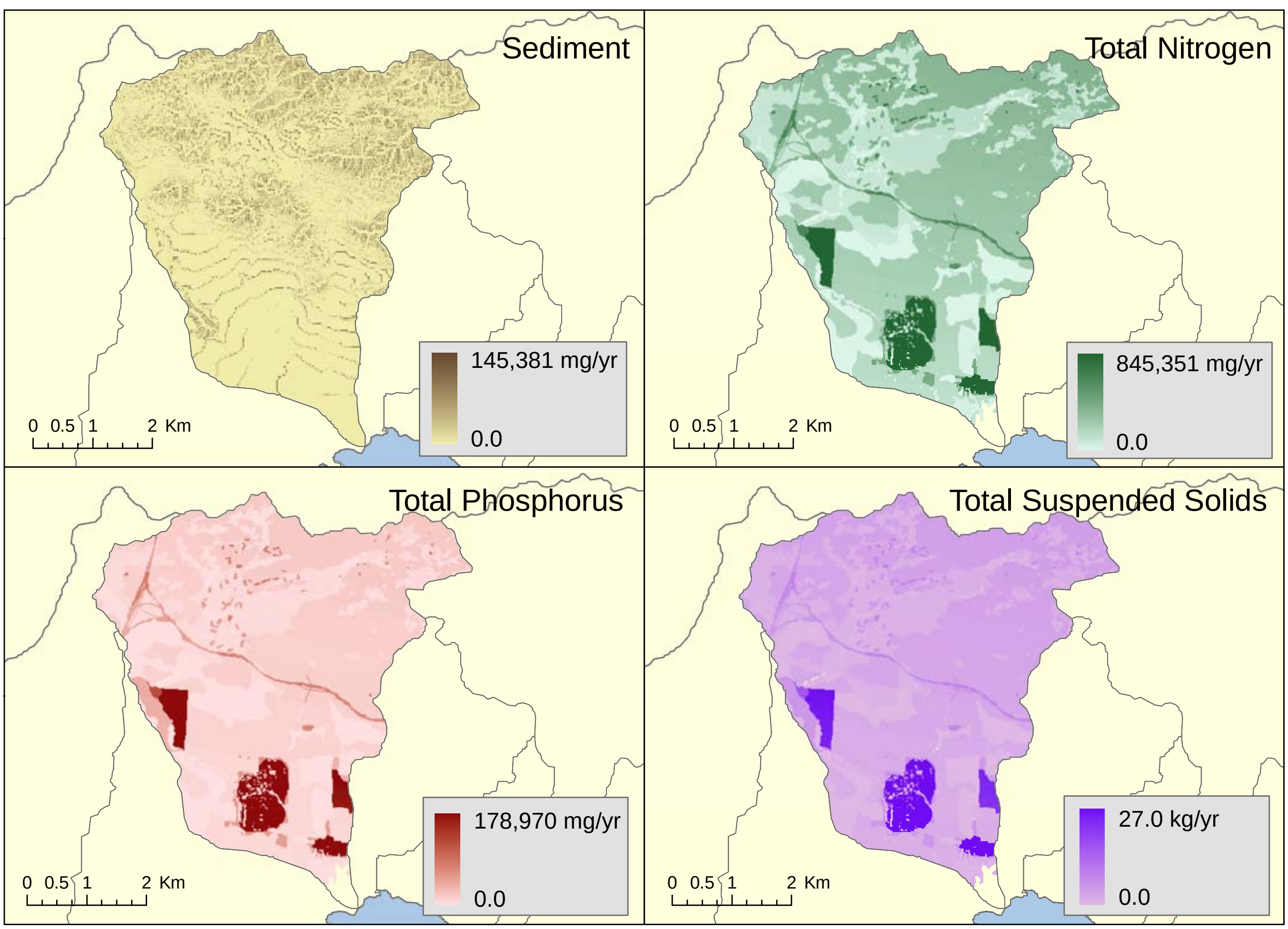

Figure 2.22. Localized annual pollutant contributions by grid cell in Quebrada Coquí.

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SW 5 – Quebrada Amoros

The Quebrada Amoros subwatershed (SW5) is the largest area, 7.4 km², of the four smaller subwatersheds in the Jobos Bay drainage basin. Quebrada Amoros subwatershed, along with SW1, SW6 and SW9, has a considerably smaller catchment area than the other five subwatersheds of the study area. The subwatershed boundaries are defined by areas of the landscape that drain to the Quebrada Amoros stream channel (Figure 2.24). Quebrada Amoros is an intermittent stream that delivers water to Jobos Bay during periods of elevated surface water runoff.

Image 10. Example of grassland re-growth on a recently tilled field. (Photo Credit: T. Potter, USDA-ARS)

The Quebrada Amoros subwatershed has the most homogeneous composition of land cover types in the entire Jobos Bay watershed. Grassland covers 84% of the subwatershed, while no other land cover type composes more than 3.5% of the landscape (Figure 2.23). Similar to SW4, the grasslands of the north are naturally vegetated around the foothills, but those grasslands on the coastal plain have been re-vegetated since past agricultural usage was ended. A fraction of the grasslands north of Highway 53 are pasture lands used for cattle grazing.

The subwatershed has the smallest amount of developed land cover totaling less than 0.5 km² of residential development. With 131 residents/ km², only one other subwatershed of Jobos Bay has a lower population density (SW7). One addition to the small extent of built environment in the subwatershed is the presence of a golf course on the eastern boundary. The course straddles the divide between the Quebrada Amoros subwatershed and SW6; as a result it contributes to both subwatersheds' pollutant loadings.

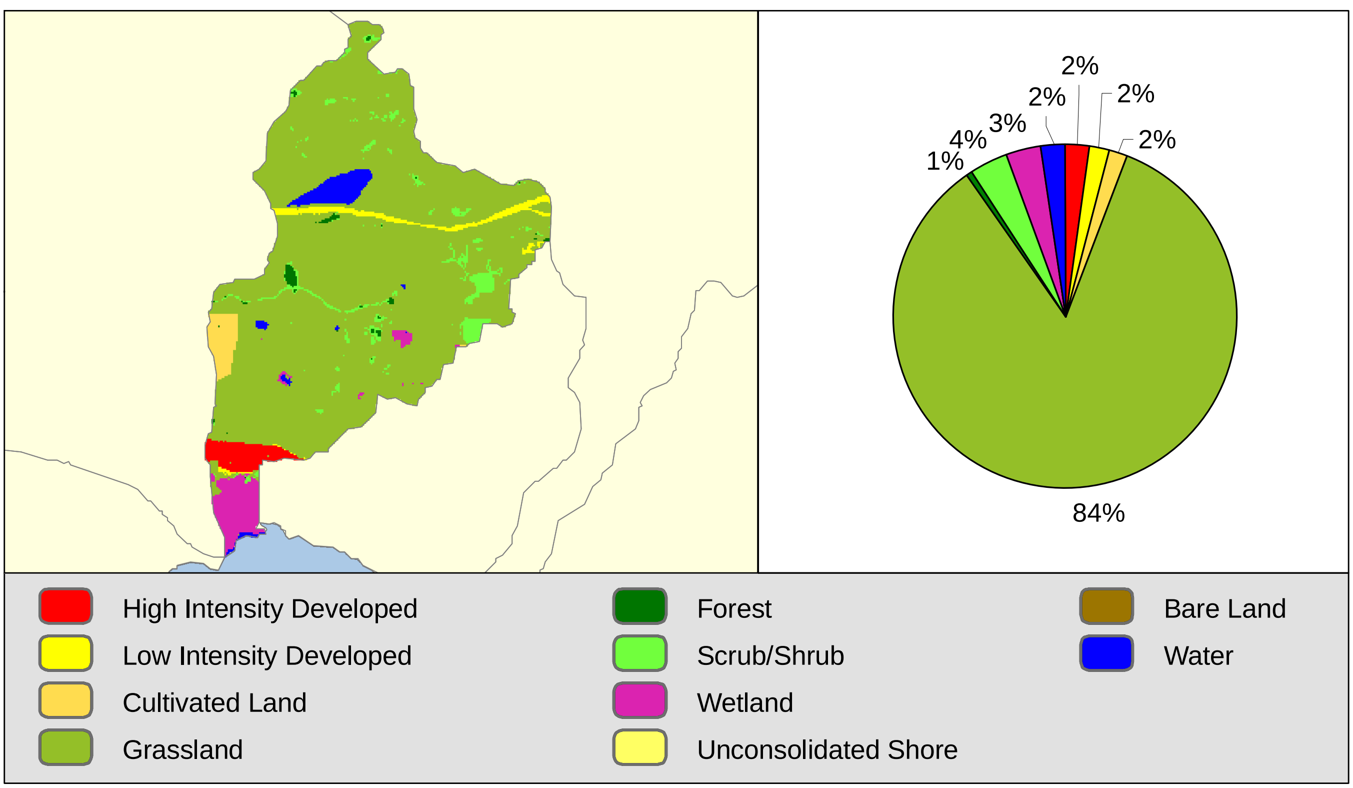

Figure 2.23. Spatial distribution and percent coverage of Quebrada Amoros land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

Quebrada Amoros Subwatershed

Summit to Sea Characterization

NOAA | Center for Coastal Monitoring & Assessment

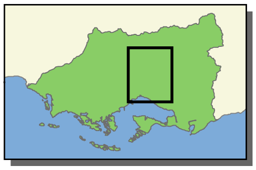

Figure 2.24. Quebrada Amoros subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

Figures 2.25 and 2.26 show information on the pollutant loadings of the Quebrada Amoros subwatershed to Jobos Bay. Predicted pollutant loads are not substantial compared to the other subwatersheds, which is expected due to the small basin size and lack of human activity on the landscape.

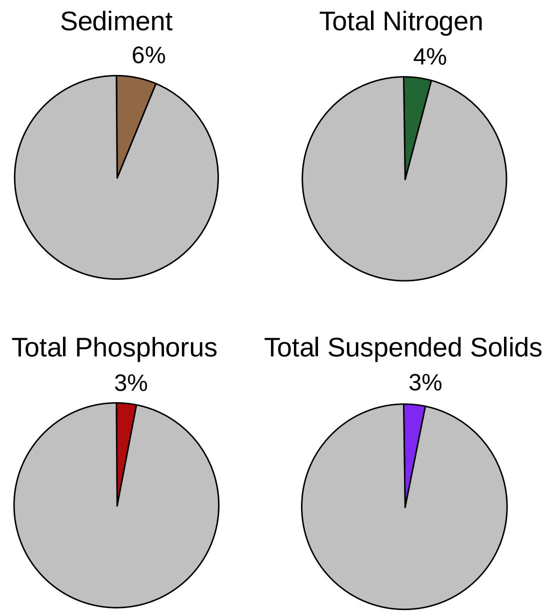

Figure 2.25. Quebrada Amoros subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids..

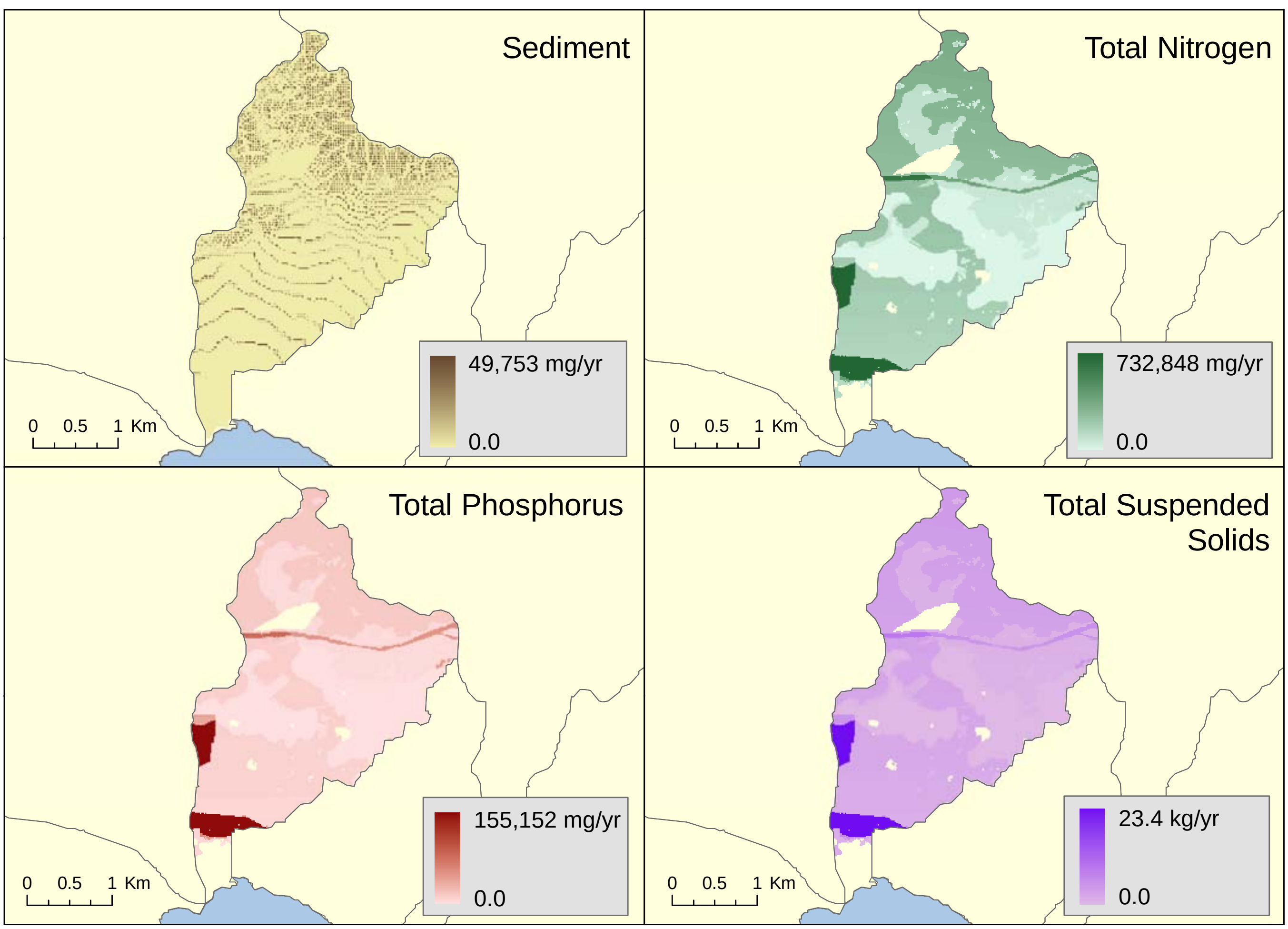

Figure 2.26. Localized annual pollutant contributions by grid cell in Quebrada Amoros.

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SW 6 – Northern Bay

The Northern Bay subwatershed (SW6) covers 4.8 km² of land that borders Jobos Bay's northern coastline. The subwatershed's upstream reach begins just south of Highway 53 and broadens as it extends southward. At the basin's seaward boundary, approximately 2.5 km of shoreline defines the southern edge of the subwatershed. The subwatershed is further described in the east by the drainage divide between the Northern Bay subwatershed and the catchment of Río Seco (Figure 2.29).

The Northern Bay subwatershed has no defined permanently or temporarily flooded stream channels. Instead, networks of intermittently flooded wetlands in the form of narrow flood plains are spread throughout the center of the basin. These formations are commonly a result of periodic overland sheet flow through sparsely vegetated landscapes. A combination of bare soil, grass and shrubs characterize these areas in irregular-shaped bands running parallel to the flow direction. SW6 is the only subwatershed where these types of intermittently flooded wetlands occur. With a lack of a primary stream network, flow to Jobos Bay is by way of several distributed points of discharge.

Figure 2.27. Periodic clearing of agricultural lands not in production between 2004 (USDA, 2004) and 2007 (USACE, 2007).

A variety of land cover types are present on the Northern Bay subwatershed landscape (Figure 2.28). Grassland is again the dominant land cover at 56% of the subwatershed, but other vegetated types such as scrub/shrub and wetlands account for 11% and 14% of the landscape, respectively. Two distinct wetland types exist in the subwatershed, one of which is discussed above. The primary wetland aggregation is a long strip of mangrove that narrows as it extends from SW5 to the mouth of Río Seco. This mangrove forest borders the entire stretch of the Northern Bay's shoreline, forming a buffer between Jobos Bay and all upland activities.

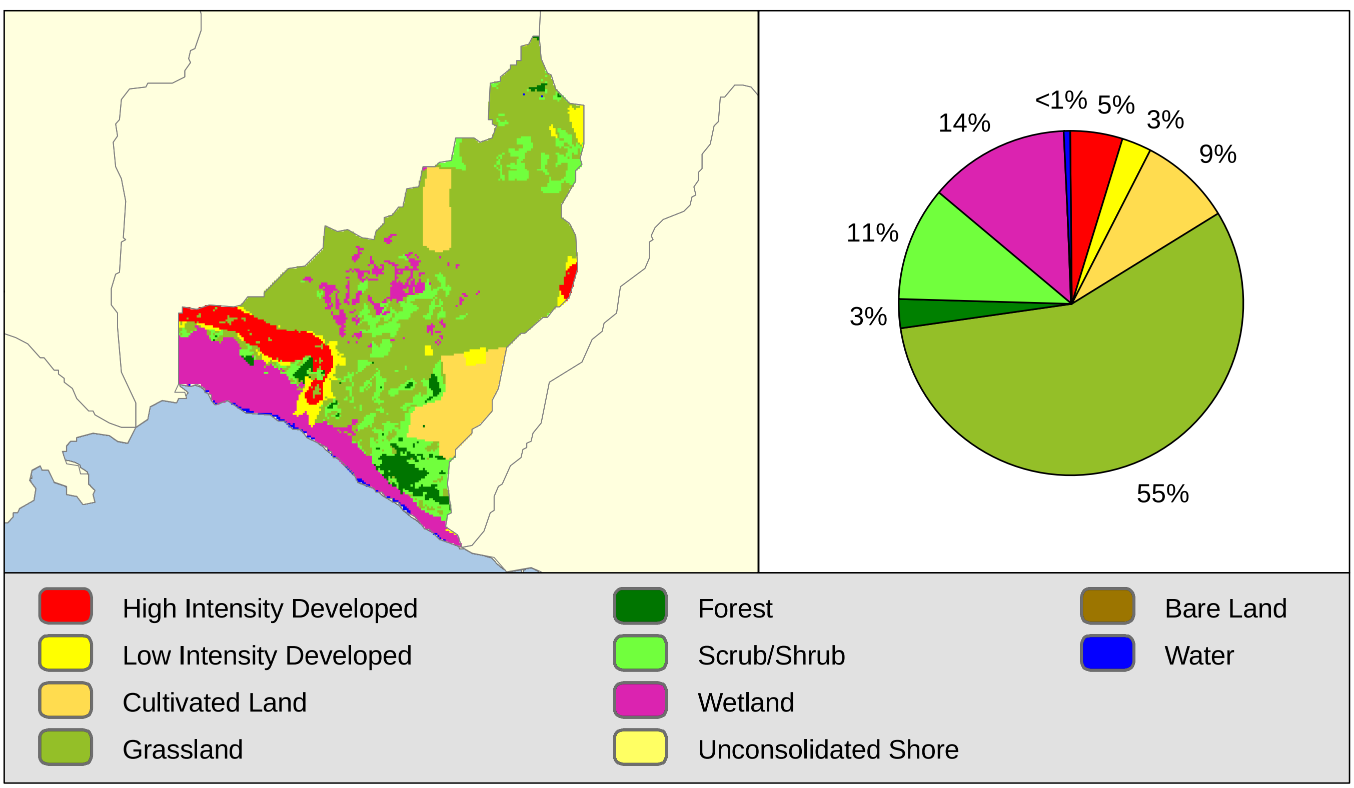

Figure 2.28. Spatial distribution and percent coverage of Northern Bay land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

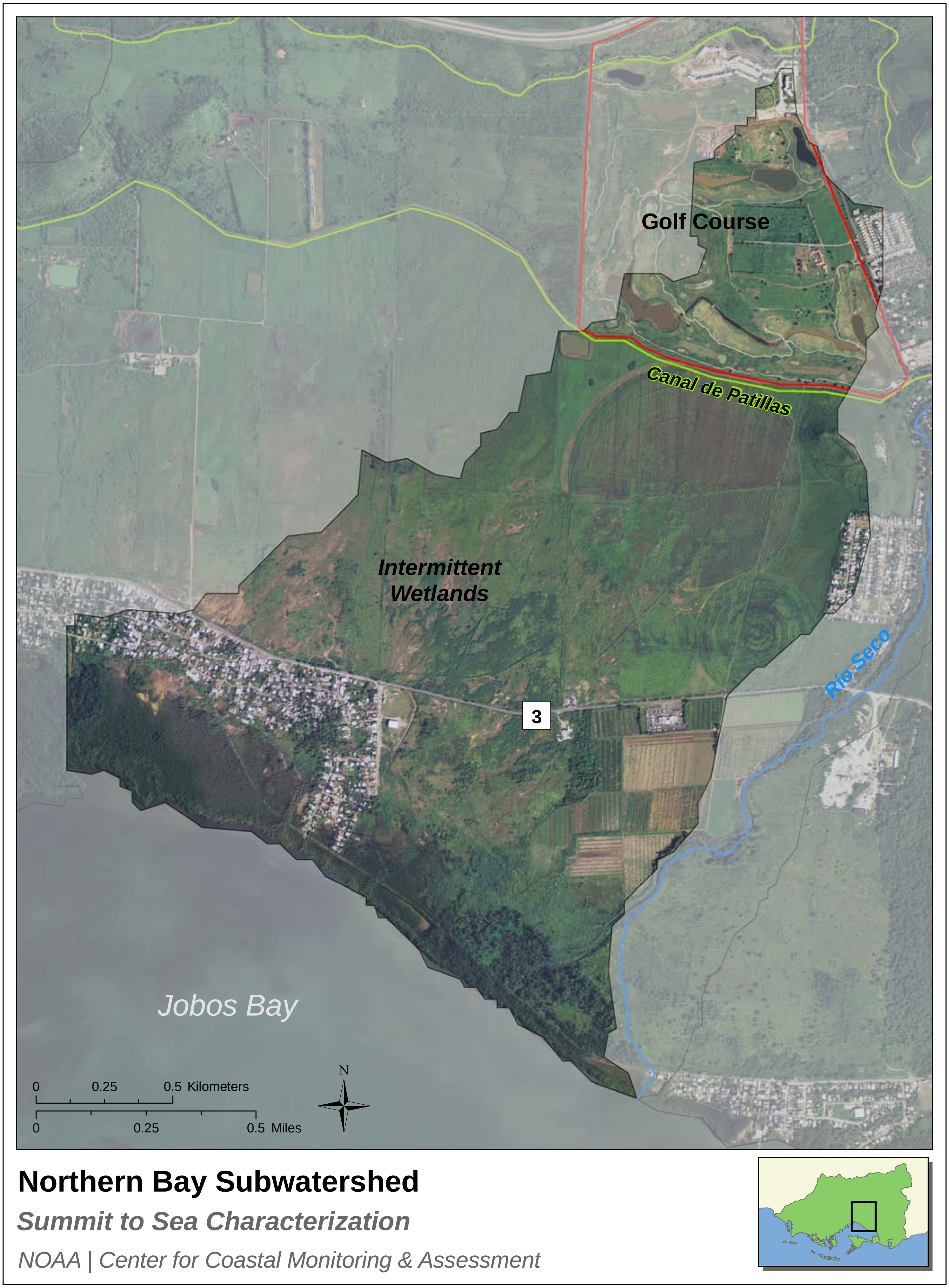

Figure 2.29. Northern Bay subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

Cultivated lands represent a small amount of land cover, 9% of the subwatershed's area, but have the potential to increase in proportion. Just south of Canal de Patillas are three center pivot irrigation systems not currently in production. However, a review of 2004 and 2007 aerial photography revealed that these fields were subject to periodic clearing without commercial planting (Figure 2.27). If placed into production, cultivated land in the Northern Bay subwatershed could triple from the current 0.4 km².

The subwatershed has some urban development which is comparable to other subwatersheds with a population density and road density just above the Jobos Bay means for these metrics. A residential development is located along Route 3 in the southwest corner, comprising 8% of SW6. A portion of the golf course in the northern-most reach of the basin is represented in the land cover dataset as grassland, but may be more reflective of row crop agriculture due to nutrient and pesticide application.

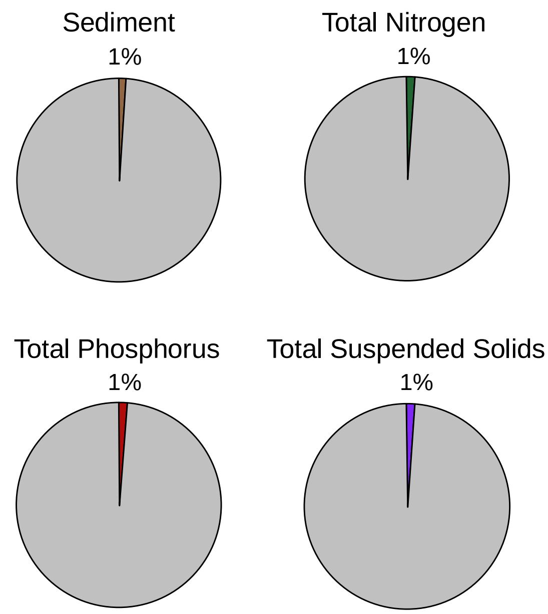

Figure 2.30. Northern Bay subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

Under existing land cover conditions, the Northern Bay subwatershed contributes only 1% of the total loads for each of the pollutants assessed in this study (Figure 2.30). Wetland areas and growth of woody vegetation, such as forest and shrubs, maintain these low values of pollutant loads in the Northern Bay subwatershed (Figure 2.31).

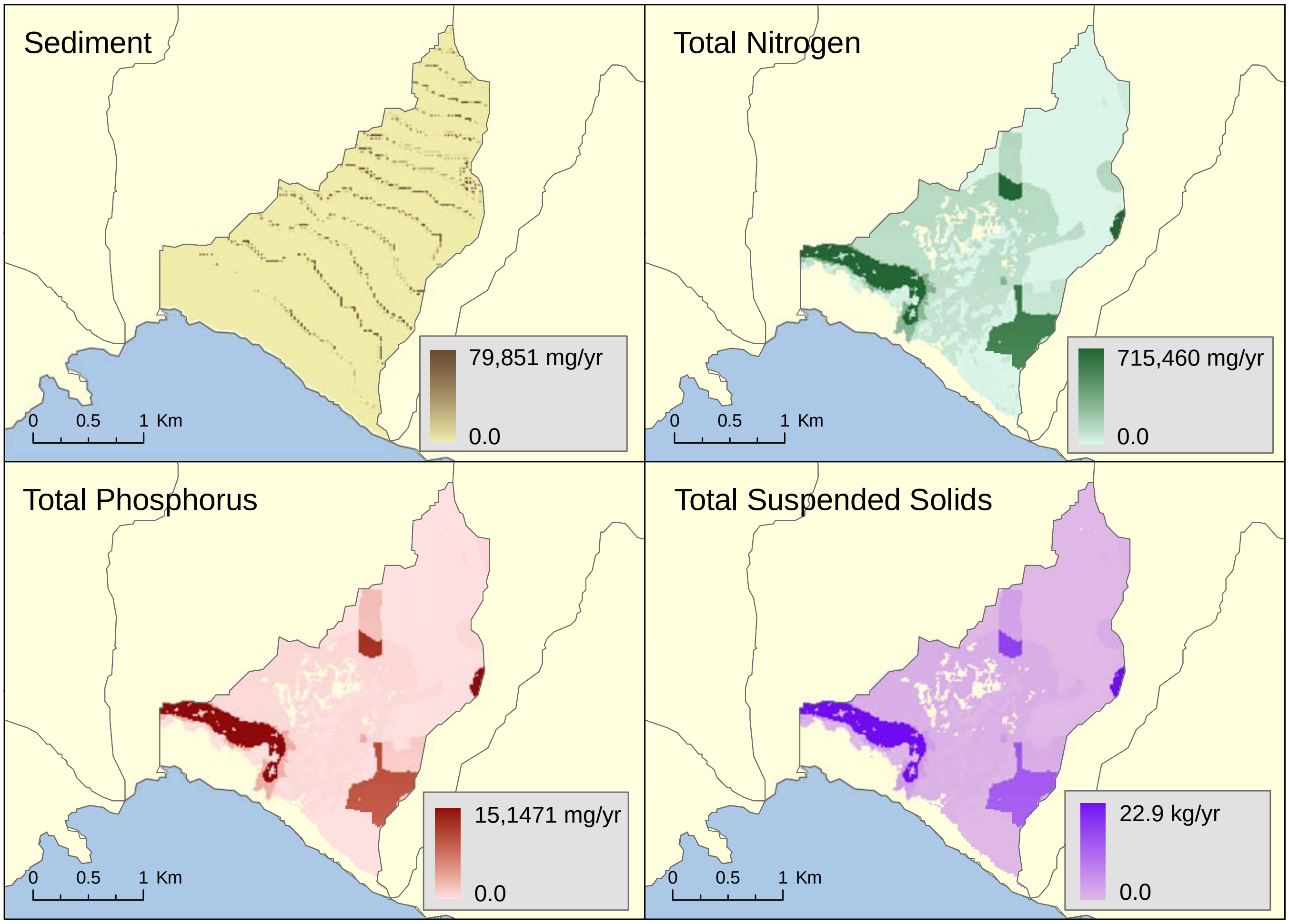

Figure 2.31. Localized annual pollutant contributions by grid cell in the Northern Bay.

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SW 7 – Río Seco

The Río Seco subwatershed (SW7), encompassing 29.5 km², is the largest delineated sub-unit of the Jobos Bay watershed. The Río Seco subwatershed is the northern most reaching subwatershed, and as a result includes terrain unique to that of the other subwatersheds in the study area (Figure 2.33). Unlike most other areas of the Jobos Bay watershed, the subwatershed is described by the well-defined drainage network of Río Seco and its associated tributaries. The Río Seco is the only major river system that discharges directly into Jobos Bay throughout the year. The headwaters of the river begin 3 km to 5 km into the foothills of the La Sierra de Cayey mountain range. The subwatershed's northern boundary is formed by the drainage divide between Río Nigua and Río Seco tributaries. As smaller streams converge and form Río Seco, the subwatershed narrows to a width of 0.5 km at its ultimate discharge into Jobos Bay.

Highway 53 partitions the subwatershed into two distinct zones characterized by different topography, ecology and land cover. The northern portion, constituting 85% of the Río Seco subwatershed, is located in the foothills of the La Sierra de Cayey mountain range. The highest elevation throughout the entire study area, 715 m (2,346 ft), is reached along the northern boundary of the subwatershed. The higher elevations in the north are subjected less to the orographic effects that maintain a semi-arid climate in the majority of the Jobos Bay watershed. Precipitation ranges in the northern section (130 -175 cm/yr) are substantially more than that of the southern section (95 - 130 cm/yr) of the Río Seco subwatershed. As a result, the northern portion is at the transition between the Subtropical Dry and Subtropical Moist ecological life zones, while the remainder of Jobos Bay lies completely in the Subtropical Dry zone (Ewel and Whitmore, 1973).

The rugged landscape of the Río Seco subwatershed does not allow many of the land uses that are prevalent throughout the Jobos Bay watershed. The subwatershed's average topographic slope is 17º and is almost triple that of the next steepest subwatershed, SW4's 6º slope. However, south of Highway 53 is a 4 km² strip of the subwatershed with a terrain more comparable to the majority of the Jobos Bay watershed that permits typical land use development.

The Río Seco subwatershed is the most pristine basin in the study area with 97% of the total area being covered by vegetation (Figure 2.32). Uncommon in most of Jobos Bay watershed, the forested lands in the mountainous foothills populate 14.8 km² of the 29.5 km² (50% of the subwatershed). There are natural scrub/shrub and grass-

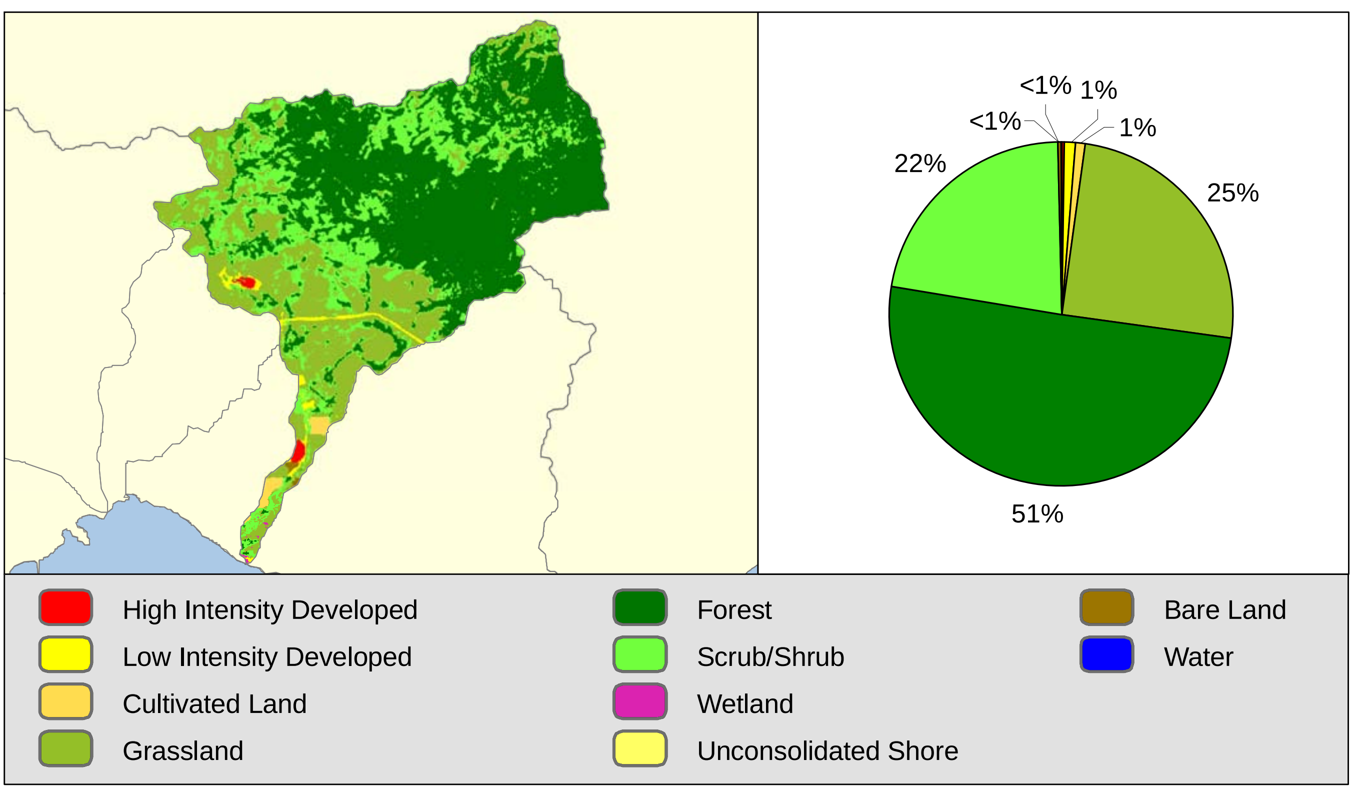

Figure 2.32. Spatial distribution and percent coverage of Río Seco land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

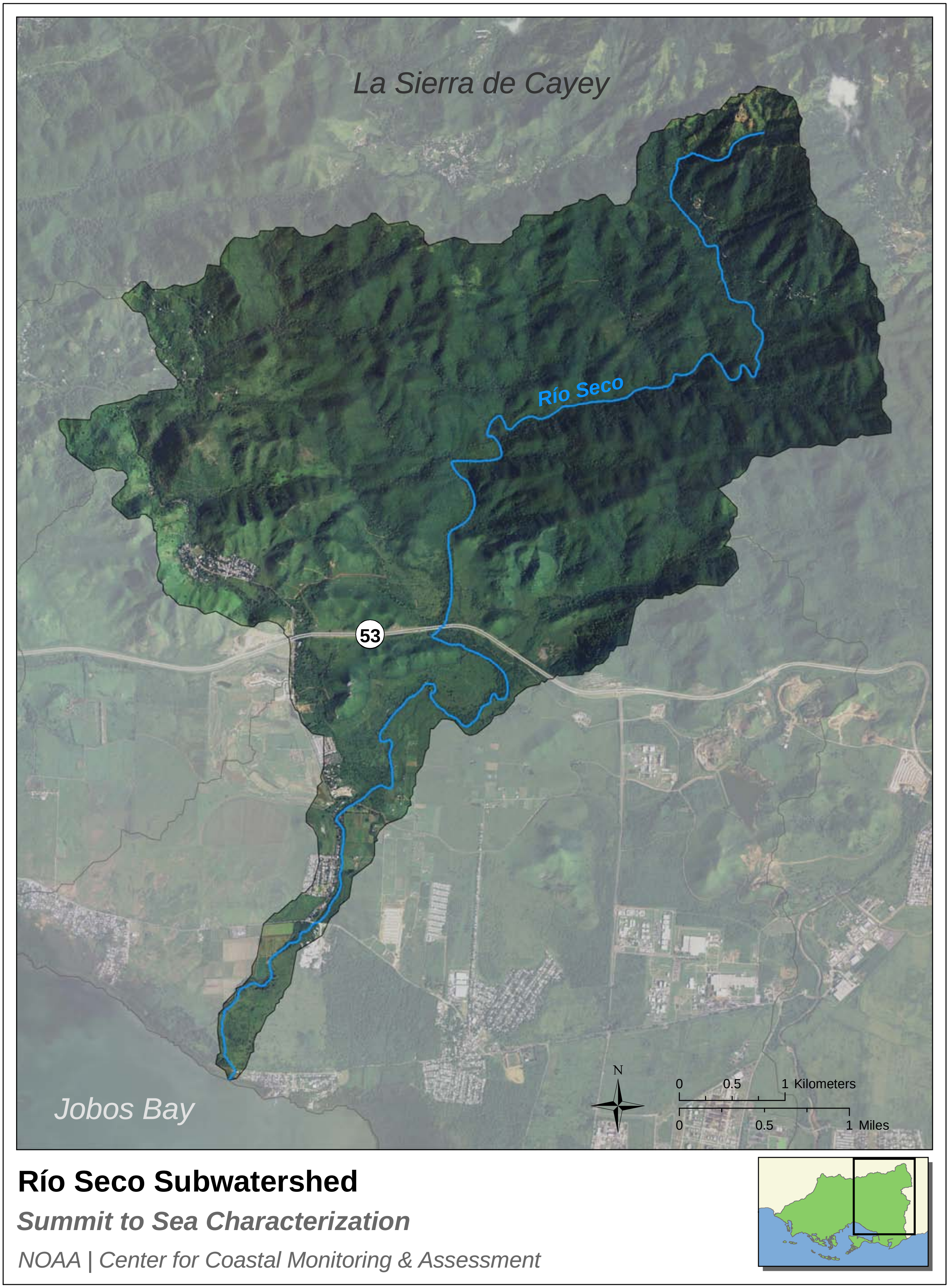

Figure 2.33. Río Seco subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

land extensions from the adjacent deciduous forests on an additional 22% and 25% of the area, respectively.

Developed lands, including both residential and agricultural, make up just over 2% of the total land cover in the subwatershed combined. Urban development, with the exception of two small residential communities, is almost non-existent in the basin. This area has the lowest population density (33 people/km²) in Jobos Bay with a total of 988 residents. Furthermore, the subwatershed has the lowest road density in the study area (2.4 km/ km²). Extensive areas north of Highway 53 are without roads and offer little potential for future development until the infrastructure is first built.

Considering Río Seco is the only major river system in the Jobos Bay watershed, the subwatershed has the highest modeled delivery of surface runoff to Jobos Bay (Appendix B). Additionally, the Río Seco subwatershed is predicted to deliver the highest sediment loads in the study area (Figure 2.34). This can be explained by the presence of the mixed-relief foothills in a large portion of the subwatershed's northern reach (Figure 2.35). Increased precipitation, as well as steeper slopes, facilitate the removal of sediment from the landscape during storm events. On the other

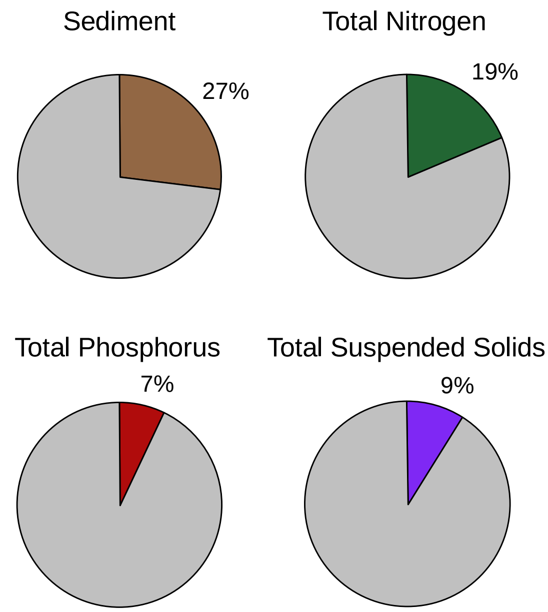

Figure 2.34. Río Seco subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

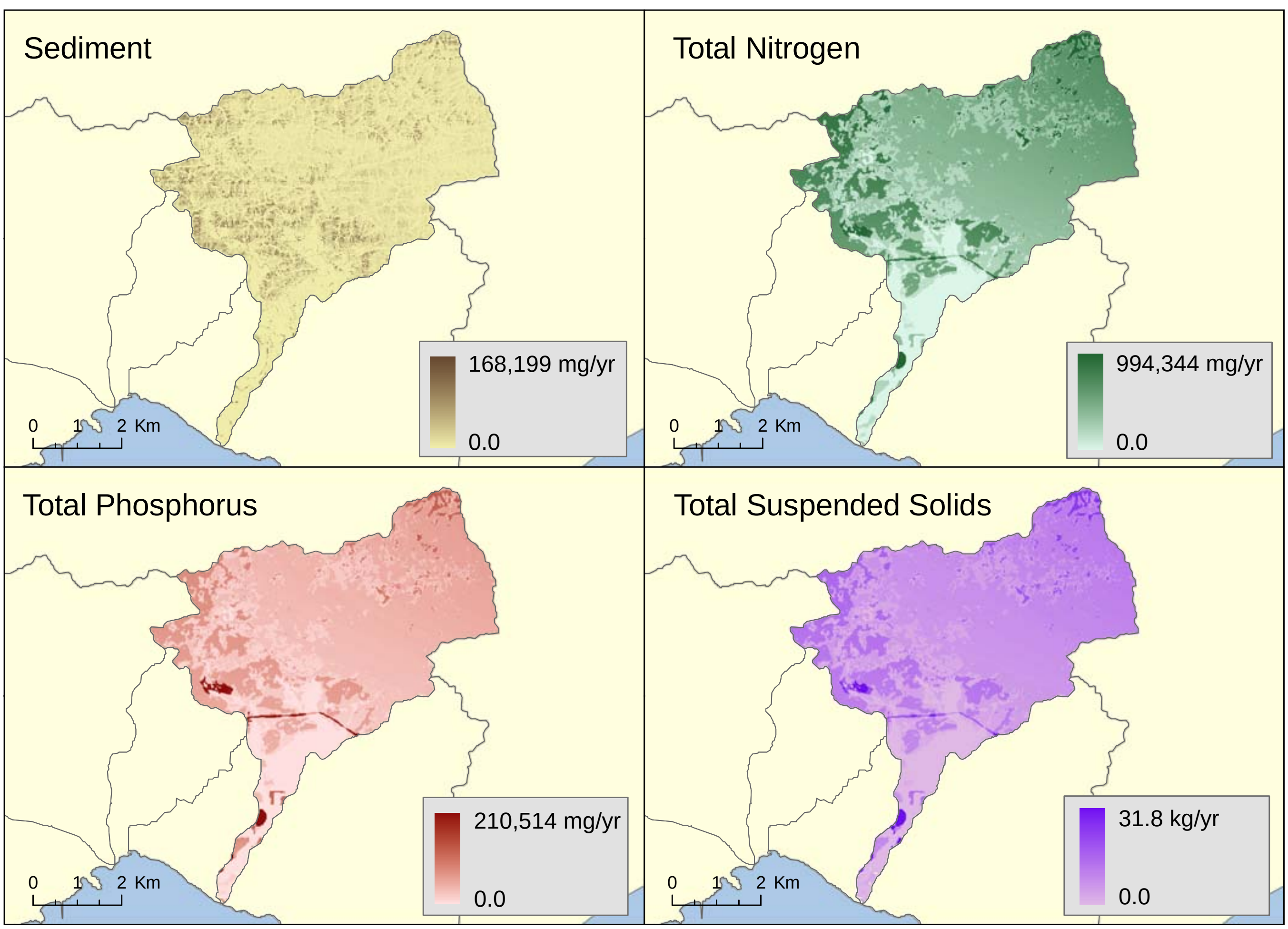

Figure 2.35. Localized annual pollutant contributions by grid cell in Río Seco.

hand, TP, TSS and to a lesser degree TN loads are all considerably lower than would be expected based on run-off volume alone. The subwatershed was responsible for 7% of TP and 9% of TSS, both substantially less than the three other subwatersheds of comparable size (SW2, SW4 and SW8). This is a function of the presence of naturally vegetated landscapes and lack of pollutant inducing anthropogenic activity in the subwatershed.

SW 8 – Barrio Jobos

The Barrio Jobos subwatershed (SW8) encompasses a total area of 25.7 km^2 on the eastern edge of the larger Jobos Bay watershed. The subwatershed's eastern boundary is formed by the drainage divide between the Jobos Bay watershed and the catchment area of Río Guamaní; while Río Seco's drainage divide defines the western boundary (Figure 2.37). Its landward reach begins just north of Highway 53 in the low foothills of La Sierra de Cayey. A portion of the runoff generated in the foothills is stored in Lago Melanía before it is distributed out of the subwatershed by the Canal de Patillas irrigation channel. A series of intermittently flooded streams, including Quebrada Melanía, carry surface waters to man-made drainage canals that empty into Jobos Bay's eastern-most shoreline.

The Barrio Jobos subwatershed has the most even distribution of land cover types in comparison to the other subwatersheds of Jobos Bay. No single land cover dominates any portion of the basin. The patchy landscape has several aggregations of each land cover classification at different locations in the basin (Figure 2.36). Vegetated cover types prevail in the area with grassland, scrub/shrub, forest and wetland accounting for 80% of the total coverage. Although present in the west, cultivated lands only make up 1% of the subwatershed's total area.

Developed lands in the Barrio Jobos subwatershed comprise 15% of the total area, most of which are high intensity development. High intensity developed lands in the subwatershed are one of two types; residential or industrial. Puerto Jobos on the Jobos Bay coast and, to the east, Barrio Jobos district of Guayama are the only two residential communities in the subwatershed. Their combined population of 5,705 residents is the largest and only substantial residential community on the eastern side Jobos Bay. The Barrio Jobos subwatershed residential and industrial development is supported by the third highest road densities in the entire study area, behind SW1 and SW2. In addition, the municipality of Guayama operates a landfill adjacent to Lago Melanía in the northern reach of the subwatershed.

The most prominent land use features in the Barrio Jobos subwatershed are a diverse range of industrial activities. There are two centers of activity on the east edge of the subwatershed with related industries aggregated together. The northern center is home to several major pharmaceutical and chemical facilities owned by Colgate-Palmolive, Baxter Caribe and Ayerst-Wyeth. Less than 1 km south is a complex of energy-related industries that are located near the coastline bordering the Caribbean Sea. Chevron Phillips operates a petroleum refinery to produce gasoline from

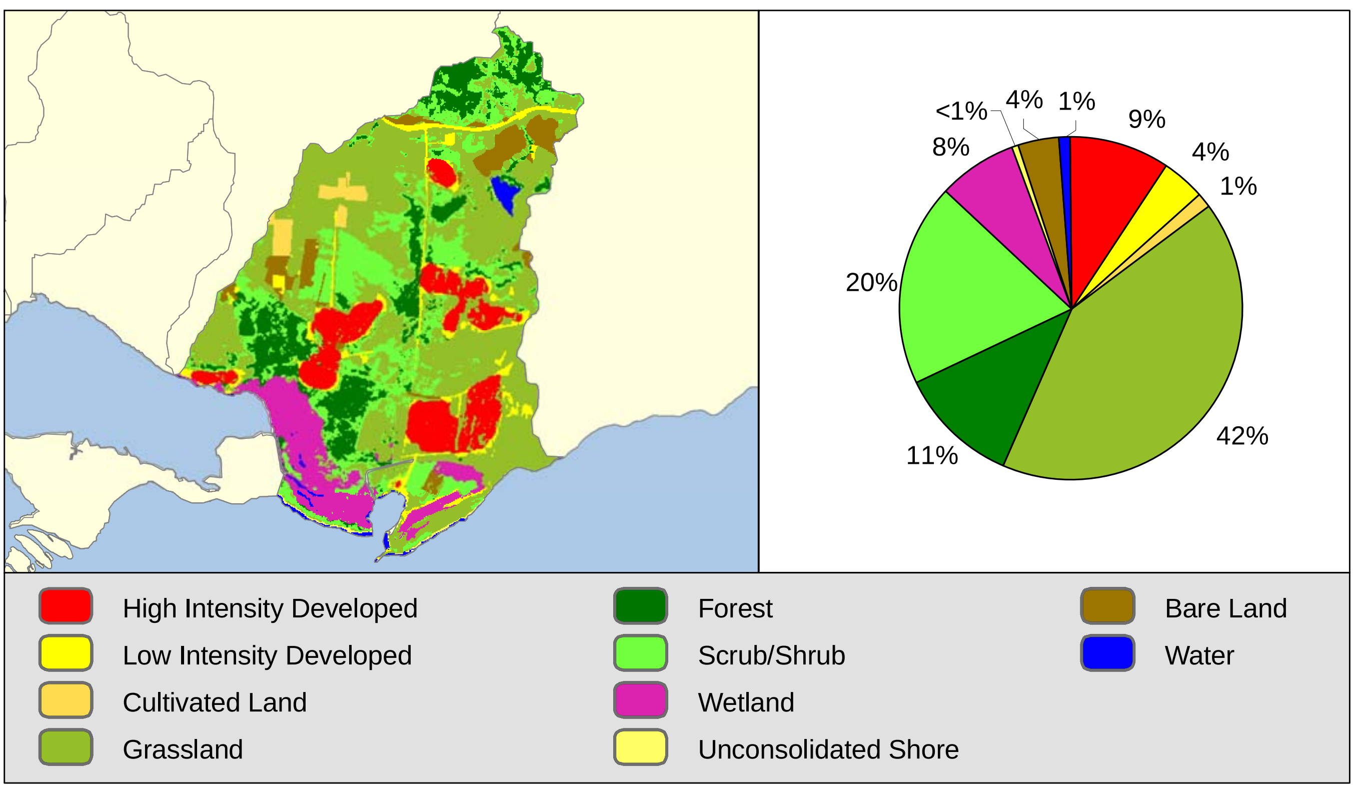

Figure 2.36. Spatial distribution and percent coverage of Barrio Jobos land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

Figure 2.37. Barrio Jobos subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

crude oil and adjacent to the refinery is a coal-fired power plant managed by AES Corp. AES Corp. sells the generated power to the Puerto Rico Electric Power Authority.

Barrio Jobos subwatershed was a major contributor to the predicted loading of sediment, TN, TP and TSS to Jobos Bay (Figure 2.38). The subwatershed was responsible for the second largest loads of TP (18%) and TSS (22%), only behind SW2. As a function of the patchy landscape of Barrio Jobos, localized pollutant contributions are distributed throughout the area (Figure 2.39). The long-term effects of concentrated industrial production of chemicals and pharmaceuticals are an important aspect of Barrio Jobos's contribution to the Bay that is not captured in this analysis.

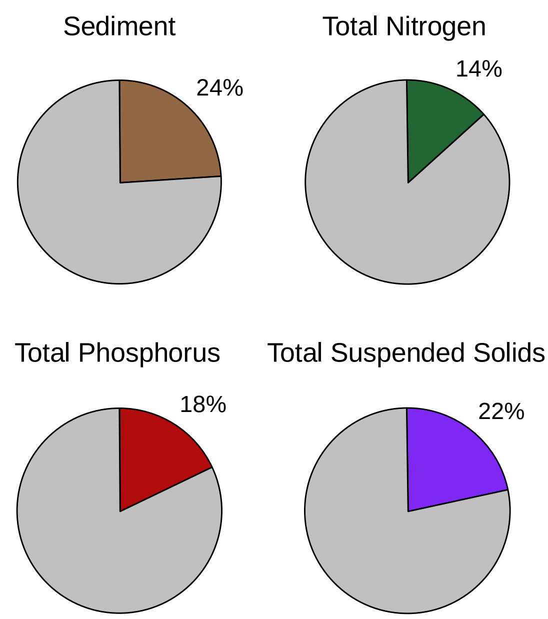

Figure 2.38. Barrio Jobos subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

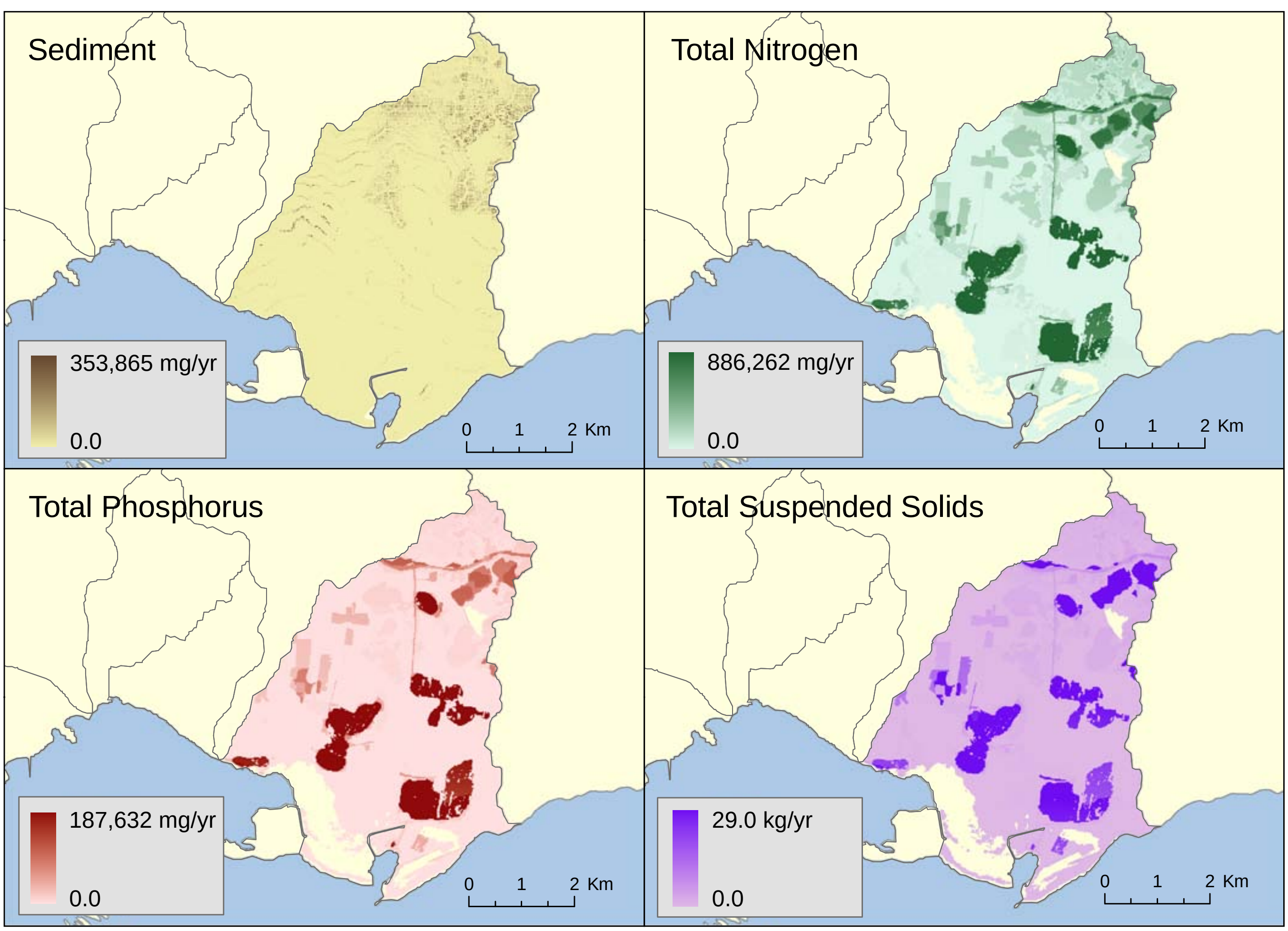

Figure 2.39. Localized annual pollutant contributions by grid cell in Barrio Jobos.

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SW 9 – Punta Pozuelo

The Punta Pozuelo subwatershed's 3.4 km² form a peninsula that separates the protected waters of inner Jobos Bay from the Caribbean Sea. Punta Pozuelo connects to the Puerto Rican mainland by a 300 m wide shared border with the Barrio Jobos subwatershed (Figure 2.41). The subwatershed is the only basin in the study area that does not discharge its entire runoff into Jobos Bay. The peninsula lacks any substantial relief and is too narrow to allow surface runoff to aggregate and form major stream channels. Instead, surface waters generated by precipitation events discharge to the nearest shoreline by overland sheet flow. As a result, surface flow from the Punta Pozuelo subwatershed will be distributed between Jobos Bay and the Caribbean Sea. During rain events, a sediment plume drains west from the shallow coastal lagoons of Punta Pozuelo into Jobos Bay (A. Dieppa, pers. obs.).

Image 11. View of fringing mangrove forest at the edge of Punta Pozuelo. (Photo Credit: T. Potter, USDA-ARS)

Punta Pozuelo can be characterized as a typical coastal community with areas of natural vegetation and low density residential development. The dominant land cover of the subwatershed is mangrove forests and accompanying tidal ponds and salt flats. When considered as a single landscape feature, these wetlands comprise 57% of the subwatershed's total area (Figure 2.40). This mangrove system is distributed along the low energy coastline that borders Jobos Bay; while the higher energy coast facing the Caribbean Sea is formed by sand beaches.

Behind the beaches of Punta Pozuelo lie low intensity developed lands of a residential community. The community is home to 615 permanent residents making it the least populated subwatershed in the entire study area.

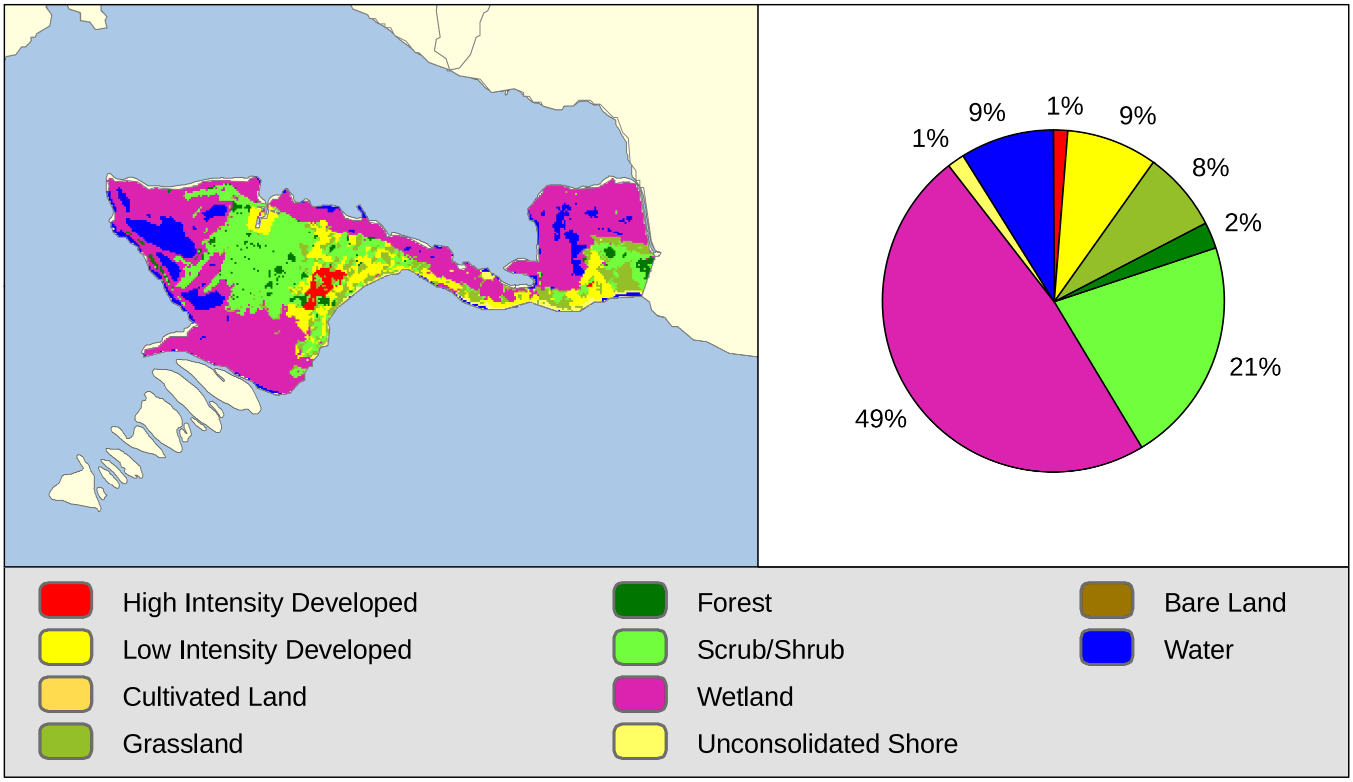

Figure 2.40. Spatial distribution and percent coverage of Punta Pozuelo land cover categories. Map and statistics were derived from Puerto Rico's GAP Analysis Project land cover dataset (PRGAP, 2006).

Figure 2.41. Punta Pozuelo subwatershed boundary and selected land cover features. Orthophotography reflects 2004 ground conditions (USDA, 2004).

Moreover, with 2.8 km/km² of roadways, only SW7 has a lower average road density. The upland areas not developed for residential use are primarily covered by a coastal scrub/shrub forest that covers 21% of the subwatershed area. A small marina is cut into the scrub/shrub forest at a man-made inlet connecting to Jobos Bay.

The Punta Pozuelo subwatershed does not support any agricultural, commercial or industrial land uses. Furthermore, most of the drainage area is covered by natural vegetation. As a result, the small subwatershed contributes only negligible amounts of predicted pollutant loads to Jobos Bay and the Caribbean Sea (Figures 2.42 and 2.43).

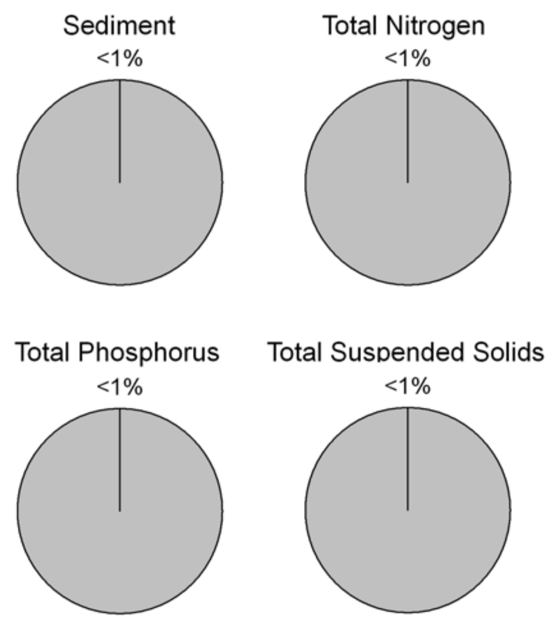

Figure 2.42. Punta Pozuelo subwatershed's percent of total predicted pollutant loads to Jobos Bay for sediment, total nitrogen, total phosphorus and total suspended solids.

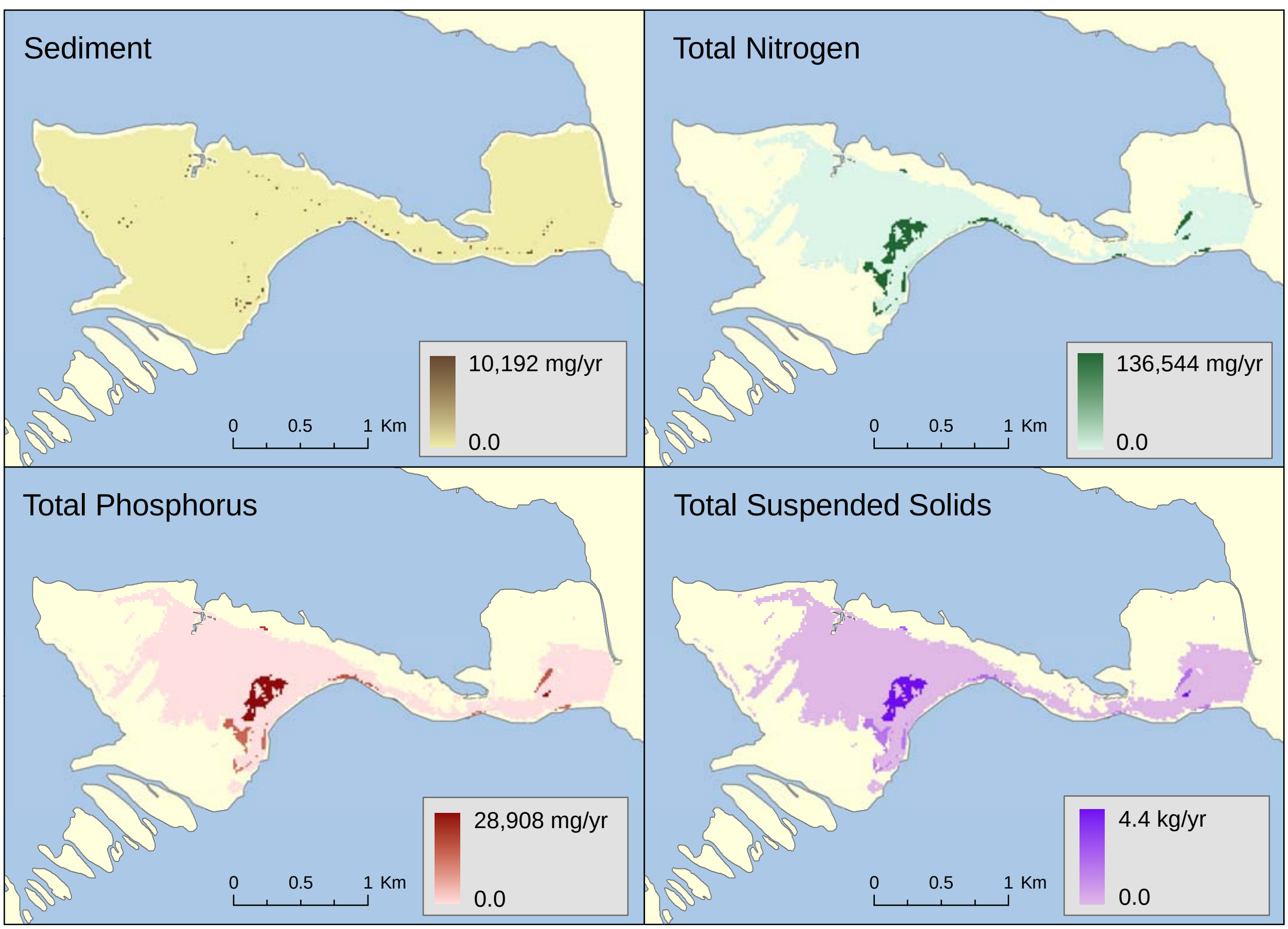

Figure 2.43. Localized annual pollutant contributions by grid cell in Punta Pozuelo.

2.3. MARINE CHARACTERIZATION

Environmental Setting

Jobos Bay is one of the few natural harbors on the southern coast of Puerto Rico. It is the second largest estuary in Puerto Rico with just over 25 km² of surface area, but has more than three times the shoreline of any other estuarine area. The shallow embayment's southern boundary is formed by a series of mangrove islands and associated fringing coral reefs to the west, and the Punta Pozuelo peninsula to the east. Jobos Bay's irregular shape and varied circulation patterns have induced three ecologically unique estuarine zones. Similar to PRNC's (1972) delineation, the Inner Bay, Central Bay and Outer Bay are depicted in Figure 2.44.

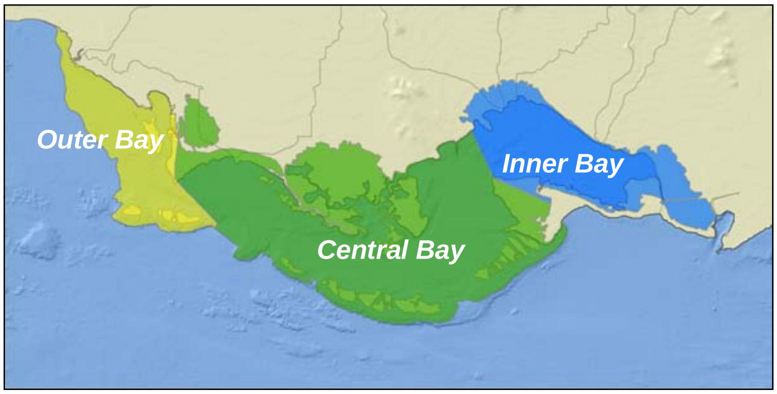

Figure 2.44. Estuarine zones of Jobos Bay.

The Inner Bay is the eastern-most zone of the estuary and is enclosed by the Puerto Rican mainland and Punta Pozuelo on three sides. It experiences the least water exchange with the open ocean as it connects only to the Central Bay on its western side. The Inner Bay is the shallowest of the zones with an average depth of about 3 m; however depths range from less than 1 m on the shelf near the mouth of the Inner Bay to 8 m in the dredged channel near the south shore (NGDC, 2007) (Figure 2.45). Río Seco, the primary year-round surface water input to Jobos Bay, drains on the northern coast of the Inner Bay. A silty bottom is regularly stirred up by the daily winds and creates a persistently turbid water column (PRNC, 1972).

The Central Bay is the largest and most complex estuarine zone of Jobos Bay. Unlike the mostly enclosed Inner Bay, the Central Bay has regular water exchange with the Caribbean Sea. The mangrove islands Cayos Caribe and Cayos de Barca, which form the southern boundary, allow Caribbean waters to pass through their shallow channels during incoming tides. Furthermore, Boca del Infierno, a natural channel of 4 m depth, provides an unobstructed exchange of water with the Caribbean Sea. The Central Bay has an average depth of approximately 5 m, but varies widely between the mangrove forests at the bay edges to the Aguirre Navigational Channel through the middle. The Aguirre Navigational Channel is the most distinct bottom feature located in the Central Bay. The

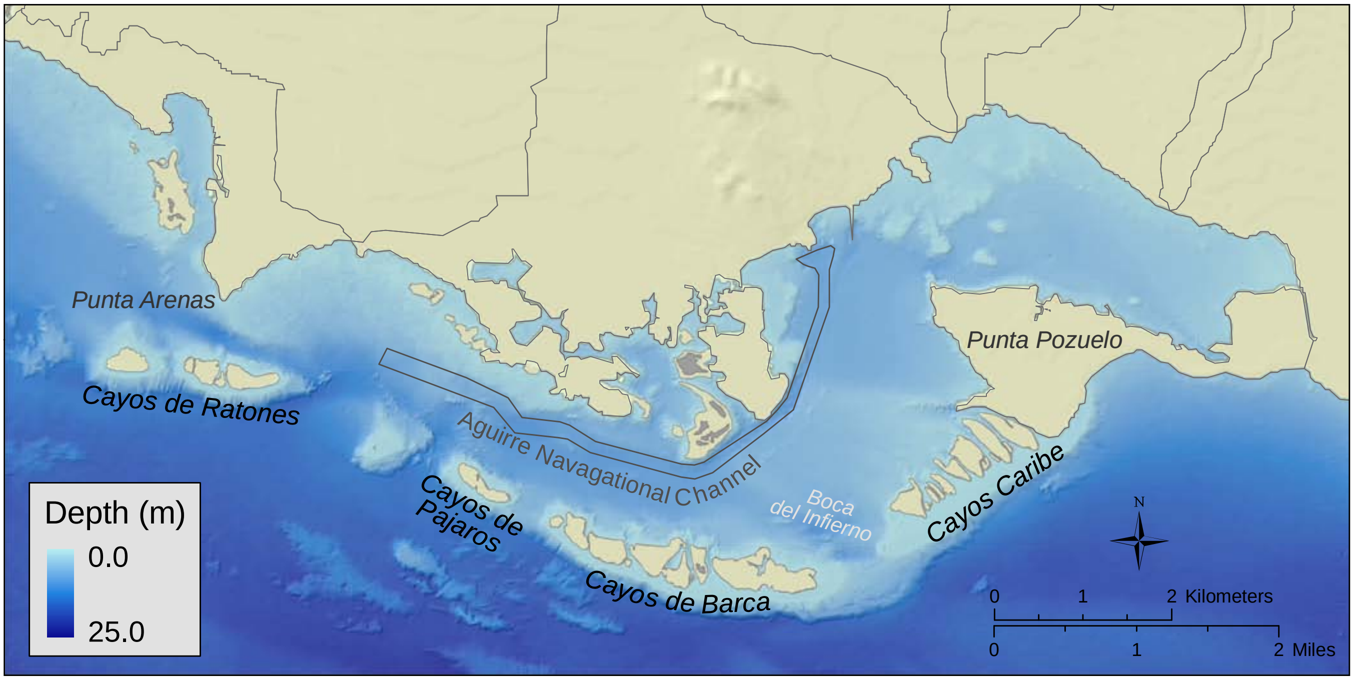

Figure 2.45. Bathymetry and physical features of Jobos Bay.

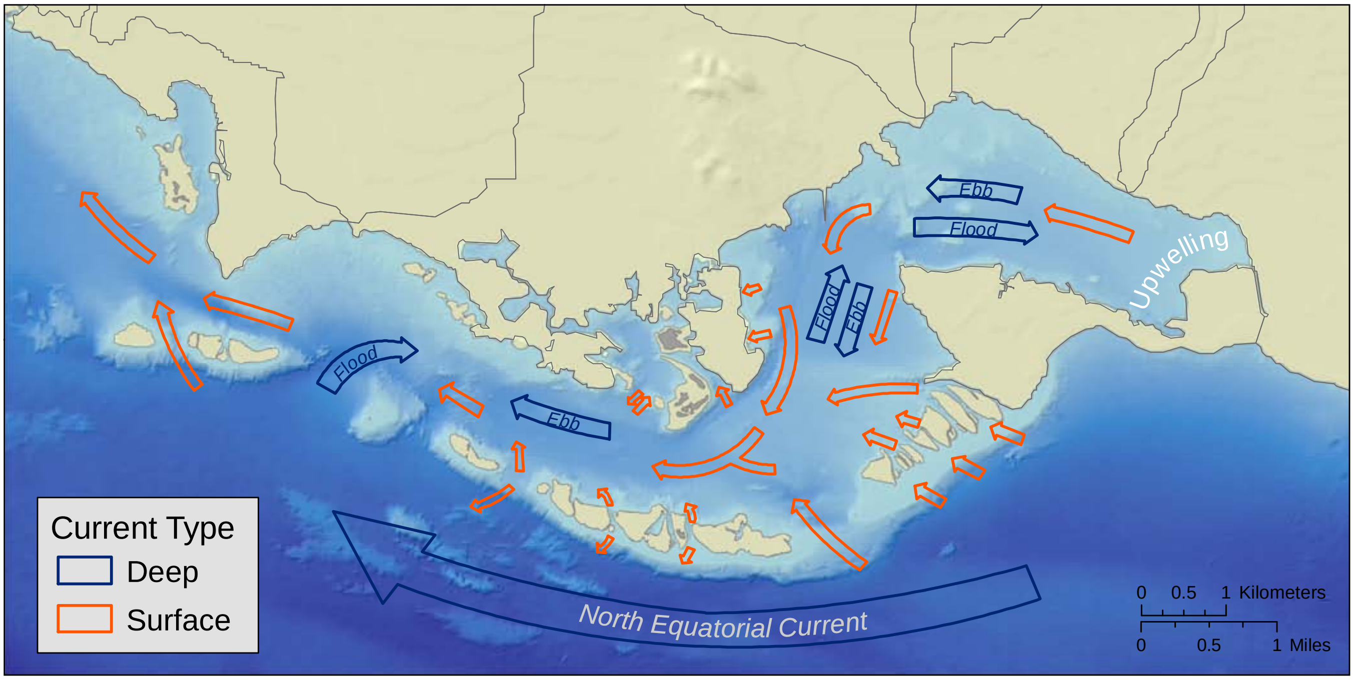

Figure 2.46. Marine currents in Jobos Bay (Adapted from PRWRA (1972)). Both deep and surface currents are displayed in the context of flood and ebb tide conditions.

10 m to 15 m deep channel is open to the Caribbean Sea in the west between Cayos de Ratones and Cayos de Pajaros, and runs east until it reaches Central Aguirre, near the entrance to the Inner Bay.

The Outer Bay zone of Jobos Bay is characterized by its exposure to the Caribbean Sea to the west and restricted flow with the Central Bay. The Outer Bay is distinguished from the Central Bay by extrusion of the mainland at Punta Arenas. A 10 to 14 m deep channel allows water exchange between the adjacent estuarine zones. Cayos de Ratones form the southern boundary of the Outer Bay and are the western-most mangrove islands in Jobos Bay. The zone has an average depth of just over 4 m. Given its open exposure to the Caribbean Sea, the Outer Bay is most influenced by the ocean currents outside of Jobos Bay.

The North Equatorial Current, flowing from east to west, is the dominant current along Puerto Rico's southern coast. It brings ocean water to Jobos Bay that enters at the surface through channels between the mangrove islands and along the bottom through the Aguirre Navigational Channel. Considering the arid conditions in the watershed and lack of surface flow to Jobos Bay, most of the bay's water comes from the open ocean. Under prevailing southeasterly wind conditions, surface water is flushed from the Inner and Central Bays in a southwesterly direction, promoting extensive upwelling along the eastern shore of the Inner Bay (PRNC, 1975). Surface flow westward in the Central Bay is augmented by ocean currents passing through Cayos Caribes and Boca del Infierno. Surface currents in Jobos Bay average 10 cm/s, but may range from 0.0 to 25 cm/s. Refer to Figure 2.46 for a more detailed visualization of currents in Jobos Bay.

The generalized tidal flow pattern is for flood tides to move water eastward and ebb tides to generate westward flow. The mean residence time for a water mass in the Inner Bay is approximately 5.5 days, while residence in the other estuarine zones may be shorter. The tidal excursion, the average distance traveled by a water particle, during a half-tide cycle is 574 m in the Inner Bay and 667 m in the Central Bay. Tides in Jobos Bay are primarily diurnal, but are slightly complicated by a second tidal cycle that occurs every 13.3 days (PRWRA, 1972). Field *et al.* (2002) reported that average tide heights range from 18 cm below mean sea level to 12 cm above, amounting to a 30 cm range.

JBNERR staff has been operating water quality monitoring sites in and around Reserve boundaries since 1995. Figure 2.47 displays the location of four sites in the Central Bay that the NERR staff routinely measure *in situ* temperature, conductivity, salinity, dissolved oxygen, pH and turbidity. In addition, monthly grab samples are taken for nutrients and phytoplankton pigments at these stations. The JBNERR monitoring effort is part of the NOAA System-Wide Monitoring Program (SWMP); a national network of monitoring sites to develop quantitative measurements of short-term variability and long-term changes in water quality, biotic diversity and land use characteristics of estuarine eco-systems (NOAA, 2006). The four SWMP sites are strategically located to represent the different marine environments of Jobos Bay; with two inside lagoonal features (Stations 9 and 10) and the other two in more exposed parts of Jobos Bay (Stations 19 and 20).

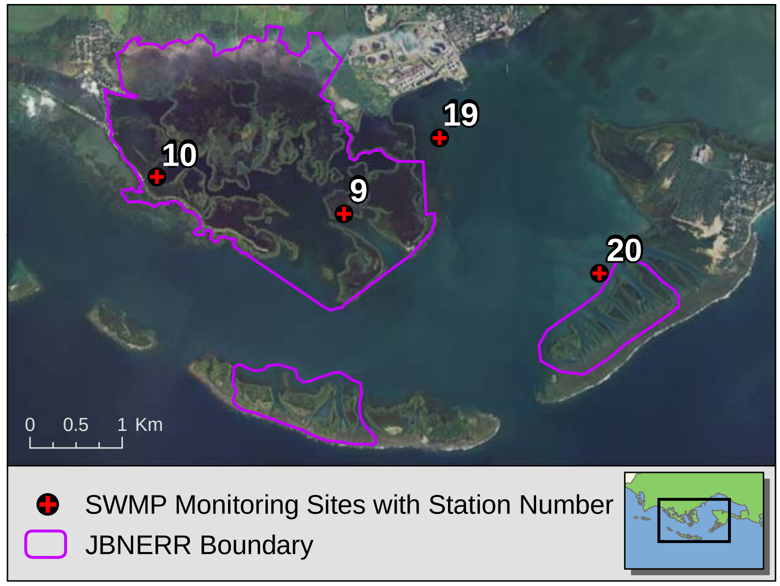

Figure 2.47. Location of the four System-Wide Monitoring Program (SWMP) monitoring sites within Jobos Bay. Jobos Bay National Estuarine Research Reserve (JBNERR) staff routinely measure water quality and nutrients at these sites.

Table 2.2 summarizes the median values with standard deviations for water quality parameters gathered at Jobos Bay SWMP sites between 1995 and 2007 (NERRS, 2008). The median water temperature for all four SWMP sites was between 28.6 - 29.0º C. Similar to water temperature, the other parameters have a relatively narrow range indicating there is little variability in water quality between SWMP locations. However, there was a marginal difference in medians for some water quality parameters between the sites within lagoons and the more exposed sites. For instance, salinities for the two sites within lagoons (Stations 9 and 10) ranged from 36 - 36.8 psu, while the salinities outside of lagoons (Stations 19 and 20) were slightly less (34.5 - 35.5 psu). Station 9 exhibits a lower concentration of dissolved oxygen (3.8 mg/L) compared to the range of the other three SWMP sites (5.4 - 6.5 mg/L). Furthermore, Station 9 recorded the highest median values of every nutrient sampled for except nitrate (NO_3) and nitrite plus nitrate (NO_2+NO_3). Appendix C displays medians for nutrients and phytoplankton pigments collected for Jobos Bay SWMP sites between 2002 and 2005.

Table 2.2. Summary of System-Wide Monitoring Program water quality data for the four stations in Jobos Bay (NERRS, 2008). Statistics are presented as median values with one standard deviation provided in parenthesis.

Site ID	Collection Years	Temperature (ºC)	Conductivity (mS)	Salinity (psu)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)
9	1995-2007	28.6 (±2.2)	55.6 (±5.5)	36.8 (±3.7)	3.8 (±2.0)	7.7 (±0.3)	8 (±110)
10	1996-2006	29.0 (±1.8)	54.5 (±5.0)	36.0 (±3.7)	5.4 (±1.4)	7.8 (±0.3)	3 (±112)
19	2002-2006	28.8 (±1.5)	52.5 (±3.3)	34.5 (±2.4)	6.5 (±1.6)	8.1 (±0.2)	0 (±37.0)
20	2002-2007	28.8 (±1.8)	53.9 (±2.6)	35.5 (±1.9)	6.2 (±2.1)	8.1 (±0.5)	1 (±106)

Benthic Habitat Summary

The Jobos Bay marine ecosystem includes 48 km² of mangrove, seagrass, coral reef and other habitat types that span both intertidal and subtidal areas. Knowledge of Jobos Bay's benthic habitats came from the mapping efforts of Kendall *et al.* (2001) throughout Puerto Rico. NOAA's Biogeography Branch acquired aerial photography for the nearshore waters of Puerto Rico, including Jobos Bay, in 1999. Twenty-one distinct benthic habitat types within eight geographic zones were mapped directly into a GIS using visual interpretation of these orthorectified aerial photographs. An assessment of classification accuracy was conducted on the maps at locations within the project area that included the full complement of conditions representative of Puerto Rico. The maps were determined to be 93.6% (Kappa = 0.93) accurate overall, with accuracies in some categories of 100% (Kendall *et al.*, 2001).

Although the maps represent benthic conditions of nearly ten years ago, it is assumed that there has been no dramatic alteration to benthic habitat distributions since 1999. In fact, Field *et al.* (2002) reported that most of the existing habitats are representative of what was present a century ago, despite substantial alteration of the Jobos Bay watershed. It is likely that some habitat distributions have experienced a small degree of change; however the Kendall *et al.* (2001) benthic habitat maps are considered the best available data in Jobos Bay.

Jobos Bay's variable environmental conditions have led to the establishment of several different benthic habitat types in the system. The Jobos Bay ecosystem is characterized by the interaction between four primary habitat types: mangrove forests, submerged aquatic vegetation (SAV), coral reefs and unconsolidated sediments. The presence of different benthic cover types tends to support a rich and complex assortment of marine fauna. Many organisms are not associated with a single habitat and instead move freely between different habitat types in order to satisfy daily forage and cover needs. Furthermore, an individual may use a number of habitats during different stages in its life cycle. For example, many fish species are born among the roots of fringing mangroves, but as the fish mature they migrate seaward and take up residence on the coral reef. Jobos Bay, with its diversity of benthic habitat types, hosts a variety of different marine species.

Image 12. Four primary habitat types in Jobos Bay. Clockwise from top left: mangrove, submerged aquatic vegetation (seagrass), coral reef and unconsolidated sediments (sand). (Photo Credit: NOAA Biogeography Branch)

Mapping of Jobos Bay revealed 10 different benthic habitats of varying prevalence, and a large area of unknown bottom type covering 38% of the entire bay (Table 2.3). The 18 km² ribbon of unknown bottom was indistinguishable on aerial photography due to a combination of persistent turbidity and greater depths (Figure 2.48). It is believed that much of this unknown bottom is covered by SAV or mud depending on the regular environmental conditions. However, no comprehensive research has been completed in the area to definitively describe the bottom type.

Table 2.3. Jobos Bay benthic habitat summary statistics. Statistics were derived from the Puerto Rico shallow-water mapping efforts of Kendall *et al.* (2001). Polygon Count represents the number of discrete, contiguous areas of a single habitat type.

Habitat Type	Polygon Count	Area (km²)	Percent of Total Area
Colonized Pavement	5	0.27	0.5%
Linear Reef	20	1.83	3.8%
Macroalgae	3	0.70	1.5%
Mangrove	56	12.01	24.9%
Mud	51	1.89	3.9%
Patch Reef (Individual)	2	0.01	<0.1%
Reef Rubble	1	0.05	0.1%
Sand	1	0.02	<0.1%
Scattered Coral/Rock in Unconsolidated Sediment	1	0.04	0.1%
Seagrass	91	13.06	27.1%
Unkown	3	18.32	38.0%
Total	234	48.20	100

Of the known benthic habitats, SAVs are the most common, covering slightly less than 30% of the bay. Seagrass beds totaling 13 km², and macroalgae to a much lesser degree of 0.7 km², are the two types of SAV found in Jobos Bay. Seagrass beds cover 70% of Jobos Bay's shallows up to 3 m in depth (Field *et al.*, 2002). Four types of seagrasses have been observed in Jobos Bay: turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), shoal grass (*Halodule wrightii*), and paddle grass (*Halophila decipiens*). The pattern of zonation observed in Jobos Bay is controlled by salinity, light availability and exposure to air. Generally, shoal grass inhabits only the shallowest areas, turtle and manatee grasses intermix on the shallower portions of the seagrass bed while turtle grass is the sole occupant of the deeper bed, and finally paddle grass grows in the much deeper areas (PRNC, 1975). Paddle grass was observed beginning at depths of 4 m, while no maximum depth was determined for seagrass growth in Jobos Bay (García-Sais *et al.*, 2003). The presence of seagrass is limited to locations where there is an adequate amount of sunlight to support photosynthesis.

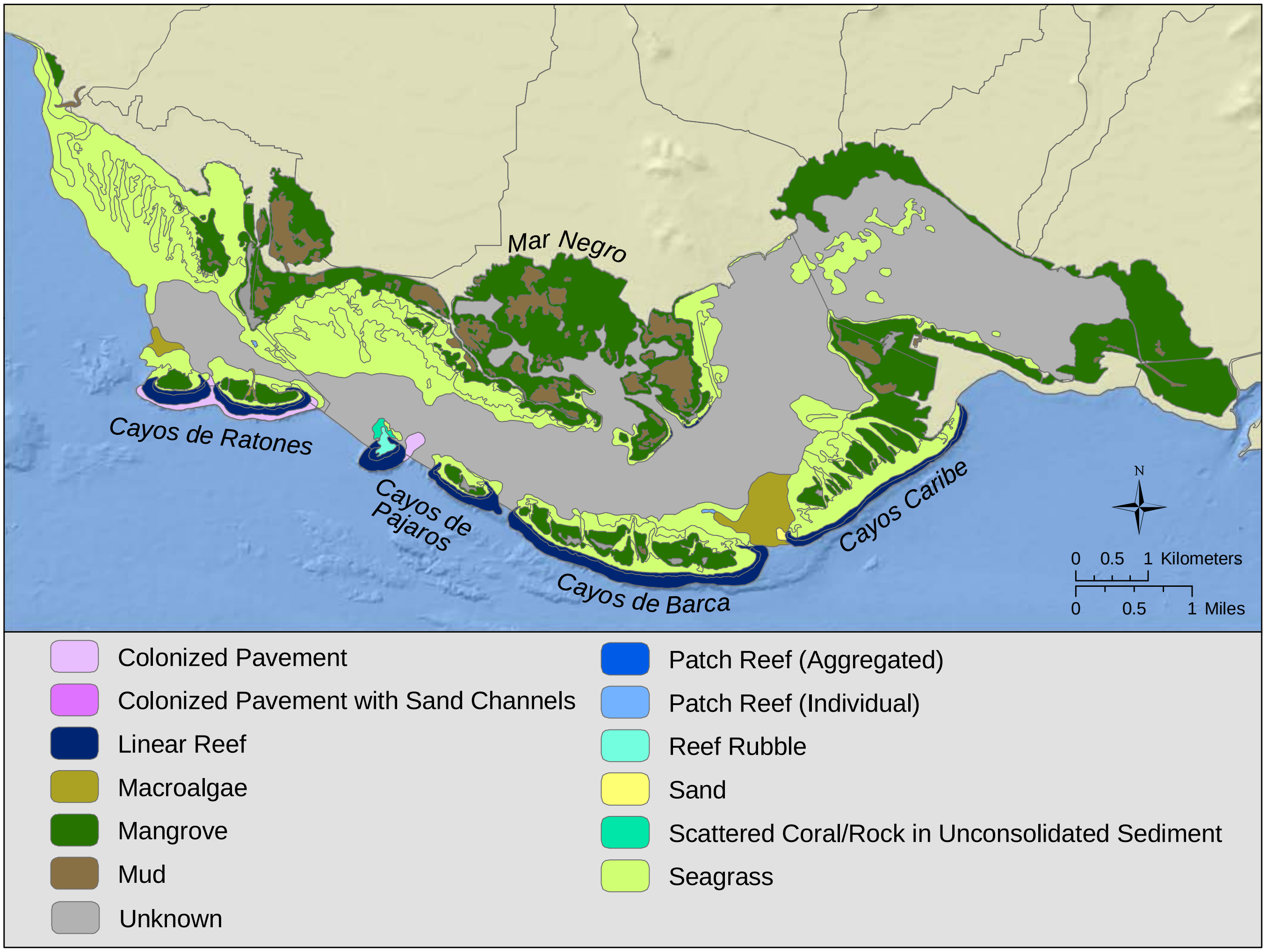

Figure 2.48. Distribution of benthic habitats in Jobos Bay. Data is from Kendall *et al.* (2001) benthic mapping in Puerto Rico.

Mangroves are a dominant feature of the Jobos Bay marine ecosystem and cover 12 km^2; that is 25% of the entire bay. An inventory of Puerto Rico's mangrove resources indicated that Jobos Bay contained nearly 50% of this habitat on the southern coast of Puerto Rico (Martínez *et al.*, 1979). For that reason, Jobos Bay is considered a site of unique ecological value and fundamental in maintaining biodiversity in Puerto Rico. This emergent vegetation borders all of Jobos Bay's undisturbed shoreline and represents the transition between the bay and the upland, except at urban developments in Coastal Salinas and Central Aguirre. The influence of varied shore morphology, tides and river flow have created three different forms of mangrove forests in Jobos Bay. Hogarth (1999) describes these forms:

- Tide-dominated – often referred to as fringe forests, are characterized by regular tidal inundation over a shallow intertidal zone and occur along the edges of the estuary.
- Basin – on the landward side of fringing mangroves are large areas of mangrove with only infrequent tidal inundation.
- Overwash – small mangrove islets that are completely overwashed by the tides.

The mangrove forest forms are found in different biogeographic areas of Jobos Bay. In addition to the varied forest forms, tides and shore morphology give rise to salinity and depth gradients that control the zonation patterns of the three mangrove species of Jobos Bay. Jobos Bay has a consistent pattern of red mangroves (*Rhizophora mangle*) at the estuarine edge with black mangrove (*Avicennia germinans*) behind them in hypersaline areas and white mangroves (*Laguncularia racemosa*) behind them in areas of higher freshwater input (Field *et al.*, 2002). The buttonwood (*Conocarpus erectus*) often populates the transition between the mangrove forests and upland vegetation (A. Dieppa, pers. obs.). The tall luxuriant mangrove forests found in other tropical areas are regularly limited in this part of Puerto Rico. Scarce surface runoff results in higher salinities and lower nutrient inputs than would be found in mangroves along coasts with more rainfall (Ewel and Whitmore, 1973).

Of the remaining benthic habitat types listed in Table 2.3, both linear and patch reefs are some of the most productive habitats found in Jobos Bay. The less than 2 km² of coral reefs comprise only 4% of the total benthic habitat, but provide important habitat and nursery grounds for fish and invertebrates of commercial and recreational value. Most of Jobos Bay's corals are in linear reef formations that are oriented parallel to the shore of the mainland. The Central Bay zone contains the bulk of coral reefs in the study area. In fact, each bay zone is characterized by a unique composition of benthic habitats and warrants further discussion (Appendix D).

Image 13. A stand of red mangroves (*Rhizophora mangle*) on a cay in southern Jobos Bay. (Photo Credit: T. Potter, USDA-ARS)

The Inner Bay zone of Jobos Bay is the least diverse area of benthic habitat types. Virtually, the entire shoreline of the Inner Bay is covered by fringing mangrove forests. Two separate mangrove basin forests exist beyond the mangrove fringe on the eastern and western extremes of the estuarine zone. The low elevations and small, but important freshwater inputs from drainage canals connected to Quebrada Melanía form a 1 km² basin forest in the east (Figure 2.49). Similar conditions created by Quebrada Coquí produce a slightly larger mangrove forest on the northwest shore of the Inner Bay. As a result of low tidal and riverine currents, these basin forests likely serve as sediment and nutrient sinks rather than sources for export (Hogarth, 1999). With the exception of a 0.5 km² patch of seagrass in the middle of the zone, most of the Inner Bay's subtidal habitat is unknown. As discussed earlier, it is assumed that much of this unknown area is SAV and mud. Given the shallow depths of the Inner Bay, it is reasonable to suggest that this bottom type is predominantly seagrass. There is no coral reef coverage present in the Inner Bay zone of Jobos Bay.

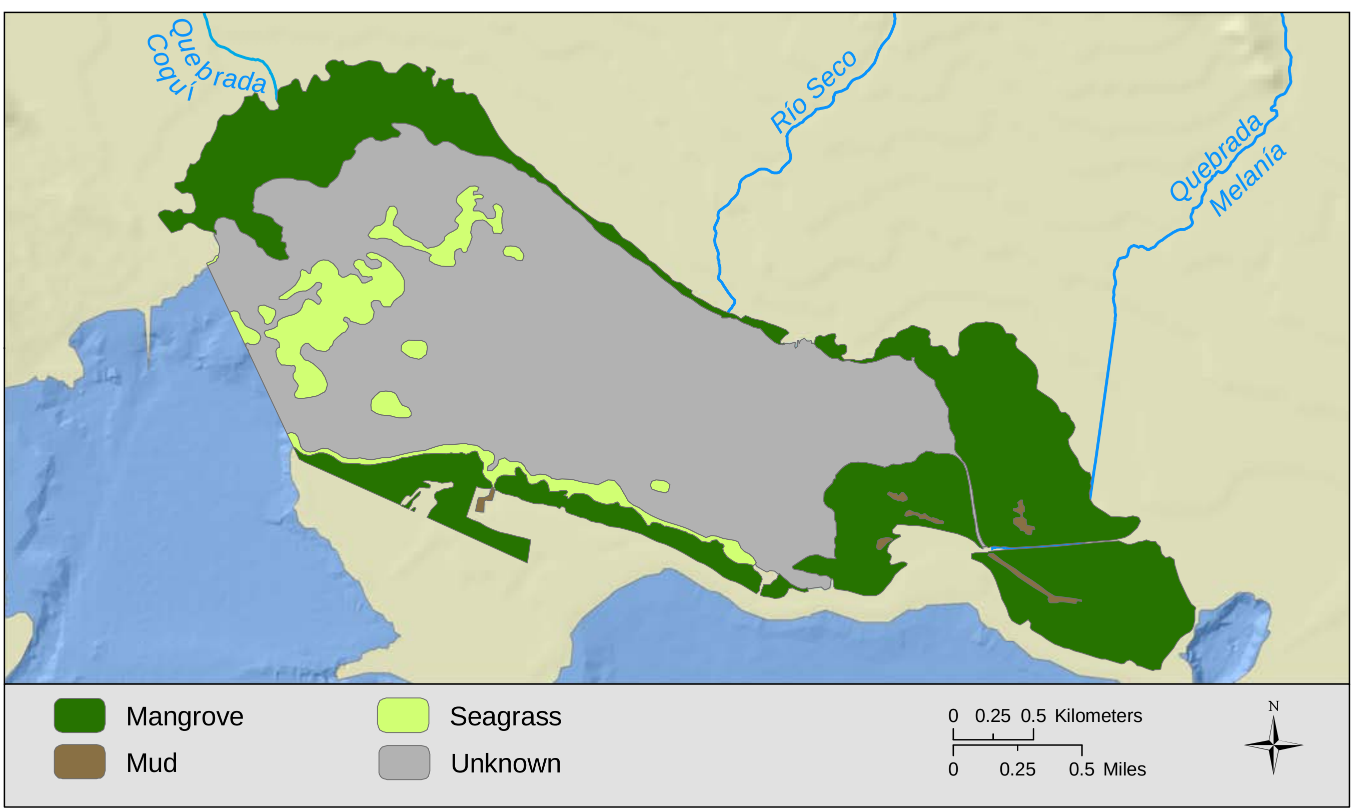

Figure 2.49. Distribution of benthic habitats in the Inner Bay zone. Data is from Kendall *et al.* (2001) benthic mapping in Puerto Rico.

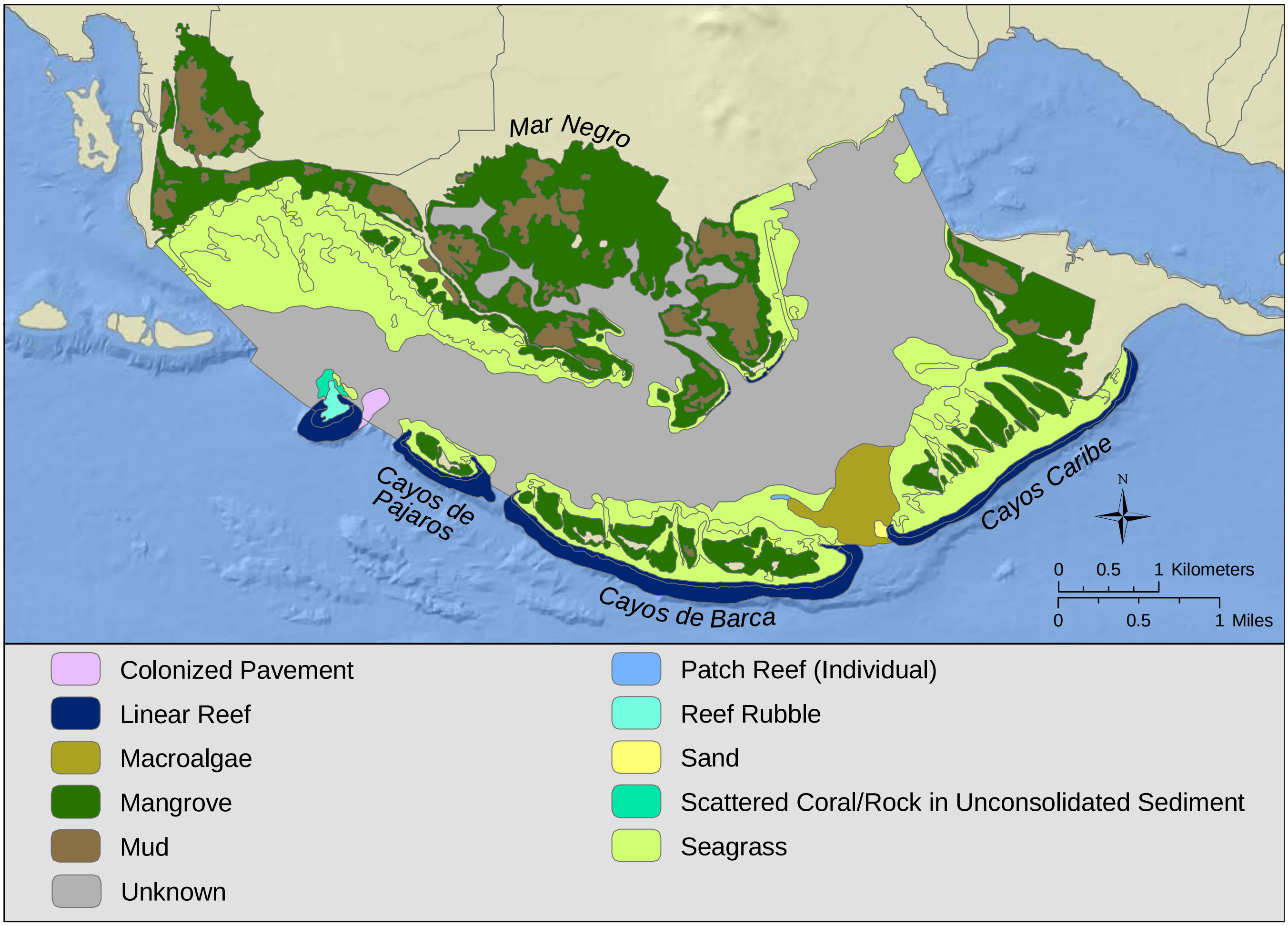

Figure 2.50. Distribution of benthic habitats in the Central Bay zone. Data is from Kendall *et al.* (2001) benthic mapping in Puerto Rico.

Unlike the Inner Bay, the Central Bay zone of Jobos Bay has a diversity of benthic habitats and biogeographic areas. Seagrass (25% of the zone), mangrove (24%), mud flat (6%), coral reef (5%) and macroalgae (2%) are all present in substantial quantities. There are two distinctive habitat features in the zone: the Mar Negro wetland complex and the southern fringing cays (Figure 2.50).

The Mar Negro wetland complex, the largest aggregation of wetlands in the study area, is the source of the Central Bay coastline's indented shape. Several branches of coastal lagoon extend from Jobos Bay into the wetland area and are defined by mangrove fringe forests along the tide channels and seaward boundaries. These fringe forests are flooded daily by high tides and periodic storm surges, thus maintaining a stable salinity regime. Just behind the fringing mangroves are expansive areas of unconsolidated sediment with little to no vegetation. These large ponds are characterized by limited physical exchange with the surrounding waters of Jobos Bay and tend to contain higher levels of salinity. Closer to the landward margin, shallow upward sloping mud bottoms are exposed during low tides. These mud flats serve as the transition between the benthic habitats of Mar Negro and the upland landscape of Central Aguirre.

Just 1 km offshore of Mar Negro is a linear formation of over 30 mangrove cays that run west from Punta Pozuelo to the edge of Jobos Bay. These reef-fringed, mangrove islands form the southern boundary of Jobos Bay and are aggregated into three groups referred to locally as (east to west): Cayos Caribe, Cayos de Barca and Cayos de Pajaros. The cays of Jobos Bay are an integration of coral reef, seagrass and mangrove habitats that conform to a pattern of zonation typical of Caribbean reefs (Figure 2.51). The back reef zone, the most landward feature of the cay, rises up from the deeper lagoon behind it. The shallow depths of the back reef, also referred to as reef flat, support large continuous seagrass beds and tear-shaped overwash mangrove forests. The mangrove islets are separated by channels of 3 - 4 m depth with a strong flow of water running perpendicular to the linear reef (García-Sais *et al.*, 2003). The reef crest, a flattened segment of reef that is emergent during low tides, acts as a physical barrier

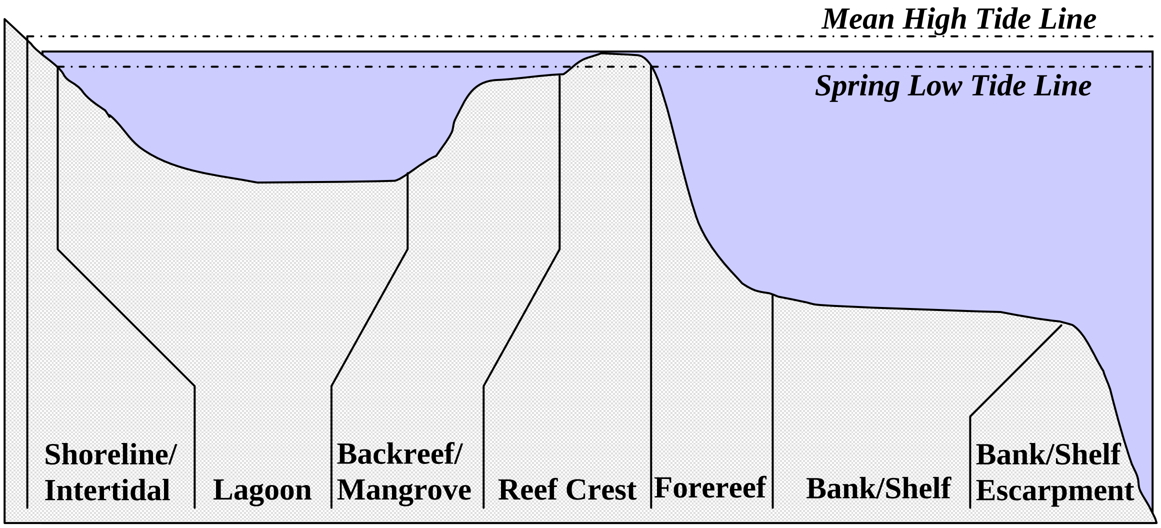

Figure 2.51. Cross-section of typical zonation in the Caribbean Sea when a fringing reef is present (Source: Kendall *et al.* (2001)). Jobos Bay is described by the Lagoon zone with its fringing cays on the Backreef zone.

against wave action, allowing development of seagrass and mangroves on the back reef. Beyond the reef crest, at depths below 2 m, the upper fore reef zone is characterized by a diffuse spur and groove formation that extends to about 10 - 12 m deep. The deeper fore reef is a steep drop-off wall that reaches to the base of the reef at 16 m depths (García-Sais *et al.*, 2003). A marine community assessment conducted by García-Sais *et al.* (2003) on the fore reef of Cayos Caribe and Cayos de Barca resulted in an inventory of percent cover of sessile benthic biota. At both sites, algal turf was the predominant cover of 61 and 62%, but significant amounts of stony corals were also found at both sites, 20 and 21% cover. Stony corals included great star coral (*Monastrea cavernosa*), boulder star coral (*Monastrea annularis*), mustard hill coral (*Porites astreoides*), massive starlet coral (*Sidastrea siderea*) and several others of lesser cover.

The Central Bay estuarine zone contains just less than 1.5 km² of coral reef, with the reefs of the fringing cays accounting for 98.5% of that total. However, there are two small linear reefs not associated with the fringing cays at Cayo Puerca and Punta Colchones (Figure 2.52). These two reefs represent almost all of the corals located inside of Jobos Bay at 21,298 m². García-Sais *et al.* (2003) surveyed several sites along these two reefs and found almost no live cover of stony corals. They observed that these reef formations are relict staghorn coral (Acropora palmata) communities that are now mostly rubble overgrown with calcareous and turf algae. Throughout both the reefs, a green calcareous alga known as watercress alga (*Halimeda opuntia*) was the main component colonizing available hard substrate.

The Outer Bay is the smallest of the three estuarine zones of Jobos Bay, but hosts a variety of benthic habitat types. Seagrass is the primary benthic cover with a total area of nearly 5 km² accounting for 64% of the zone's bottom. Most of the seagrass is located on a large, uninterrupted bed that extends 1 - 1.5 km from the mainland shoreline at coastal Salinas (Figure 2.53). Unlike both the Inner and Central Bay zones, the mainland shoreline is without fringe mangroves. Instead, the mangrove forests are primarily all offshore mangrove islands. The zone's seaward boundary is formed by five mangrove cays referred to as Cayos de Ratones. These cays are a continuation of the fringing formation existing in

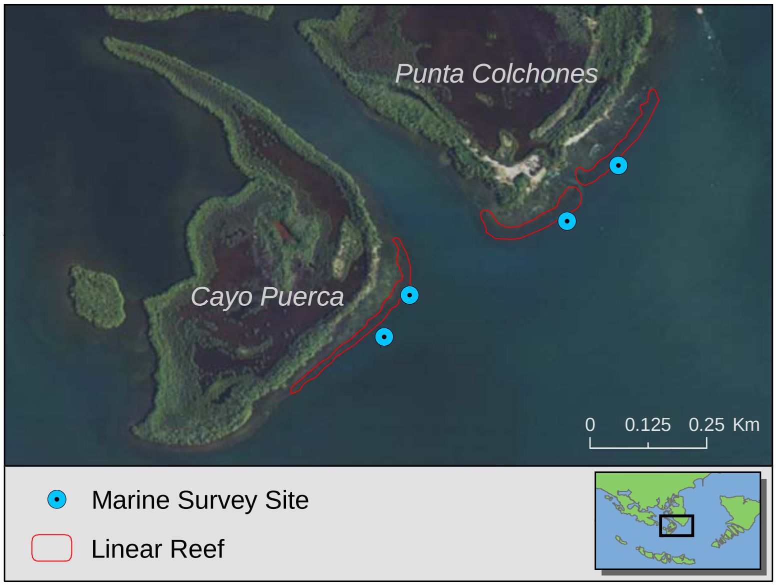

Figure 2.52. Reefs at Cayo Puerca and Punta Colchones with marine survey sites from García-Sais *et al.* (2003).

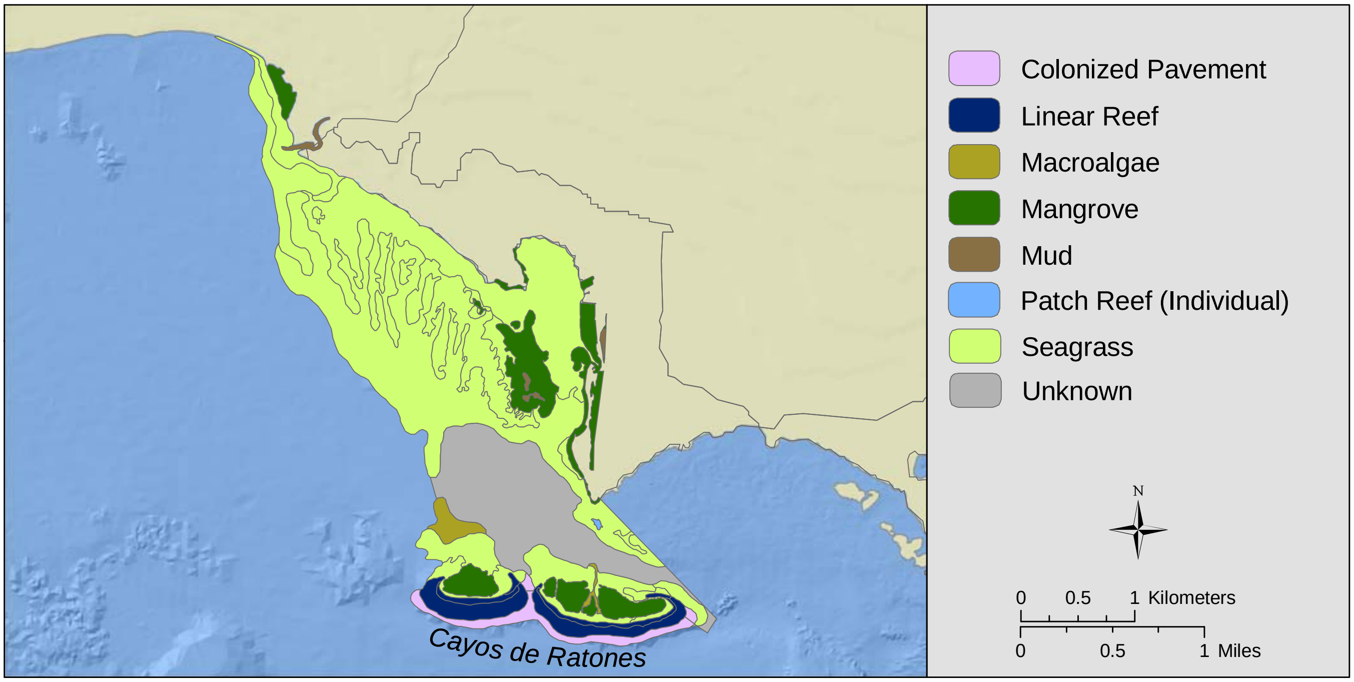

Figure 2.53. Distribution of benthic habitats in the Outer Bay zone. Data is from Kendall *et al.* (2001) benthic mapping in Puerto Rico.

the Central Bay and exhibit the same pattern of zonation. The linear reefs of the fringe cays are the only locations of substantial coral reef formation in the Outer Bay. The Outer Bay zone is the most comprehensively mapped area of Jobos Bay as only 16% has been described as unknown bottom. This is most likely a result of decreased turbidity in the water column from increased flushing by Caribbean currents.

Based upon the mapping work by Kendall *et al.* (2001), little is known about the benthic habitats that lie outside of Jobos Bay. In the surrounding area 3 km from the edge of Jobos Bay, only 10% of the seafloor has been characterized. Aside from a small linear reef, and patches of colonized pavement and macroalgae, 90% of the bottom was classified as unknown. This area has an average depth of 17 m and an unrestricted interaction with the flow of the Caribbean Sea.

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CHAPTER 3: WATER QUALITY AND SEDIMENT MONITORING PLAN

NOAA's COAST Branch will conduct an assessment of contaminants in both the water column and sediments of Jobos Bay. As previously discussed, the Jobos Bay watershed is host to a variety of residential, commercial and industrial activities that likely contribute pollutants to receiving waters of the adjacent coral reef ecosystem. NOAA water quality and sediment sampling will establish the baseline conditions of Jobos Bay and monitor for changes induced by conservation practices in the watershed.

NOAA's National Status and Trends (NS&T) program, administered by the COAST Branch, has been monitoring pollution in U.S. coastal waters since 1986. Data collected during CEAP field work can be compared to the historical NS&T sediment database for 280 sites around the United States to determine the concentrations of pollutants relative to other areas of the country.

3.1 DATA COLLECTION AND METHODS

Data to be Collected

NOAA scientists collect samples in two different environmental matrices in order to detect contaminants in the environment: the water column and the sediments of Jobos Bay. Due to the nature of reactivity of different chemicals and nutrients in the environment, contaminants are investigated in one matrix and not the other:

- Water column – analyzed for pesticides (Appendix E) and nutrients, including TN, TP, nitrate/nitrite, ammonium, urea and silica.
- Sediment – analyzed for the standard suite of NS&T analytes (Appendix F)

Methods of Measurement

Detailed descriptions of analytical methods are available in Kimbrough *et al.* (2006) and Kimbrough and Lauenstein (2006).

3.2. SURVEY DESIGN

Water column samples are taken at each of the four NOAA SWMP sites (Figure 3.1), in order to leverage the existing nutrient and water quality (DO, conductivity, temperature) data set. The NOAA nutrient suite is more comprehensive than the standard SWMP nutrient suite and provides additional information.

In order to make inferences about the entire study area and improve sampling efficiency, a stratified random sampling design is implemented for the sediment sampling. Jobos Bay is operationally divided into four zones, with one of the zones being the NERRS boundary (Figure 3.2). Within each of these zones, 10 sites are randomly selected for sediment sampling. Sediment samples are taken using NS&T program protocols (Lauenstein and Cantillo, 1993) at a total of 44 sites, including the four SWMP sites.

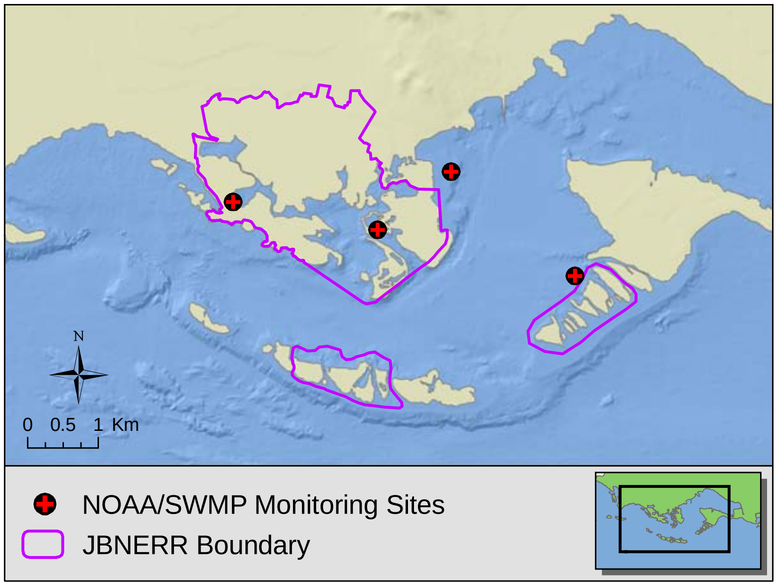

Figure 3.1. Co-location of System Wide Monitoring Program (SWMP) and NOAA water column sampling sites.

3.3. DATA ANALYSIS AND DISTRIBUTION

Data Analysis

After QA/QC has been performed on the data, they will be statistically analyzed for spatiotemporal patterns, including variations in space and time as they relate to climatologic (e.g. rainfall) and anthropogenic forcing factors (e.g. watershed land use).

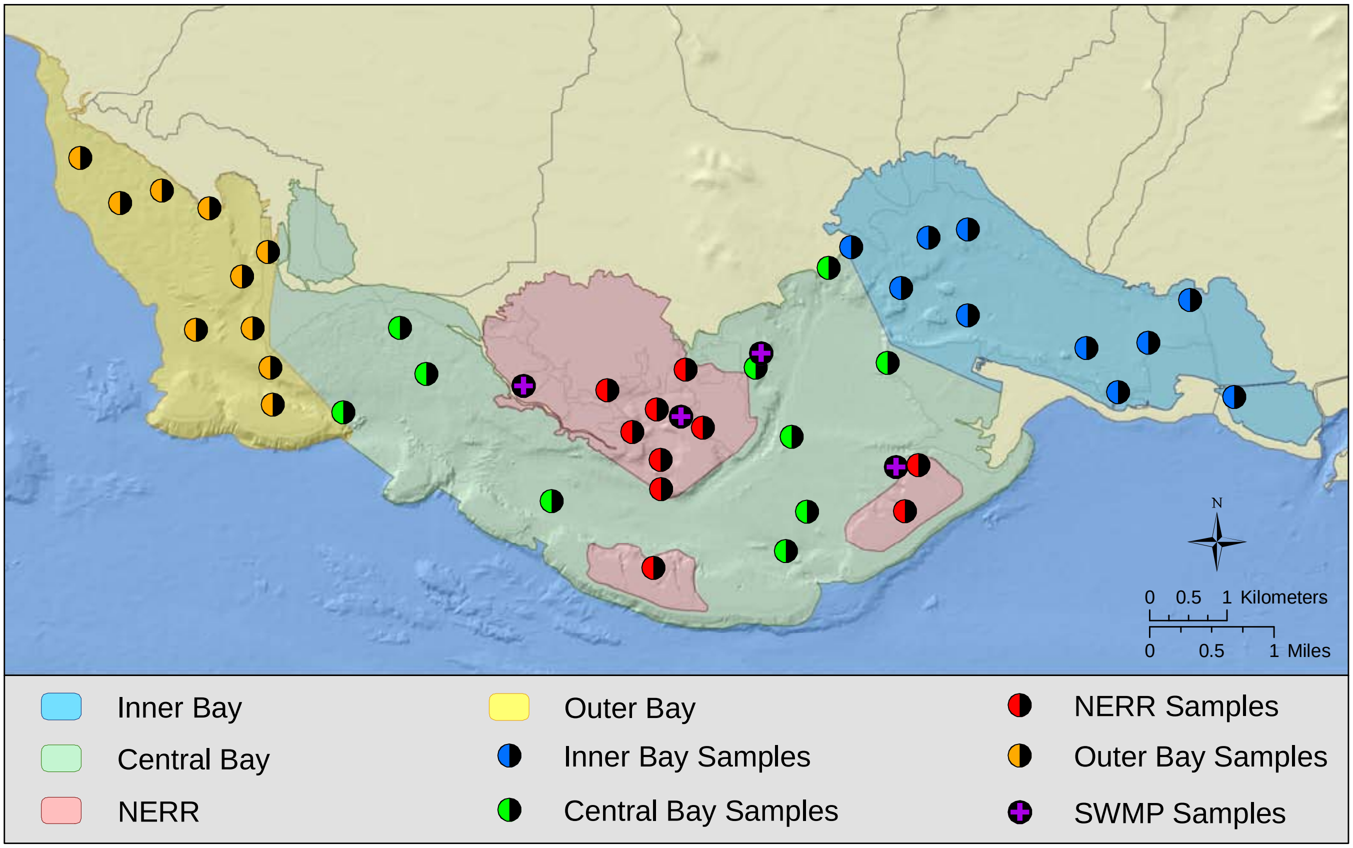

Figure 3.2. Sediment sampling strata and 44 sediment sampling sites in Jobos Bay.

Data Storage and Distribution

As the data are analyzed, information will be made available on the National Status and Trends online database, which provides contaminant data from the coastal U.S. from the past 20 years. All data are described by geographic coordinates to facilitate mapping by the user.

CHAPTER 4: REEF FISH AND HABITAT MONITORING PLAN

In order to assess the benefits of agricultural conservation practices to the health of near-shore coral reef ecosystems, a comprehensive monitoring approach must be implemented in Jobos Bay. NOAA's Biogeography Branch has been mapping and monitoring benthic habitats and sampling reef fish populations in Puerto Rico and the U.S. Virgin Islands since 2000. As a result, the Biogeography Branch has an established monitoring protocol that will aid the CEAP partners in evaluating the relationship between agricultural conservation and coral reef ecosystems.

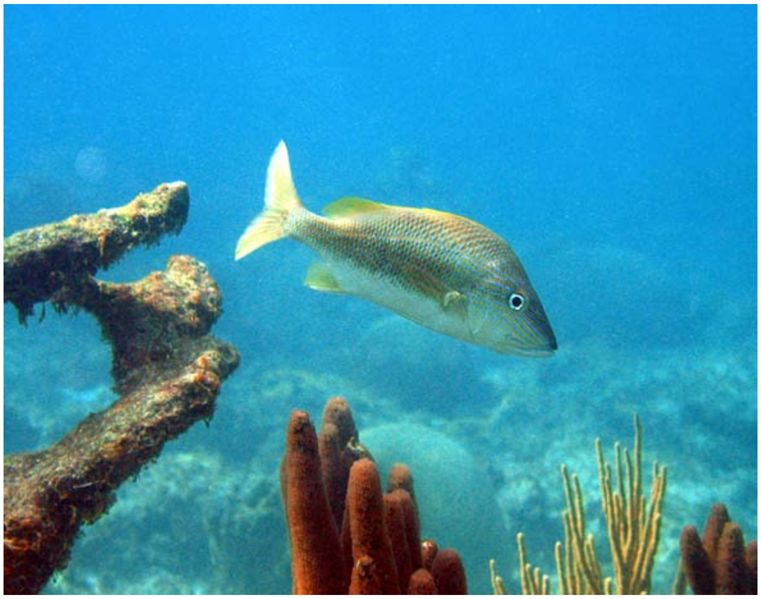

Image 14. White grunt (*Haemulon plumierii*) and coral in Puerto Rico. (Photo Credit: NOAA Biogeography Branch)

This chapter is a brief summary of a proposed reef fish monitoring plan designed for Jobos Bay to be implemented by the CEAP program. A more detailed description of NOAA Biogeography Branch's reef fish monitoring techniques can be found in Menza *et al.*'s (2006) *A Guide to Monitoring Reef Fish in the National Park Service's South Florida / Caribbean Network*.

4.1. DATA COLLECTION AND METHODS

Data to be Collected

NOAA dive teams collect several types of fundamental, *in situ*, data on reef fishes and benthic habitats at each site. These data types allow for reef fish population and community assessments and improved survey performance:

Reef Fish
- Identification of individual fish to the lowest possible taxonomic classification (usually to the species level)
- Abundance and size-frequency distribution of each taxa

Benthic Habitat
- Depth
- Substrate composition
- Benthic floral and faunal composition
- Vertical rugosity
- Benthic habitat type (relevant to strata of the stratified sampling design)

Methods of Measurement

Reef fish and benthic habitat data are collected by NOAA certified scientific divers using non-destructive, underwater visual surveys. All divers are trained to recognize the distinguishing marks and morphologies of different species, accurately measure lengths underwater and identify benthic habitat features.

Visual surveys are conducted along 25 m long by 4 m wide (100 m^2) belt transects at a constant survey time of 15 minutes. The belt transect method (adapted from Brock, 1954) holds time and area constant, thus reducing biases associated with species detectability among distinct habitat types and ensuring a known probability of sample unit selection. Considering the low visibility and numerous mangrove complexes of Jobos Bay, belt transects are most appropriate compared to other methods (i.e. point count) because they place the diver closer to fish.

Divers are taken to sample sites by small motorboats using previously selected geographic coordinates and a handheld GPS unit. Once on site, an anchor or weighted buoy line is deployed to mark the location of the sample unit. A dive team, consisting of one diver to perform the belt transect and another diver to complete a benthic habitat assessment, descends to the seafloor. The belt transect diver begins the survey by fastening the end of a tape measure to the anchor or weighted buoy line and proceeds away from the location at a random compass heading (0 - 360º). The diver gathers data for all fishes within 2 m of either side of the transect line and up to the estimated transect ending (25 m). In mangroves, the diver swims along the mangrove edge, looking 2 m into the mangrove and 2 m away from the mangrove. The diver is allowed to look forward to the end of the transect in order to minimize measurement bias attributed to diver movements. The tape measure is unreeled as the diver swims forward and records fish seen in holes, under ledges and in the water column without altering the habitat structure in any manner. As the diver progresses each new observed species is recorded and the number of individuals per species is tallied in 5 cm size increments up to 35 cm using visual estimation of fork length. Fish over 35 cm are estimated to the nearest centimeter and recorded individually.

Image 15. Diver conducting benthic habitat survey. (Photo Credit: NOAA Biogeography Branch)

The second diver trails the fish census diver and records data on small-scale benthic habitat composition and structure along the 25 m transect. The habitat diver places a 1 m² quadrat at five separate positions that have been randomly chosen before entering the water (Figure 4.1). The diver records information on habitat structure type, depth, and percent cover of abiotic and biotic features. Percent cover is obtained as if looking at the quadrat in a two dimensional plane instead of three dimensions. The second diver can also collect additional information such as surveys of coral bleaching, conch, lobster and urchin. All data is entered into a standardized form throughout the survey.

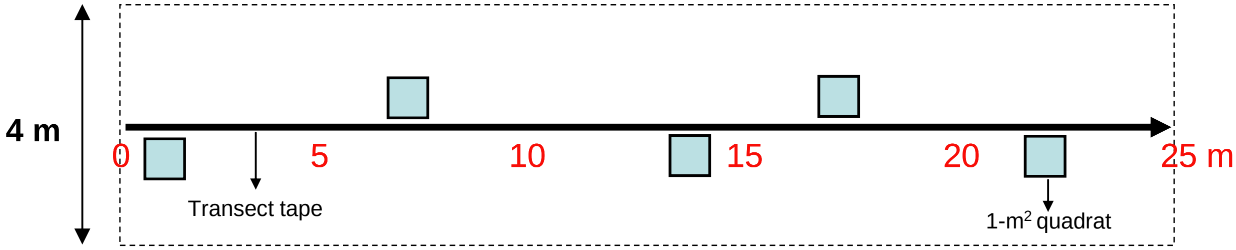

Figure 4.1. Schematic representation of the placement of the 1 m² quadrat along a 25 m transect tape during fish and benthic substrate surveys. Broken line represents the total area surveyed (100 m²).

Low Visibility Alternatives

NOAA recognizes that portions of Jobos Bay, particularly the inner bay, may have reduced visibility due to suspended sediment throughout the water column. The sampling methods described in this report assume the divers are able to clearly see 2 m on either side of them while swimming the transect line. If it is determined that this visibility is not regularly attainable in Jobos Bay, alternative sampling techniques will be explored. Some alternatives may include narrowing the belt transect's width or employing a fish capture technique such as push nets, traps or gill nets.

4.2. SURVEY DESIGN

Population to be Sampled

The Biogeography Branch will investigate the 117 km² associated with Jobos Bay. Although conservation practices will only be altered in a subwatershed that drains directly to Jobos Bay, fish populations depend on and interact with surrounding areas over a large spatial scale. To comprehensively monitor fish that depend on Jobos Bay and determine the effect of conservation practices, samples are taken from both inside and outside Jobos Bay. The survey domain, which defines the population to be sampled, is chosen to include as much area around Jobos Bay as possible (Figure 4.2). Considering logistical constraints, the maximum distance offshore to be sampled is 3 km from the nearest bay feature. Bathymetric data derived from the National Geophysical Data Center (NGDC, 2007) was used to define the geographical areas within safe repetitive diving limits (30 m).

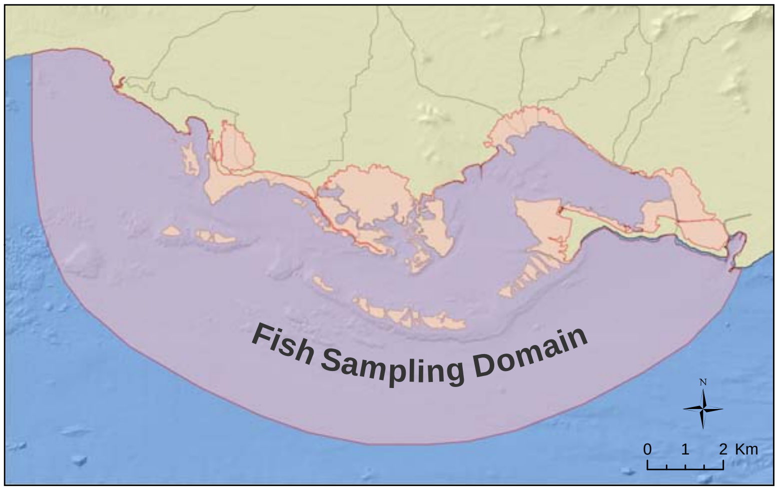

Figure 4.2. Survey domain of the Jobos Bay reef fish and habitat monitoring plan. Monitoring will be conducted throughout Jobos Bay and up to 3 km outside of the Bay.

Sampling Design

A stratified random sample design was employed to improve sampling efficiency and allow rigorous inferences to the study area or designated strata. The survey domain was partitioned into 18 strata based on two spatial variables: benthic habitat and geographic zone. Benthic habitat type and geographic zone were selected because they were covariates of reef fish in past Biogeography Branch studies and allowed the survey domain to be divided into regions of homogenous variance.

Kendall *et al.*'s (2001) benthic habitat map for Puerto Rico was used to aggregate the survey domain into four general habitat types: hard bottom, soft bottom, mangrove and unknown (Figure 4.3A). Hard bottom features were characterized by bedrock, pavement or coral reef. Soft bottom features were characterized by sand, seagrass or macroalgae. Unknown features were areas that Kendall *et al.* were unable to classify in the original benthic habitat map. Menza *et al.* (2006) described several case studies that effectively parsed the survey domain according to benthic habitat to improve sampling efficiency.

Geographic zones, the other spatial stratification level, were consistent with the areas described for stratifying sediment samples (see section 3.2 Survey Design). In addition, a fifth geographic zone was included to capture the area directly outside of Jobos Bay (Figure 4.3B). Each zone was characterized by distinct conditions of estuarine circulation, ranging from an almost entirely enclosed water body to open ocean.

An overlay of both spatial variables resulted in 18 unique combinations of benthric habitat type and geographic zone. Summary information for each stratum is provided in Table 4.1.

Using the Biogeography Branch's sampling protocol described in this document; an estimated 100 sampling sites can be surveyed in a 2-week mission. These 100 sites were divided into two separate sampling groups: permanent (n=28) and random (n=72) (Figure 4.4). The 28 permanent sampling sites were intentionally located

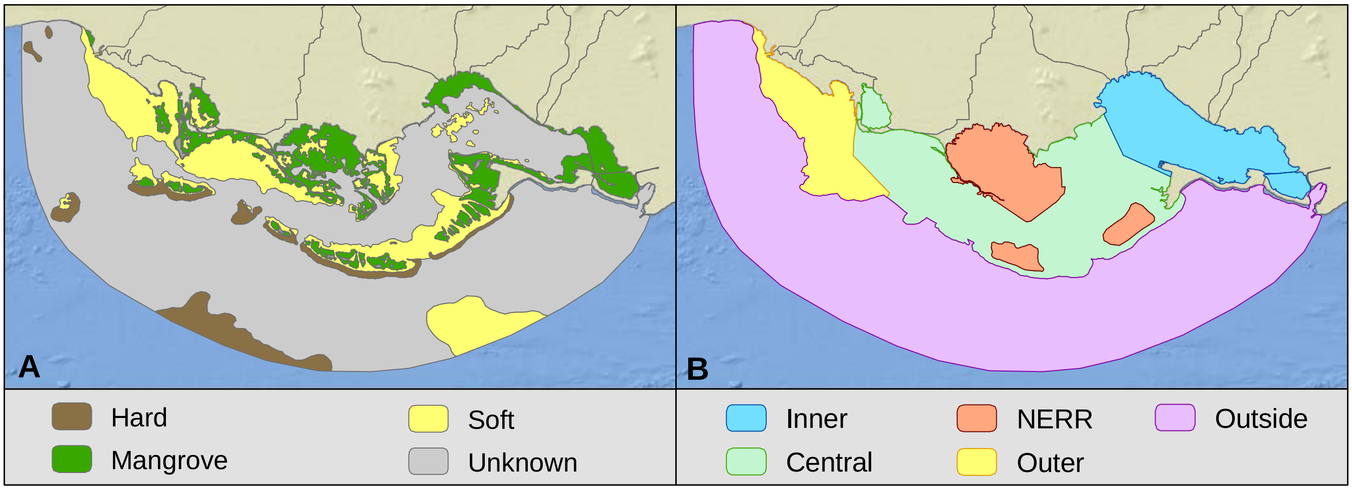

Figure 4.3. Two spatial variables were used to define 18 sampling strata: benthic habitat (A) and geographic zone (B).

in each strata and intended to be representative of the entire survey domain. Permanent sites were also positioned in areas of long-term interest, including co-location with sediment core sites as well as NOAA's active SWMP sites. During periods of fiscal constraint, the permanent sites will function as priority sampling locations to maintain a long-term monitoring program.

The other 72 sites were chosen at random throughout the survey domain. During the initial sampling mission, random samples will be distributed evenly among the 18 strata with 4 samples in each stratum. The variance in each stratum can then be evaluated and a Neyman allocation will be employed with the 72 random samples on successive survey missions. A Neyman allocation, or optimal allocation, distributes sampling units according to both stratum size and the standard deviation of metric measurements within a stratum. The advantage of having random sites in addition to permanent sampling sites is two-fold; it allows for a complete spatial characterization of the survey domain whenever possible and provides the ability to prove/disprove the permanent sites as being representative of the survey domain.

Table 4.1. Strata codes and corresponding variables used to define sampling strata. Strata used for the reef fish and benthic habitat monitoring plan are defined by the intersection of geographic zone and habitat type.

INR-MAN	Inner	Mangrove	4.0
INR-SOF	Inner	Soft Bottom	0.7
INR-UNK	Inner	Unknown	6.0
CNT-HAR	Central	Hard Bottom	1.6
CNT-MAN	Central	Mangrove	3.1
CNT-SOF	Central	Soft Bottom	7.7
CNT-UNK	Central	Unknown	9.6
NER-HAR	NERR	Hard Bottom	0.003
NER-MAN	NERR	Mangrove	4.1
NER-SOF	NERR	Soft Bottom	2.2
NER-UNK	NERR	Unknown	1.4
OTR-HAR	Outer	Hard Bottom	0.6
OTR-MAN	Outer	Mangrove	0.8
OTR-SOF	Outer	Soft Bottom	5.1
OTR-UNK	Outer	Unknown	1.3
OSD-HAR	Outside	Hard Bottom	3.6
OSD-SOF	Outside	Soft Bottom	3.5
OSD-UNK	Outside	Unknown	61.8

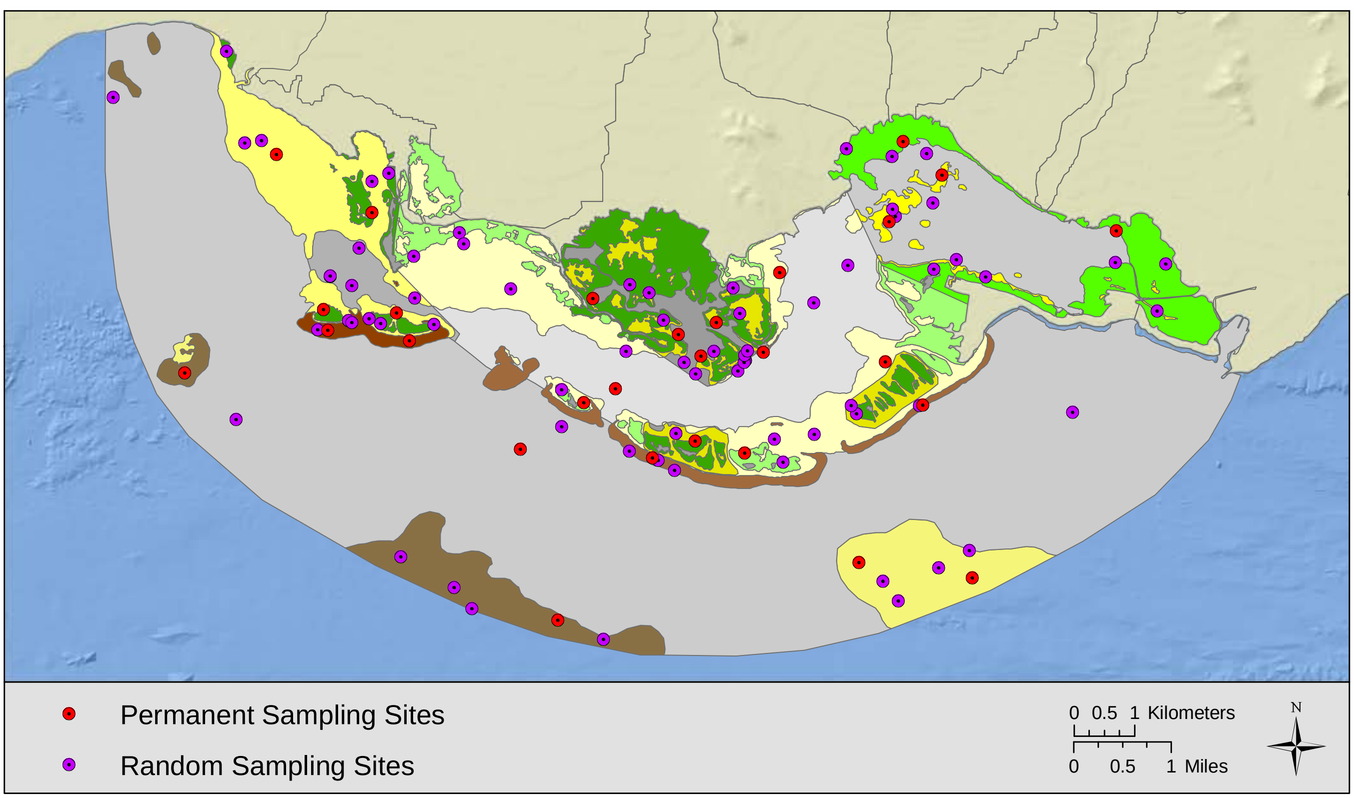

Figure 4.4. Permanent and random reef fish sampling sites with the corresponding sampling strata. Each stratum was assigned a different color based on its benthic habitat type: hardbottom (browns), mangrove (greens), softbottom (yellows), and unknown (grays).

4.3. DATA ANALYSIS AND DISTRIBUTION

Population and Community Assessments

Several meaningful metrics for individual species and assemblages are generated from the reef fish survey data. These metrics are useful to assess the status and trends of populations and communities over time and spatial locations within the survey domain:

- *Frequency of occurrence:* the proportion of sampled sites that a given species was seen in. The measure can be used to assess the change in spatial distribution of a species over time.
- *Diversity indices:* several measures of species composition, including species richness and the Shannon index (Shannon, 1948), are calculated as a general measure of biodiversity for the fish community.
- *Relative abundance:* essentially density (numbers of animals observed per unit sample area) has been used in reef ecosystems to characterize changes in fish population sizes (Polunin and Roberts, 1993; Friedlander and Parrish, 1998; Nagelkerken *et al.*, 2000)
- *Biomass:* an integrated measure of total mass of living fish matter for given ages. When completed for each species in the survey area, biomass can be summed for a community estimate.

Strata weighting factors are applied to all metrics to account for the varying proportions of strata throughout the survey domain. The metrics are then used to answer specific questions defined by the CEAP partners related to fish assemblage changes due to improved agricultural conservation practices. NOAA's Biogeography Branch has an established record of employing the sampling design approach to assess reef fish population and community dynamics (Monaco *et al.*, 2001; Christensen *et al.*, 2003; Kendall *et al.*, 2004; Monaco *et al.*, 2007; Pittman *et al.*, 2007).

Data Storage and Distribution

Upon completion of the field mission, each diver is responsible for entering his/her data into NOAA Biogeography's National Coral Reef Ecosystem Assessment and Monitoring Program (NCREAMP) database. The NCREAMP database is publicly available on the World Wide Web (NOAA, 2007b) and provides data from field surveys in Puerto Rico since 2000 (Figure 4.5). The database offers information on fish metrics (richness, Shannon index, abundance and biomass) as well as both fish and habitat photos that have been acquired during sampling. All data are described by geographic coordinates to facilitate mapping by the user.

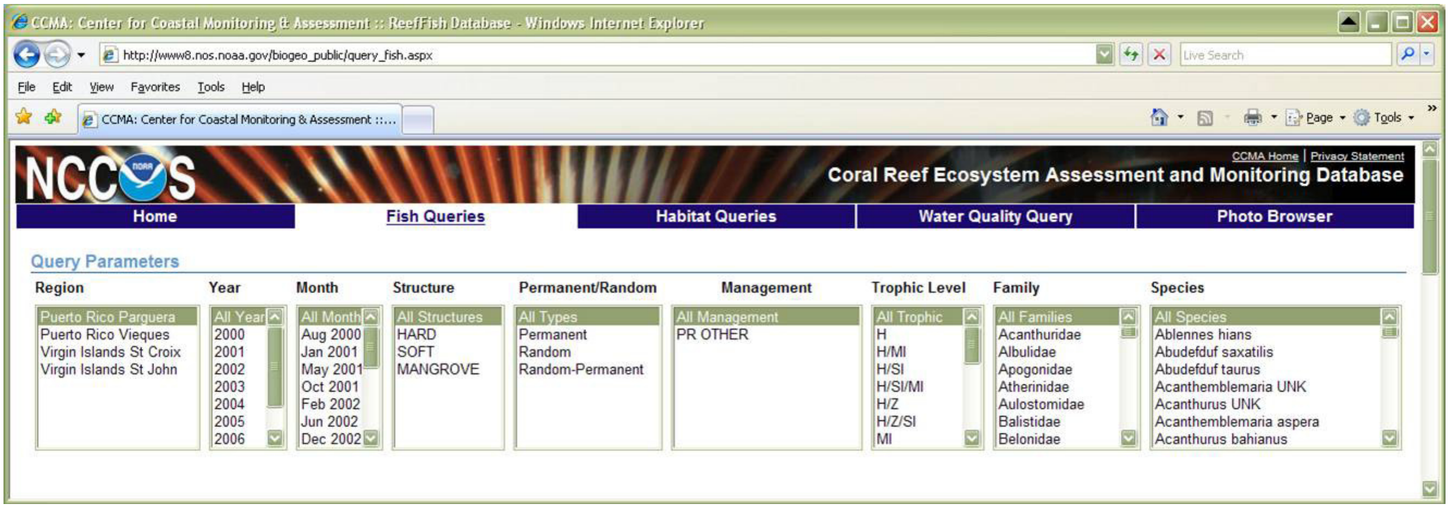

Figure 4.5. Coral Reef Ecosystem Assessment and Monitoring on-line database allows users to query diver surveys and retrieve the information.

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Appendix A. Jobos Bay subwatershed characterization summary statistics. The Jobos Bay watershed does not have an ID because it is an aggregation of every subwatershed listed in this table. Mean Slope is an average of all the individual grid cell slope values located within the subwatershed boundary. Population and road data was derived from 2000 U.S. Census data (U.S. Bureau of the Census, 2001). Road Density is defined as the total length of road (km) per area (km^2).

Watershed ID	Name	Area (km^2)	Mean Slope (degrees)	Total Population (persons)	Population Density (persons/ km^2)	Road Density (km/ km^2)
SW1	Coastal Salinas	3.3	0.2	2,461	746	5.6
SW2	Upper Salinas	22.6	0.7	12,272	543	6.1
SW3	Central Aguirre	16.5	1.4	2,652	161	4.4
SW4	Quebrada Coquí	24	6.4	5,169	215	4.6
SW5	Quebrada Amoros	7.4	4.9	971	131	4.1
SW6	Northern Bay	4.8	0.9	1,263	263	4.9
SW7	Río Seco	29.5	16.7	988	33	2.4
SW8	Barrio Jobos	25.7	3.7	5,705	222	5.0
SW9	Punta Pozuelo	3.4	0.6	615	181	2.8
-	Jobos Bay	137.3	3.95	32,096	234	4.4

Appendix B. Predicted annual and percent loads of runoff, sediment, total nitrogen, total phosphorus and total suspended solids by subwatershed. All predictions are the result of NOAA Summit to Sea modeling using the Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT). Jobos Bay is an aggregation of the subwatersheds listed in the table; as a result those values serve as column totals.

Watershed ID	Name	Surface Water Runoff (million L/yr)	Sediment (million kg/yr)	Total Nitrogen (kg/yr)	Total Phosphorus (kg/yr)	Total Suspended Solids (kg/yr)
SW1	Coastal Salinas	250	0.6	554	106	15,775
SW2	Upper Salinas	7,327	36	19,377	3,125	437,903
SW3	Central Aguirre	1,679	35	4,805	718	110,464
SW4	Quebrada Coquí	6,820	108	13,565	1,247	204,835
SW5	Quebrada Amoros	1,244	27	2,686	227	38,361
SW6	Northern Bay	353	4	843	107	15,882
SW7	Río Seco	8,166	116	11,604	532	111,440
SW8	Barrio Jobos	4,744	105	8,428	1,335	263,883
SW9	Punta Pozuelo	10	0.02	24	5	758
-	Jobos Bay	30,593	432	61,886	7,402	1,199,301

Appendix C. Summary of NOAA System-Wide Monitoring Program (SWMP) nutrient and phytoplankton pigment data for the four stations in Jobos Bay (NERRS, 2008). Grab samples were collected and analyzed monthly for the included collection years. All values are medians with one standard deviation provided in parenthesis.

Site ID	Collection Years	PO_4 (mg P/L)	NH_4 (mg N/L)	NO_2 (mg N/L)	NO_3 (mg N/L)	NO_2+NO_3 (mg N/L)	DIN (mg N/L)	Chlorophyll a (µg/L)	Phaeophyton (µg/L)
9	2002-2005	0.026 (±0.026)	0.150 (±0.100)	0.002 (±0.007)	0.009 (±0.010)	0.010 (±0.010)	0.163 (±0.124)	0.510 (±0.720)	0.650 (±0.920)
10	2002-2005	0.012 (±0.002)	0.140 (±0.120)	0.002 (±0.00)	0.011 (±0.002)	0.013 (±0.011)	0.150 (±0.144)	NA	NA
19	2002-2005	0.012 (±0.001)	0.121 (±0.112)	0.001 (±0.001)	0.010 (±0.008)	0.009 (±0.012)	0.135 (±0.153)	NA	NA
20	2002-2005	0.012 (±0.009)	0.120 (±0.110)	0.001 (±0.005)	0.007 (±0.005)	0.007 (±0.008)	0.135 (±0.121)	NA	NA

Appendix D. Summary of benthic habitats in each estuarine zone of Jobos Bay. For the purposes of this study, Jobos Bay was divided into three discrete estuarine zones. Polygon Count represents the number of discrete, contiguous areas of a single habitat type. Statistics of benthic habitat types were derived from the Puerto Rico shallow-water mapping efforts of Kendall *et al.* (2001).

Estuarine Zone	Habitat Type	Polygon Count	Area (ha)	Percent of Total Area
Inner	Mangrove	7	396.6	37.2%
Inner	Mud	7	5.0	0.5%
Inner	Seagrass	10	68.4	6.4%
Inner	Unknown	1	596.9	56.0%
	Total	**25**	**1,066.9**	**100%**
Central	Colonized Pavement	2	6.3	0.2%
Central	Linear Reef	14	143.4	4.8%
Central	Macroalgae	1	60.1	2.0%
Central	Mangrove	36	723.9	24.3%
Central	Mud	40	180.2	6.1%
Central	Patch Reef (Individual)	1	0.8	<0.1%
Central	Reef Rubble	1	5.3	0.2%
Central	Sand	1	1.9	0.1%
Central	Scattered Coral/Rock in Unconsolidated Sediment	1	4.1	0.1%
Central	Seagrass	60	744.7	25.0%
Central	Unknown	1	1,108.2	37.2%
	Total	**158**	**2,978.9**	**100%**
Outer	Colonized Pavement	3	20.7	2.7%
Outer	Linear Reef	6	39.3	5.1%
Outer	Macroalgae	2	10.2	1.3%
Outer	Mangrove	13	80.5	10.4%
Outer	Mud	4	4.3	0.6%
Outer	Patch Reef (Individual)	1	0.5	0.1%
Outer	Seagrass	21	492.6	63.6%
Outer	Unknown	1	126.8	16.4%
	Total	**51**	**774.9**	**100%**

Appendix E. List of pesticides that NOAA/CCMA investigated for in water column samples and the corresponding analytical method.

Pesticide	Analytical Method
Schedule 1	
chlorpyrifos	GC-NCI-MS
β-endosulfan	GC-NCI-MS
α-endosulfan	GC-NCI-MS
endosulfan sulfate	GC-NCI-MS
ethalfluralin	GC-NCI-MS
lindane	GC-NCI-MS
pendimethalin	GC-NCI-MS
tribufos	GC-NCI-MS
trifluralin	GC-NCI-MS
Schedule 2	
acetochlor	HPLC-APCI-MS
alachlor	HPLC-APCI-MS
ametryn	HPLC-APCI-MS
atrazine	HPLC-APCI-MS
atrazine, desethyl (DEA)	HPLC-APCI-MS
atrazine, desisopropyl (DIA)	HPLC-APCI-MS
carbaryl	HPLC-APCI-MS
chlorothalonil	HPLC-APCI-MS
diazinon	HPLC-APCI-MS
diuron	HPLC-APCI-MS
ethoprop	HPLC-APCI-MS
fluometuron	HPLC-APCI-MS
malathion	HPLC-APCI-MS
metalaxyl	HPLC-APCI-MS
metolachlor	HPLC-APCI-MS
metribuzin	HPLC-APCI-MS
norflurazon	HPLC-APCI-MS
prometon	HPLC-APCI-MS
prometryn	HPLC-APCI-MS
propazine	HPLC-APCI-MS
propiconazole	HPLC-APCI-MS
simazine	HPLC-APCI-MS
tebuconazole	HPLC-APCI-MS
tebuthiuron	HPLC-APCI-MS
thidiazuron	HPLC-APCI-MS

Appendix F. Standard suite of NOAA National Status and Trends (NS&T) analytes investigated in sediment samples.

Analyte Name	Group
Coprostanol	Ancillary
Lipid Weight	Ancillary
Percent Lipid	Ancillary
Percent Moisture	Ancillary
Percent Solid	Ancillary
Sediment Clay	Ancillary
Sediment Fines	Ancillary
Sediment Gravel	Ancillary
Sediment Sand	Ancillary
Sediment Silt	Ancillary
Total Carbon	Ancillary
Total Inorganic Carbon	Ancillary
Total Organic Carbon	Ancillary
Chlorpyrifos	Contemporary Pesticide
Endosulfan I	Contemporary Pesticide
Endosulfan II	Contemporary Pesticide
Endosulfan Sulfate	Contemporary Pesticide
Aluminum (Al)	Element
Antimony (Sb)	Element
Arsenic (As)	Element
Cadmium (Cd)	Element
Chromium (Cr)	Element
Copper (Cu)	Element
Iron (Fe)	Element
Lead (Pb)	Element
Manganese (Mn)	Element
Mercury (Hg)	Element
Nickel (Ni)	Element
Selenium (Se)	Element
Silicon (Si)	Element
Silver (Ag)	Element
Thallium (Tl)	Element
Thorium (Th)	Element
Tin (Sn)	Element
Zinc (Zn)	Element
Clostridium perfringens	Microorganism
1,2,3,4-Tetrachlorobenzene	Organochlorine
1,2,4,5-Tetrachlorobenzene	Organochlorine
2,4’-DDD	Organochlorine
2,4’-DDE	Organochlorine
2,4’-DDT	Organochlorine

Appendix F. Continued. Standard suite of NOAA National Status and Trends (NS&T) analytes investigated in sediment samples.

Analyte Name	Group
4,4'-DDD	Organochlorine
4,4'-DDE	Organochlorine
4,4'-DDT	Organochlorine
Aldrin	Organochlorine
Alpha-Chlordane	Organochlorine
Alpha-Hexachlorocyclohexane	Organochlorine
Beta-Hexachlorocyclohexane	Organochlorine
Cis-Nonachlor	Organochlorine
Delta-Hexachlorocyclohexane	Organochlorine
Dieldrin	Organochlorine
Endrin	Organochlorine
Gamma-Chlordane	Organochlorine
Gamma-Hexachlorocyclohexane	Organochlorine
Heptachlor	Organochlorine
Heptachlor-Epoxide	Organochlorine
Mirex	Organochlorine
Oxychlordane	Organochlorine
Pentachloroanisole	Organochlorine
Pentachlorobenzene	Organochlorine
Total chlordanes	Organochlorine
Total DDT	Organochlorine
Total dieldrin	Organochlorine
Total Hexachlorocyclohexane	Organochlorine
Total Organochlorines	Organochlorine
Trans-Nonachlor	Organochlorine
Dibutyltin	Organometalic
Monobutyltin	Organometalic
Tetrabutyltin	Organometalic
Total butyltins	Organometalic
Tributyltin	Organometalic
Tripentyltin	Organometalic
Tripropyltin	Organometalic
Dichlorobiphenyls	Polychlorinated biphenyl
Heptachlorobiphenyls	Polychlorinated biphenyl
Hexachlorobiphenyls	Polychlorinated biphenyl
Nonachlorobiphenyls	Polychlorinated biphenyl
Octachlorobiphenyls	Polychlorinated biphenyl
PCB101/90	Polychlorinated biphenyl
PCB105	Polychlorinated biphenyl
PCB110/77 (PCB110 is dominant)	Polychlorinated biphenyl

Appendix F. Continued. Standard suite of NOAA National Status and Trends (NS&T) analytes investigated in sediment samples.

Analyte Name	Group
PCB112	Polychlorinated biphenyl
PCB118	Polychlorinated biphenyl
PCB128	Polychlorinated biphenyl
PCB138	Polychlorinated biphenyl
PCB153/132/168	Polychlorinated biphenyl
PCB170/190	Polychlorinated biphenyl
PCB18	Polychlorinated biphenyl
PCB180	Polychlorinated biphenyl
PCB187	Polychlorinated biphenyl
PCB195/208	Polychlorinated biphenyl
PCB201/173/157	Polychlorinated biphenyl
PCB206	Polychlorinated biphenyl
PCB209	Polychlorinated biphenyl
PCB28	Polychlorinated biphenyl
PCB44	Polychlorinated biphenyl
PCB52	Polychlorinated biphenyl
PCB66	Polychlorinated biphenyl
PCB8/5	Polychlorinated biphenyl
Pentachlorobiphenyls	Polychlorinated biphenyl
Tetachlorobiphenyls	Polychlorinated biphenyl
Total polychlorinated biphenyl	Polychlorinated biphenyl
trichlorobiphenyl	Polychlorinated biphenyl
* 3,3',4,4'- Tetrachlorobiphenyl	Polychlorinated biphenyl (coplanar)
* 3,3',4,4',5- Pentachlorobiphenyl	Polychlorinated biphenyl (coplanar)
* 3,3',4,4',5,5'- Hexachlorbiphenyl	Polychlorinated biphenyl (coplanar)
* 1,2,3,4,6,7,8-HPolychlorinated dibenzo-p-dioxin	Polychlorinated dibenzo-p-dioxin
* 1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	Polychlorinated dibenzo-p-dioxin
* 1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	Polychlorinated dibenzo-p-dioxin
* 1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	Polychlorinated dibenzo-p-dioxin
* 1,2,3,7,8-Pentachlorodibenzo-p-dioxin	Polychlorinated dibenzo-p-dioxin
* 2,3,7,8-Tetrachlorodibenzo-p-dioxin	Polychlorinated dibenzo-p-dioxin
* Octachlorodibenzo-p-dioxin	Polychlorinated dibenzo-p-dioxin
* 1,2,3,4,6,7,8-HPolychlorinateddibenzofuran	Polychlorinateddibenzofuran
* 1,2,3,4,7,8,9-HPolychlorinateddibenzofuran	Polychlorinateddibenzofuran
* 1,2,3,4,7,8-Hexachlorodibenzofuran	Polychlorinateddibenzofuran
* 1,2,3,6,7,8-Hexachlorodibenzofuran	Polychlorinateddibenzofuran
* 1,2,3,7,8,9-Hexachlorodibenzofuran	Polychlorinateddibenzofuran
* 1,2,3,7,8-Pentachlorodibenzofuran	Polychlorinateddibenzofuran
* 2,3,4,7,8-Pentachlorodibenzofuran	Polychlorinateddibenzofuran
* 2,3,7,8-Tetrachlorodibenzofuran	Polychlorinateddibenzofuran
* Octachlorodibenzofuran	Polychlorinateddibenzofuran

Appendix F. Continued. Standard suite of NOAA National Status and Trends (NS&T) analytes investigated in sediment samples.

Analyte Name	Group
Benzofluoranthene	Polynuclear aromatic hydrocarbon
C1-Chrysenes	Polynuclear aromatic hydrocarbon
C1-Dibenzo(a,h)anthracene	Polynuclear aromatic hydrocarbon
C1-DibenzOrganotinhiophenes	Polynuclear aromatic hydrocarbon
C1-Fluoranthenes/Pyrenes	Polynuclear aromatic hydrocarbon
C1-Fluorenes	Polynuclear aromatic hydrocarbon
C1-Naphthalenes	Polynuclear aromatic hydrocarbon
C1-NaphthobenzOrganotinhiophene	Polynuclear aromatic hydrocarbon
C1-Phenanthrenes/Anthracenes	Polynuclear aromatic hydrocarbon
C2-Chrysenes	Polynuclear aromatic hydrocarbon
C2-Dibenzo(a,h)anthracene	Polynuclear aromatic hydrocarbon
C2-DibenzOrganotinhiophenes	Polynuclear aromatic hydrocarbon
C2-Fluorenes	Polynuclear aromatic hydrocarbon
C2-Naphthalenes	Polynuclear aromatic hydrocarbon
C2-NaphthobenzOrganotinhiophene	Polynuclear aromatic hydrocarbon
C2-Phenanthrenes/Anthracenes	Polynuclear aromatic hydrocarbon
C3-Chrysenes	Polynuclear aromatic hydrocarbon
C3-Dibenzo(a,h)anthracene	Polynuclear aromatic hydrocarbon
C3-DibenzOrganotinhiophenes	Polynuclear aromatic hydrocarbon
C3-Fluorenes	Polynuclear aromatic hydrocarbon
C3-Naphthalenes	Polynuclear aromatic hydrocarbon
C3-NaphthobenzOrganotinhiophene	Polynuclear aromatic hydrocarbon
C3-Phenanthrenes/Anthracenes	Polynuclear aromatic hydrocarbon
C4-Chrysenes	Polynuclear aromatic hydrocarbon
C4-Naphthalenes	Polynuclear aromatic hydrocarbon
C4-Phenanthrenes/Anthracenes	Polynuclear aromatic hydrocarbon
DibenzOrganotinhiophene	Polynuclear aromatic hydrocarbon
Fluorescent aromatic comp.(hw)	Polynuclear aromatic hydrocarbon
Fluorescent aromatic comp.(lw)	Polynuclear aromatic hydrocarbon
NaphthobenzOrganotinhiophene	Polynuclear aromatic hydrocarbon
Total Fluorescent aromatic compounds	Polynuclear aromatic hydrocarbon
Total high molecular weight Polynucleararomatic hydrocarbon	Polynuclear aromatic hydrocarbon
Total low molecular weight Polynucleararomatic hydrocarbon	Polynuclear aromatic hydrocarbon
Total Polynucleararomatic hydrocarbon	Polynuclear aromatic hydrocarbon
1,6,7-Trimethylnaphthalene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
1-Methylnaphthalene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
1-Methylphenanthrene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
2,6-Dimethylnaphthalene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
2-Methylnaphthalene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
Acenaphthene	Polynuclear aromatic hydrocarbon (2 & 3 ring)

Appendix F. Continued. Standard suite of NOAA National Status and Trends (NS&T) analytes investigated in sediment samples.

Analyte Name	Group
Acenaphthylene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
Anthracene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
Biphenyl	Polynuclear aromatic hydrocarbon (2 & 3 ring)
Fluorene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
Naphthalene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
Phenanthrene	Polynuclear aromatic hydrocarbon (2 & 3 ring)
Benz[a]anthracene	Polynuclear aromatic hydrocarbon (4 or more ring)
Benzo[a]pyrene	Polynuclear aromatic hydrocarbon (4 or more ring)
Benzo[b]fluoranthene	Polynuclear aromatic hydrocarbon (4 or more ring)
Benzo[e]pyrene	Polynuclear aromatic hydrocarbon (4 or more ring)
Benzo[g,h,i]perylene	Polynuclear aromatic hydrocarbon (4 or more ring)
Benzo[k]fluoranthene	Polynuclear aromatic hydrocarbon (4 or more ring)
Chrysene	Polynuclear aromatic hydrocarbon (4 or more ring)
Dibenzo[a,h]anthracene	Polynuclear aromatic hydrocarbon (4 or more ring)
Fluoranthene	Polynuclear aromatic hydrocarbon (4 or more ring)
Indeno[1,2,3-c,d]pyrene	Polynuclear aromatic hydrocarbon (4 or more ring)
Perylene	Polynuclear aromatic hydrocarbon (4 or more ring)
Pyrene	Polynuclear aromatic hydrocarbon (4 or more ring)

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