A SENSITIVE BIOLUMINESCENT ECOSYSTEM: A MASTER PLAN FOR PUERTO MOSQUITO BAY IN VIEQUES, PUERTO RICO

By

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Abstract

A few years ago, Puerto Mosquito Bay, an iconic bioluminescent bay in Vieques, Puerto Rico, lost its prominent glow. The phenomenon precipitated an investigation by local environmental authorities on the potential causes for this black out.

The main objectives of this project were:

(1) to examine the ecological impacts affecting the concentration of bioluminescent dinoflagellates;

(2) to explore effective management strategies to mitigate the negative ecological impacts;

(3) to design a master plan for the protection of Puerto Mosquito Bay and for the provision of recreational activities and facilities.

Lessons learned from case studies, and analysis of the study area and region provided a framework to address two goals:

1) To recommend watershed management strategies for the restoration and protection of stream corridors discharging into Puerto Mosquito Bay.

2) To design a master plan that will conserve and preserve the bioluminescent ecosystem in Puerto Mosquito Bay, while providing recreational activities and facilities such as kayaking and camping compatible to Puerto Mosquito Bay and its surrounding landscape.

The recommendations and master plan could be used as a framework by planners, managers, and decision makers for future land planning and design ideas for the protection and preservation of a fragile bioluminescent ecosystem.

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1.1. Introduction of the Phenomenon

The brightest bioluminescent bay in the world[1] lost its refulgent glow on January 29, 2014. Environmental authorities and researchers were nonplussed about what caused the Puerto Mosquito Bay to cease showcasing its nocturnal spectacle that famously characterized it. Even though, a gap in this phenomenon has occurred in the past, it never persisted for more than a few days. In prior events, residual levels of concentration of bioluminescent organisms remained in the bay. However, this time it appeared to be a complete disappearance of the luminescent organisms.

This event was detrimental both ecologically and economically for the small island of Vieques. Viequenses rely on tourism to bolster their tenuous economy on the island. Night kayaking tours to the bay are a critical component in generating financial revenues for the local economy. This enigmatic blackout prompted elected officials to issue a moratorium restricting kayaking tours to weekend nights only and also to assemble a team of scientists to investigate the causes of the bay going dark (Alvarez, 2014).

Puerto Mosquito Bay is located on the south coast of the Island of Vieques, which is approximately ten miles off the eastern coast of Puerto Rico. The bay is situated within basins along the southern edge of a volcanic upland. This bay encloses about 158 acres. The maximum depth is about 12.1 feet and the average is about 8.8 feet (Figure 1).

[1] 2006 Guinness World's Record.

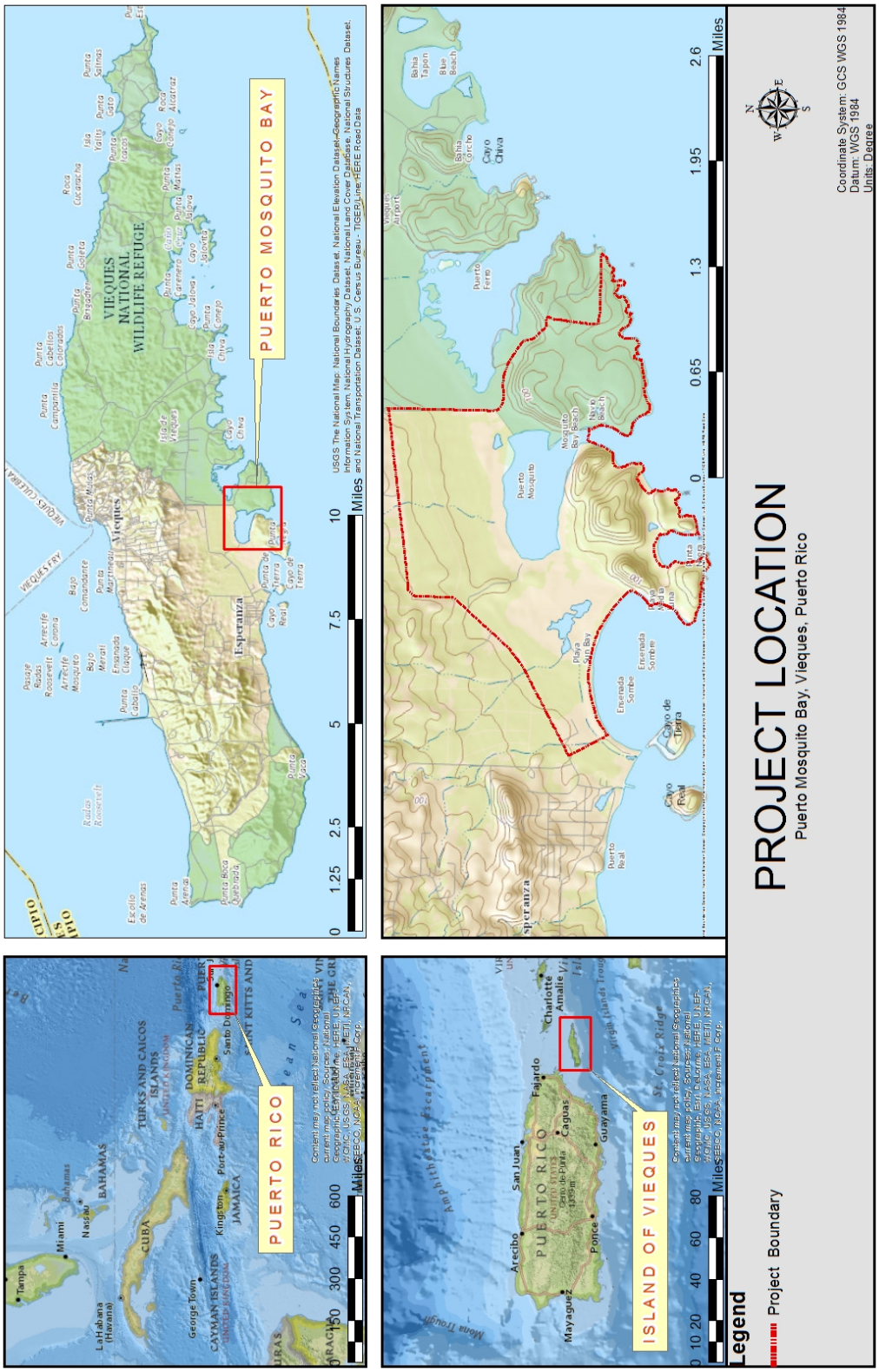

Figure 1: Puerto Mosquito Bay Location

1.2. Brief Description of Bioluminescence

Bioluminescence is light emitted by a living organism through a chemical reaction. A common example of this is the *firefly*. However, a firefly is a land organism, whereas most bioluminescent organisms are marine species found in quiescent and warm ocean waters. The kind of marine bioluminescent organisms found in Puerto Mosquito Bay are commonly known as *"dinoflagellates"*. Dinoflagellates are single-celled microscopic phytoplankton (Figure 2). When the water's surface is agitated, the wave energy generated causes pressure on the cell walls, thus serving as a catalyst for the chemical reaction within the dinoflagellates to take place and therefore illuminate the bay at night (Figure 3). They emit a blue-green part of the visible light spectrum. These organisms use their bioluminescent properties to attract potential mates, hunt prey, mitigate predatory impact, and conduct other survival activities.

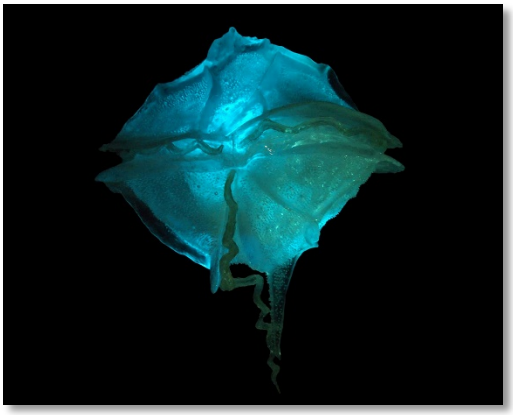

Figure 2: Dinoflagellate Specimen

1.3. Duration of the Phenomenon

The 2014 gap in this phenomenon commenced in late January when a decrease in bioluminescence and an increase in turbidity were detected. This discovery precipitated the action of the Department of Natural and Environmental Resources of Puerto Rico (DNER) to establish a temporary moratorium that restricted kayaking tours in May. As the bay regenerated and field data was being collected and analyzed, the dinoflagellates reappeared in June. According to the

Figure 3: Bioluminescent Bay

field data, the population density of the dinoflagellates in January was about 200 organisms/mL. In March, it had increased to 352 organisms/mL. And by June, it had more than doubled its number to a staggering 768 organisms/mL (ENDI, 2014). Evidently, the moratorium paid off and the dinoflagellate population was well on its way to a full recovery. Subsequently, the moratorium was lifted and normal operations (pre-moratorium) were resumed in early August 2014.

1.4. STATEMENT OF THE PROBLEM

Based on the conclusive findings from the data gathered during the moratorium, the causes of the gap in the phenomenon were attributed to seasonal tidal fluctuations, low precipitation, and low nutrients present in the ecosystem (DRNA). However, there are concerns that future black outs are possible and efforts should be considered to minimize this possibility. Thus, the main research question this project sought to answer was how the ecological impacts affecting the bioluminescent bay can be mitigated as well as managed in order to preserve the bioluminescent ecosystem of Puerto Mosquito Bay. Therefore, the central problem to be researched in this project was to accomplish three main objectives:

1. to examine the ecological impacts affecting the concentration of bioluminescent dinoflagellates.
2. to explore effective management strategies to mitigate the negative ecological impacts.
3. to design a master plan for the protection and conservation of Puerto Mosquito Bay, while providing for recreational activities and facilities to Puerto Mosquito Bay and its surrounding landscape.

1.5. SIGNIFICANCE OF THE PROJECT

This project is important because of the need to bring awareness of the ecological impacts threatening the intrinsic value of an inimitable ecosystem and presents landscape management and design solutions for the preservation of a fragile and delicate bioluminescent ecosystem, while allowing for human enjoyment.

1.6. MASTER PLAN

A master plan for long-term protection of the delicate bioluminescent ecosystem in Puerto Mosquito Bay was developed to ensure the preservation and conservation of the bay for future generations to experience and enjoy. Moreover, it provides design solutions that integrate recreational activities and facilities that are compatible with protecting bioluminescent ecosystem of the bay.

2. Literature Review and Puerto Mosquito Bay Background

2.1. BIOLUMINESCENT ECOLOGY

2.1.1. Brief Historical Background of Dinoflagellates

Pyrodinium bahamense specimens were first described by Plate in 1906 (Plate, 1906). Subsequently, two varieties of *P. bahamense* were identified, *P. bahamense var. bahamense* and *P. bahamense var. compressum* (Steidinger, Tester, & Taylor, 1980). Worldwide distribution of *P. bahamense* have been observed, particularly, *P. bahamense var. bahamense* in a variety of locations in the western North Atlantic, including Oyster Bay in Jamaica (Seliger et al. 1970, and Florida Bay (Philips & Basylak 1996), Indian River Lagoon (Badylak & Philip 2004), and Tampa Bay (Steidinger et al. 1980, Badylak et al. 2006) in Florida.

In Puerto Rico, concentrations of *P. bahamense* have been reported in Bahía Fosforescente and Bahía Monsio José near La Parguera, Puerto Rico (Margalef 1957) and Puerto Mosquito, Vieques, Puerto Rico (Seliger et al. 1969). Despite the plethora of literature on harmful algae blooms and paralytic shellfish toxin - producing marine dinoflagellates, there is no evidence of a correlation between the *P. bahamense var. bahamense* population in Puerto Mosquito Bay and any human illnesses and/or fatalities caused by PST producing dinoflagellates.

2.1.2. Physical Characteristics of Dinoflagellates

2.1.2.1. Type

In their taxonomy lineage, *Pyrodinium bahamense var. bahamense* dinoflagellates belongs to the Protista Kingdom. Protists are eukaryotic organisms that cannot be classified as a plant,

animal or fungus. They are mostly unicellular, but some are multicellular such as algae and seaweed. Protists can be *heterotrophic* - they meet their energy requirements by consuming other organisms – and *autotrophic*- they meet their energy requirements from the environment through photosynthesis. As with many phytoplankton, movement is often by flagella or cilia. Phototactic dinoflagellates tend to drift with the waves and currents near the surface of the sea as they migrate vertically within a few feet to the surface in the evening and sink down during daylight hours. Seliger et al. (1970) argue that this vertical aggregation is one of the mechanisms for accumulation of high concentration of dinoflagellates in bioluminescent bays. *P. bahamense* has been known to have a "biological clock" that can be stimulated to produce light during the night (Hasting, 1975; Bold and Wynne, 1978).

2.1.2.2. Size and Length

Pyrodinium bahamense var. bahamense specimens collected from bays in Puerto Rico and Jamaica measured a total length of 47 to 84 µm with a width of 35 to 64 µm (Balech, 1985).

2.1.2.3. Intensity of Luminescence

Most dinoflagellates emit about $6x10^8$ photons in a flash lasting only about 0.1 second. Much larger organisms such as jellyfish emit about $2x10^{11}$ photons per second for sometimes tens of seconds. The intensity of luminescence by photosynthetic dinoflagellates in strongly influence by the intensity of sunlight the previous day. The brighter the sunlight the brighter the flash which is only emitted at night. Moreover, high intensity of luminescence can be attributed to high concentration of dinoflagellates which probably is attributed to some combination of several factors such as low hydrodynamic activity, reduced exchange with coastal water, low grazing rate

by invertebrates, and phototactic vertical and lateral aggregation (Smithsonian Marine Station at Fort Pierce, 2011).

2.1.3. Abiotic Conditions for Dinoflagellates

An estuary or bay is a semi-enclosed coastal body of water which serves as a transition zone between land and sea, where freshwater and saltwater habitats interact. Thousands of marine species depend on these vital habitats. Estuaries are called the "nurseries of the sea" due to their protective environment and abundant food available to fish and shellfish for their reproduction. Abiotic conditions in an estuary may influence the composition of its environment. Many of these abiotic conditions are structured by hydrological processes such as currents, tides, and wind patterns in the embayment. For example, population dynamics of *P. bahamense* can be drastically affected by variations of levels of salinity, turbidity, temperature, dissolved oxygen, pH levels, nutrients and water depth.

2.1.3.1. Salinity

Salinity measures the concentration of dissolved salt in water. It is measured in parts per thousands (ppt or ‰). On average, the salinity of seawater is about 35 ppt, whereas in freshwater it is about 0.5 ppt. Thus, the salinity concentration in Puerto Mosquito Bay can range from 0.5 to 35 ppt given the fluctuation of entering the bay. Salinity levels fluctuate daily depending on climatological factors such as tidal cycle, precipitation levels and other weather factors. Typically, salinity levels decline in the spring as precipitation increases the freshwater flow from streams and groundwater. Conversely, salinity levels rise during the summer when temperatures rise and evaporation is accelerated in the bay (NOAA, 2008).

The results in some studies have suggested a positive correlation between lower levels of salinity and warmer water temperature with higher concentration levels of *P. bahamense*. For instance, Grasso et al. (2016) reported that isotonic or slightly hypertonic and relatively warm water are not desirable conditions for *P. bahamense*. Conversely, lower salinity and higher tide level are correlated with high *P. bahamense* abundance. (Grasso, Albrecht, & Bras, 2016). Seliger et al. (1970) have concluded based on laboratory results that *P. bahamense* are prone to migrate to high-salinity layers (S=34 ppt) than low-salinity layers (S=10-15 ppt) in the water column through vertical distribution (Seliger H. H., Carpenter, Loftus, & McElroy, 1970). Furthermore, one study concluded that the optimal salinity for *P. bahamense var. bahamense* is 35 ppt (Wall & Dale, 1969). However, salinity tolerance appears to vary based upon geographical location. For instance, *P. bahamense var. bahamense* in Florida have a salinity range of 10-45, even though blooms only transpired at 20 ppt or higher (Phlips, Badylak, Bledsoe, & Cichra, 2006). Evidently, these findings demonstrate that the tropical marine photosynthetic *P. bahamense* can tolerate a broad range of salinities.

2.1.3.2. Turbidity

Turbidity measures the level of haziness or cloudiness of a fluid. In other words, it determines how easily light can be transmitted through it. The accumulation of sediments, algae and other suspended solids in the water restricts the amount of light that can penetrate through the water.

High levels of turbidity in a bay have a negative effect on the health of the bioluminescent ecosystem. Organisms such as dinoflagellates depend on sunlight for their normal photosynthetic processes and gross primary production. *P. bahamense* is positively phototactic in direct tropical sunlight (Seliger H. H., Carpenter, Loftus, Biggley, & McElroy, 1971). Phototactic is defined as

the movement of an organism toward or away from a source of light. Therefore, *P. bahamense* will have a tendency to move toward (positive direction) a source of light like tropical sunlight.

2.1.3.3. Temperature

The temperature of the water often gives an indication of the type of organisms that thrive in the bay. Water temperature in the bay can serve as an indicator of a productive ecosystem. If the water in the bay shows an anomaly in the seasonal temperature range in which most organisms can comfortably live, it is probably an indication that some sort of ecological impact is adversely affecting the health of the bay.

Pyrodinium bahamense are mostly confined to warm tropical and subtropical waters greater than 20°C (68°F). They bloom at temperatures greater than 25°C (77°F). Phlips et al. (2006) argue that the relationships between seawater temperature and abundance in Florida (Indian River Lagoon, Tampa Bay, and Florida Bay) support the notion that *P. bahamense var. bahamense* is constrained to periods of high temperature. (Phlips, Badylak, Bledsoe, & Cichra, 2006)

Seliger et al. (1970) corroborate that the zone with high concentrations which corresponds to warm zones in Oyster Bay, Jamaica, W.I. (Seliger H. H., Carpenter, Loftus, & McElroy, 1970)

2.1.3.4. Dissolved Oxygen

Dissolved oxygen (DO) is critical for the survival of animals and plants that live in the water. The higher levels of DO in the water, the healthier the ecosystem. As oxygen from air is combined with surface waters through wind and waves actions, the dissolved oxygen level increases. However, oxygen goes into the water through two primary ecological processes: distribution from the atmosphere and photosynthesis by aquatic plants.

DO levels are affected by temperature and salinity. Solubility of oxygen in water, diminishes as the water's temperature and salinity are elevated. In other words, as the water temperature increases, the amount of oxygen that can dissolve in the water decreases. For example, freshwater at 0°C can contain up to 14.6 mg of oxygen per liter of water, but at 20°C, it can only hold 9.2 mg of oxygen per liter. In seawater, the solubility of DO is about 20 percent less than it is in fresh water at the same temperature. (NOAA, 2008)

DO levels are often influenced by seasonal water temperature fluctuations with the lowest levels occurring during the late summer months when temperatures are at the highest. (NOAA, 2008)

Oxygen depletion may occur in bays experiencing eutrophication – the process by which a body of water becomes eutrophic (overabundance of nutrients and especially nitrogen and/or phosphorous), typically as a consequence of high accumulation of mineral and organic runoff from the adjacent land including agricultural, suburban, and urban stormwater. Shallow, well-mixed bays are less susceptible to this phenomenon because wave action and circulation patterns supply the waters with plentiful oxygen.

2.1.3.5. pH Levels

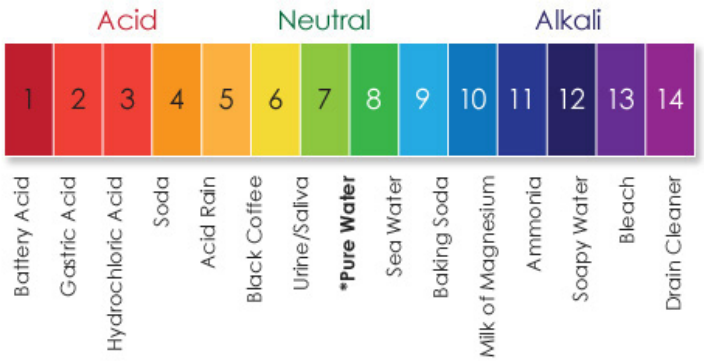

Figure 4: pH Levels Chart

The pH levels measure the acidity and alkalinity of a solution with a scale range from 1 to 14 (Figure 4). Acidic solutions contain pH levels lower than 7, whereas those higher than 7 are found in the basic (or alkaline) side of the spectrum. Pure or distilled water has a pH of 7 (neutral). Aquatic organisms are quite adaptive in pH levels between 5.0 and 9.0. Chemical components in seawater help to minimize changes to pH levels. However, pH levels have a tendency to increase in eutrophic bays. As a result of their study, Grasso et. al. (2016) attributed lower concentrations of *P. bahamense* in Puerto Mosquito Bay to a combination of lower pH levels and water temperatures resulting from storm runoff draining into the bay after a heavy precipitation event.

"One dramatic consequence of the rise in levels of atmospheric carbon dioxide (CO^2) is a decrease in pH, a process also known as ocean acidification." (Valdes-Pizzini & Sharer-Umpierre, 2014)

2.1.3.6. Low Nutrients

Nutrients are critical indicators of water quality in bays. Nutrients such as nitrogen and phosphorus are naturally introduced in a bay's waters when freshwater runoff passes over geologic formations with abundant phosphate or nitrate, or when decomposing organic matter and wildlife waste get flushed into rivers and streams (NOAA, 2008). Anthropogenic contributions to nutrient loading to the bay includes sewage treatment plants, leaky septic tanks, industrial wastewater, acid rain, and fertilizer runoff from agricultural, residential and urban areas. An overabundance of nitrogen and phosphorus acts as a pollutant in the water which leads to eutrophication of the bay.

Superfluous nutrient concentrations have been attributed to hypoxic (very low oxygen) conditions in more than 50 percent of U.S. estuaries. In extreme conditions, the bay's waters can become anoxic (having no oxygen).

2.1.3.7. Water Depth

Water levels in a bay fluctuate with the daily tides and weather conditions. In times of drought or excessive rainfall, the volume of the fresh water entering the bay from rivers or runoff, can easily change the physical, chemical and biological conditions.

Turbidity may be exacerbated with storm runoff or during periods of drought when there is a low volume of water in the bay and winds and waves disturb the muddy bottom at low tide. Conversely, excessive water level fluctuation (too high or too low) in a bay for an extended periods of time, may threaten the health of the bay's ecosystem.

2.1.3.8. Chlorophyll

Chlorophyll is a by-product of photosynthesis. Chlorophyll is a green pigment in plants that converts light energy into food and allows plants to grow. The level of concentration of chlorophyll in the water, is a key indicator of the density of phytoplankton in a bay, and the amount of primary productivity occurring as well.

Phytoplankton forms the base of the aquatic food web in a bay. The abundance of healthy organisms in a bay is linked to the amount of phytoplankton and primary productivity taking place.

"The total dinoflagellate population and chlorophyll-a showed a positive correlation in Puerto Mosquito at the surface and two meters. Pyrodinium bahamense is likely to be a major contributor to the chlorophyll-a concentrations, since it is the most abundant dinoflagellate in this bay…" (Walker, 1997).

2.2. Ecological Impacts Affecting Bioluminescent Ecosystems

Several theories developed speculating about the primary cause for the diminishing dinoflagellate population in 2014 in Puerto Mosquito Bay. These emerging theories included four main ecological impacts:

- Poor water quality
- Mangrove deforestation
- Climate change and prevailing wind patterns
- Ineffective ecotourism management plan

2.3. Watershed Management

2.3.1. Poor Water Quality

Water quality of the bay has been threatened by sedimentation, population growth and pollution. Turbidity in the bay is one of the most consequential indicators of water quality. The eutrophication of the bay can deprive dinoflagellates of their autotrophic process by increasing turbidity and reducing sunlight penetration. During high rates of precipitation, stormwater runoff can contain pollutants such as sediments, organic compounds, nutrients, trace metals, chloride, bacteria, oil and others that when flushed into the bay can significantly compromise the water quality. Furthermore, new construction leads to an increase in impervious surfaces which adds to the volume of stormwater runoff produced by high precipitation events. Impervious surfaces may divert stormwater that would typically percolate through existing pervious surfaces and to replenish the aquifers and groundwater.

Deterioration in water quality is due to increase of nutrients and turbidity due to sediment loads produced by land-based sources and anthropogenic activities, which in terms are the principal sources of habitat degradation.

A plan to protect a sensitive bay like Puerto Mosquito Bay must address land use. A watershed plan that includes sustainable green infrastructure will provide corrective measures that will assist in treating non-point source pollution in the stormwater runoff before it reaches the bay. Green infrastructure such as rain gardens, bioswales, permeable pavements and others measures can ameliorate the stormwater runoff prior to the point of entry into the bay. Pollution has a significant role to play in the deficiency of a bay's water quality. For instance, the amount of DEET (the active ingredient in insect repellants) that swimmers have sprayed on themselves that washes off in the bay may negatively affect dinoflagellates. Some studies have concluded that certain kinds of dinoflagellates (*Pyrocystis fusiformis*) are tolerant of N, N-diethyl-meta-toluamide (DEET) to certain level. However, when the threshold is surpassed, the dinoflagellates cease to exist (Ryan, 2011). Thus, DEET can be pernicious to dinoflagellates and detrimental to the health of the bioluminescent bay.

Swimming in the bay is currently prohibited and should remain so. Tour operators as well as conscientious ecotourists can help in adhering to the park rules and educating themselves about the impact they make. Pollutants such as carbon emissions from motorboats, either when they are running or idled, can cause irreversible environmental damage to the bay and therefore to dinoflagellates. Thus, their use in a sensitive bay like Puerto Mosquito should be avoided (Valdes-Pizzini & Sharer-Umpierre, 2014).

2.4. VEGETATION MANAGEMENT

2.4.1. Mangrove Deforestation

The clearing of red mangroves degrades the dinoflagellates' feeding ground. The roots of the red mangrove release tannins which are rich in Vitamin $B_{12,}$ nutrient needed by dinoflagellates (Mangrove Lagoons). Thus, the absence or reduction of these nutrients due to the removal of red mangrove roots is detrimental to the dinoflagellates' growth cycle. Furthermore, decomposed red mangrove leaves that have fallen in the water provide additional nutrients that are essential for the survival of dinoflagellates (Mangrove Lagoons).

Red mangroves along the shoreline provide numerous ecosystem services. One is storm protection for human ecosystems. "Mangrove restoration in Vietnam has been shown to attenuate wave height and thus reduce wave damage and erosion" (Hale & al., 2009, p. 23). They also benefit the region economically. "In Malaysia, the value of intact mangrove swamps for storm protection and flood control has been estimated at USD $186,420 per mile, which is the cost of replacing them with rock walls" (Hale & al., 2009, p. 23). Moreover, mangroves play a crucial role in providing ecosystem services to the local environment such as carbon sequestration and sediment storage. "Healthy mangroves also provide numerous additional benefits, such as timber and fisheries production, biofiltration, and recreational activities like recreational fishing and bird watching, services not provided by nonecosystem-based coastal protection alternatives." (Hale & al., 2009, p. 23).

Protection and restoration of red mangroves will ameliorate the natural habitat for the bioluminescent phytoplankton. Another benefit of mangrove restoration is that it provides refugia for microscopic phytoplankton and other species.

2.4.2. Climate Change and Wind Patterns

The increasing concentration of "greenhouse gasses" (GHG) in the atmosphere, caused mostly by anthropogenic activity since the beginning of the industrial revolution, has accelerated the warming of the Earth. This increase of atmospheric CO_2 concentration has modified the amount of radiation absorbed from the Earth's surface, raising the global temperature (Shipman & Wilson, 1990). Consequently, the temperature of the oceans is increasing, resulting in ocean acidity to also increase, as global warming intensifies.

There are two related factors that contribute to the rising of sea level: Thermal expansion; resulting in the warming of ocean water; and the vast input of freshwater in the ocean from melted ice sheets, ice caps, and glaciers from Greenland and Antarctica. These two factors have contributed about 75 percent of the global mean sea level increase. Thermal expansion has attributed 23 percent of the average annual rise in global sea level from 1961 to 2003 (IPCC, 2014). It has also attributed 52 percent of the average rise in global sea level from 1993 to 2003 (IPCC, 2014). Input of freshwater from the melting of ice sheets, ice caps and glaciers have contributed to 38 percent of the annual global sea-level rise from 1993 to 2003. It is projected that the oceans will rise between 20 inches to more than 3 feet by 2100 (IPCC, 2014).

The main potential stressors to bioluminescent systems due to climate change are the increases in heavy precipitation, storms, and hurricanes. Heavy precipitation and storms lead to increases in runoff into these systems. This can trigger increases in sediment and nutrient loading which would affect water quality due to increased turbidity, primary productivity, as well as frequency and extension of salinity levels fluctuation.

Dinoflagellates can also be affected by warmer temperatures expected from global climate change, because temperature is considered one of the main abiotic conditions that influence the growth of these organisms. At some point temperature may rise to a level that will inhibit survival of dinoflagellates.

Winds produced by inclement weather have been found to considerably change the composition of the optimal conditions for the organisms to thrive. These conditions are warm, calm and shallow waters (Jha, 2013). Torrential rain, strong wind gusts and storm surge can potentially cause the dinoflagellates' population to be flushed out into the ocean:

> "While no conclusions have yet been drawn, Dr. Latz said one reason for the loss of bioluminescence may be a shift in wind direction to the north last winter. Strong winds from that direction would push the dinoflagellates (which cannot swim against the current) out of the bay's narrow mouth back into the Caribbean Sea. These strong winds in January and March also made the bay extremely turbid, which interferes with bioluminescence." (Alvarez, 2014, p. 3).

While some natural disturbances like hurricane winds are impossible for managers and planners to predict, let alone address in a management plan, some adaptation strategies if properly implemented would be effective in mitigating the damages these forces of nature are likely to cause to the bioluminescent ecosystems and coastal development. For example, strategic planting of mangroves and other plant material will buffer wind gusts and erosion.

2.5. ECOTOURISM MANAGEMENT

2.5.1. Ineffective Ecotourism Management Plan

The increase kayaking has been presumed to be a plausible cause of the bay losing its nocturnal show. The interagency communication and management coordination among various jurisdictions (federal, state, and municipal) have been a challenge. The management of ecotourists who have flocked to Puerto Mosquito Bay is the responsibility of the following environmental agencies:

1) Puerto Rico Department of Natural and Environmental Resources (PRDNER)

2) Puerto Rico Environmental Quality Board (PREQB)

3) Vieques Conservation and Historical Trust (VCHT)

4) US Fish and Wildlife Service

One of the main challenges for these authorities is the coordination of their jurisdictions. Some discrepancies among details in zoning regulations and planning have weakened the protective emphasis of the bay that one would assume come with the Marine Protected Area designation. Puerto Mosquito Bay is currently classified as a natural reserve which is categorized in a lower rank of classification for the level of protection that is needed.

> "A lack of enforcement is perhaps the most consistent and persistent hurdle in the management of coastal and marine resources, not only in Puerto Rico but in all the Caribbean under US jurisdiction. There are certain activities that impact coral reef and marine stocks in which enforcement is scarce to null" (Aguilar-Perera, 2006, p. 968).

However, it will be imperative for these agencies to develop a well-conceived ecosystem-based management plan that can be effectively implemented in order to regulate a tractable number of visitors. Unregulated recreation carrying capacity of the site can degrade the bioluminescent ecosystem further.

Pollution from artificial lighting has recently been added as a potential contributor to depriving ecotourists with the full experience of maximum illumination of the bay. In other words, to fully experience the glow of the bay, the darker the ambient light the brighter the bay appears, thus the more satisfying the experience is. Recent studies on artificial light pollution have suggested that artificial lighting abates the intensity of the luminescent properties of the bay. Therefore, street, residential, commercial and other forms of ambient lighting should be monitored and reduced in order to assuage the effect on the bay (Ramos, 2003)

3. Case Study Analysis

Case studies focus on the subject being studied and in particular a specific aspect of that subject. In this case, those are 1) the ecological impacts affecting the health of the estuary ecosystem and 2) management strategies implemented to mitigate the effects of the impacts. The primary data for this was collected through comparative case study analysis from selected estuaries or bays that closely resemble the character of Puerto Mosquito Bay and/or the conservation and management issues facing the bay.

The following three estuaries or bays were analyzed:

- Morro Bay, California, USA
- Mangrove Lagoon, Salt River Bay, St. Croix, USVI
- La Parguera, Lajas, Puerto Rico

3.1. MORRO BAY, CALIFORNIA

3.1.1. Project Description

Location: 320 km north of Los Angeles and 370 km south of San Francisco

Size: 2,300-acres

Project Type: Coastal Embayment, Estuary.

Morro Bay (Figure 5) is relevant to Puerto Mosquito Bay because the challenges it had to overcome in order to reach the goal of ecological restoration. Challenges such as poor water quality, ecosystem degradation, and a lack of management plan exclusively apply to Puerto Mosquito Bay.

Morro Bay's ecosystem serves as a home for many fish, mammals, invertebrates, and plants. The ecosystem provides significant services such as recreational and commercial fishing, recreational boating, land-based agriculture including farming and grazing, and an active oyster and abalone aquaculture industry.

The watershed for the Morro Bay Estuary covers approximately 75 square miles. Sixty-eight percent of land-cover for the watershed includes agricultural land, eleven percent in urbanized residential areas and the remaining are some open spaces for public facilities and recreation areas.

A potential point-source of pollution that threatens the ecological health of Morro Bay is the 200-foot-tall stacks of the natural gas-fired power plant. Another one is the partial discharge of treated sewage into the coastal environment.

3.1.2. Benefits

- Wildlife habitats
- Ecosystem services: shellfish harvest and recreational activities

- Open spaces for public facilities and recreation areas
- Stormwater runoff detention and percolation.

3.1.3. Lessons Learned

- Watershed management strategies for mitigating point-source pollution from natural gas-fired power plant and land use cover change from agriculture, urban, and residential zoning.
- Ecosystem-based management plan to provide interagency communication and management coordination among various jurisdictions (federal, state, and municipal).

3.1.4. Photograph of Site

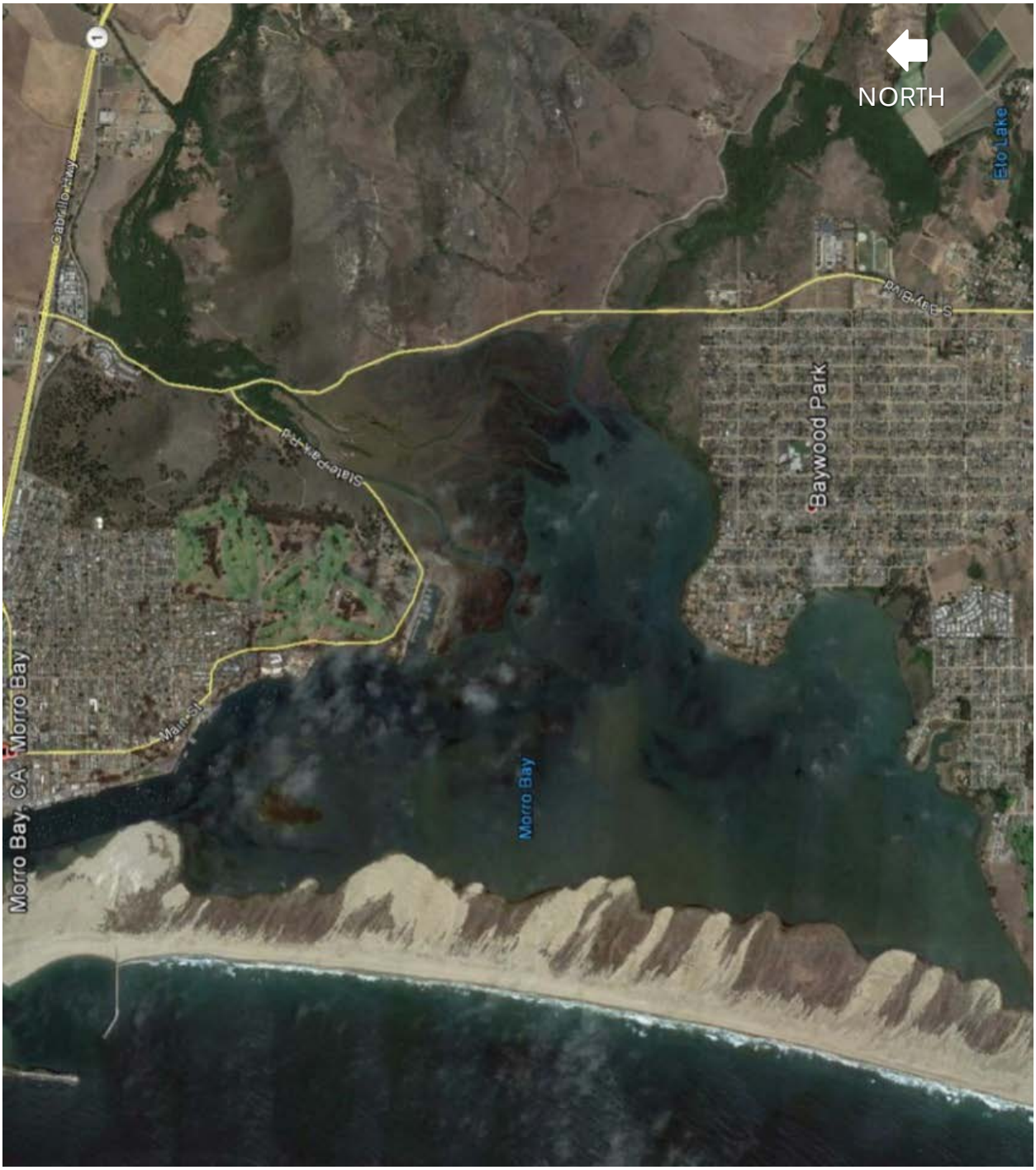

Figure 5: Morro Bay, California

3.2. MANGROVE LAGOON, SALT RIVER BAY, ST. CROIX, USVI

3.2.1. Project Description

Location: Salt River Bay National Historical Park and Ecological Preserve

Size: 9.3-acre

Project Type: Coastal Embayment, Estuary, Ecological Preserve

Mangrove Lagoon (Figure 6) shares similar bioluminescent characteristics with Puerto Mosquito Bay. It demonstrates the relationship between water quality, dinoflagellate concentration, mangrove preservation and ecotourism management. Mangrove Lagoon is located within Salt River Bay National Historical Park and Ecological Preserve (SARI) which is managed by the National Park Service (NPS) and the Government of the Virgin Islands of the United States (GVI). In order to bolster the goals of the park, NPS, SARI, and other collaborators conducted resources management and research activities. These activities have included demolition and removal of derelict structures, shoreline stabilization, evaluation of man-made peninsula, year-long sea water quality survey inside/outside the bay, installation of an automated weather station recoding rainfall, wind speed, temperature, vegetation inventory and mapping, coral monitoring, removal of invasive plants and planting of native plants around the mangrove lagoon and peninsula to bolster native plant diversity and wildlife ecosystems.

The susceptibility level of point and non-point sources pollution to Mangrove Lagoon has been considered to be high, unfortunately the bay has continued to suffer from upland erosion from development and land clearing within the watershed, discharges from live-boats, construction of fiberglass boats, and failed private septic systems which are all having adverse effects on the water quality and turbidity in the bay (Rothenberger, 2008). Therefore, NPS and GVI has taken management action to control pollution and improve the overall water quality to support the

nursery, mangrove, and coral reef ecosystems. In the last 15 years, ecotourists have flocked to the bioluminescent waters of Mangrove Lagoon. Night kayak tours have steadily been increasing to the point where an ecotourism management plan that includes acceptable levels of recreation carrying capacity is needed to conserve the natural bioluminescent ecosystem in Mangrove Lagoon.

3.2.2. Benefits

- Wildlife habitat (marine, estuarine, and terrestrial)
- Largest mangrove forest in the US Virgin Islands
- Bioluminescent bay, an ecotourists' attraction.
- Recreational activities – night kayak tours.

3.2.3. Lessons Learned

- Water quality management and pollution control.
- Ecosystem-based management plan to provide interagency communication and management coordination among various jurisdictions (federal, state, and municipal).
- Vegetation management plan for Mangrove Lagoon that include strategies such as removal of invasive plants, and planting of native plants, vegetation inventory and mapping.
- Shoreline stabilization, erosion control measures and re-pavement of park historic access road.

3.2.4. Photograph of Site

Figure 6: Mangrove Lagoon, Salt River Bay, St. Croix, USVI

3.3. BAHÍA FOSFORESCENTE, LA PARGUERA, LAJAS, PUERTO RICO

3.3.1. Project Description

Location: Southwest coast of Puerto Rico

Size: 49-acre

Project Type: Bioluminescent Bay/Estuary

Bahía Fosforescente (Figure 7) resembles Puerto Mosquito Bay in that it is also a bioluminescent bay. As with Puerto Mosquito Bay, Bahía Fosforescente is characterized by calm and shallow waters, narrow entrances and surrounded by relatively low rolling hills. At La Parguera, the low-lying lands surrounding the bay exhibit a gamut of sands, clays and muck deposit. Bahía Fosforescente attracts a large number of visitors to La Parguera who travel by boat, owned by local operators, to the coves. Therefore, a number of factors affecting the ecology of dinoflagellates in this bay in particular includes: visitation patterns, the wake caused by vessel traffic, the influence of propellers stirring up sediments, carbon emissions from gasoline and diesel motorboats, and the chemicals and contaminants from the vessels. Conversely, the bioluminescent ecology in Bahía Fosforescente has been affected by surrounding agricultural activities (timber production, mangrove cutting, charcoal production, small agricultural farms, pastures, and sugarcane production mainly in the 20th century).

A study that compared land use/land cover maps of Bahía Fosforescente and Puerto Mosquito Bay concludes that Bahía Fosforescente has more exposure to anthropogenic activities than Puerto Mosquito Bay which results in less density of vegetation than Puerto Mosquito Bay (Viruet, 2002).

The implication of these findings is that the environmental degradation thru changes of land use surrounding the bioluminescent ecosystem might negatively affect the viability of dinoflagellates.

3.3.2. Benefits

- Wildlife habitat
- Bioluminescent bay, an ecotourist attraction.
- Recreational activities – night kayak tours.
- Mangrove forest for attenuating prevailing wind and providing nutrient to dinoflagellates.

3.3.3. Lessons Learned

- Vegetation management plan for Mangrove Lagoon that include strategies such as removal of invasive plants, and planting of native plants, vegetation inventory and mapping.
- Shoreline stabilization, erosion control measures and repavement of park historic access road.
- Watershed management for pollution and erosion control.

3.3.4. Photograph of Site

Figure 7: La Parguera, Lajas, Puerto Rico

4. Site Inventory, Analysis and Synthesis

The site inventory, analysis and synthesis is divided into three section: site analysis – island, site analysis – watershed, and site analysis – park site.

4.1. SITE ANALYSIS – ISLAND

4.1.1. Point of Access and Transportation

There are two main point of access from the main island of Puerto Rico, both located on the northern coast of the island: Vieques Ferry Port and TJVQ Vieques Airport.

Sea travel is available through Fajardo –Vieques Ferry for passenger and cargo. The ferry has available four scheduled trips daily to Vieques. Even though, this mode of travel takes longer (75-90 minute ferry ride) than by air (20-30 minute flight), most travelers prefer to use this economical mode of transportation ($4USD round trip per passenger).

Air travel can be arranged through the following airline services: Air Culebra, Vieques Air Link, and Isla Nena Air Service. Flights depart from the San Juan International Airport to Vieques 5 times a day.

Ground transportation is available by public transit (bus), taxi, or car rental. Public transit (bus) includes prices that range from $2USD to $5USD per person from a specific site drop off or various sightseeing locations. Taxi services can be arranged as well, price is negotiable. For example, a trip from Isabel II to Sun Bay Beach (5 mile trip) can cost around $6USD. Car rental prices vary between $35-$50USD per day depending of the car model and year. Most car available are all-terrain vehicles (jeep) and some minivans.

4.1.2. Accommodations

Vieques offers a wide range of places to lodge. Types of accommodations includes: Villas, vacation homes, apartments, studios, hotels, and guesthouses (Figure 8).

4.1.3. Food Services

Vieques offers numerous places to eat. Food services can be conveniently provided at the places guests are staying. In addition, a number of local eateries are available such as: restaurants, cafes, bakeries, delis, and fast food (Figure 8).

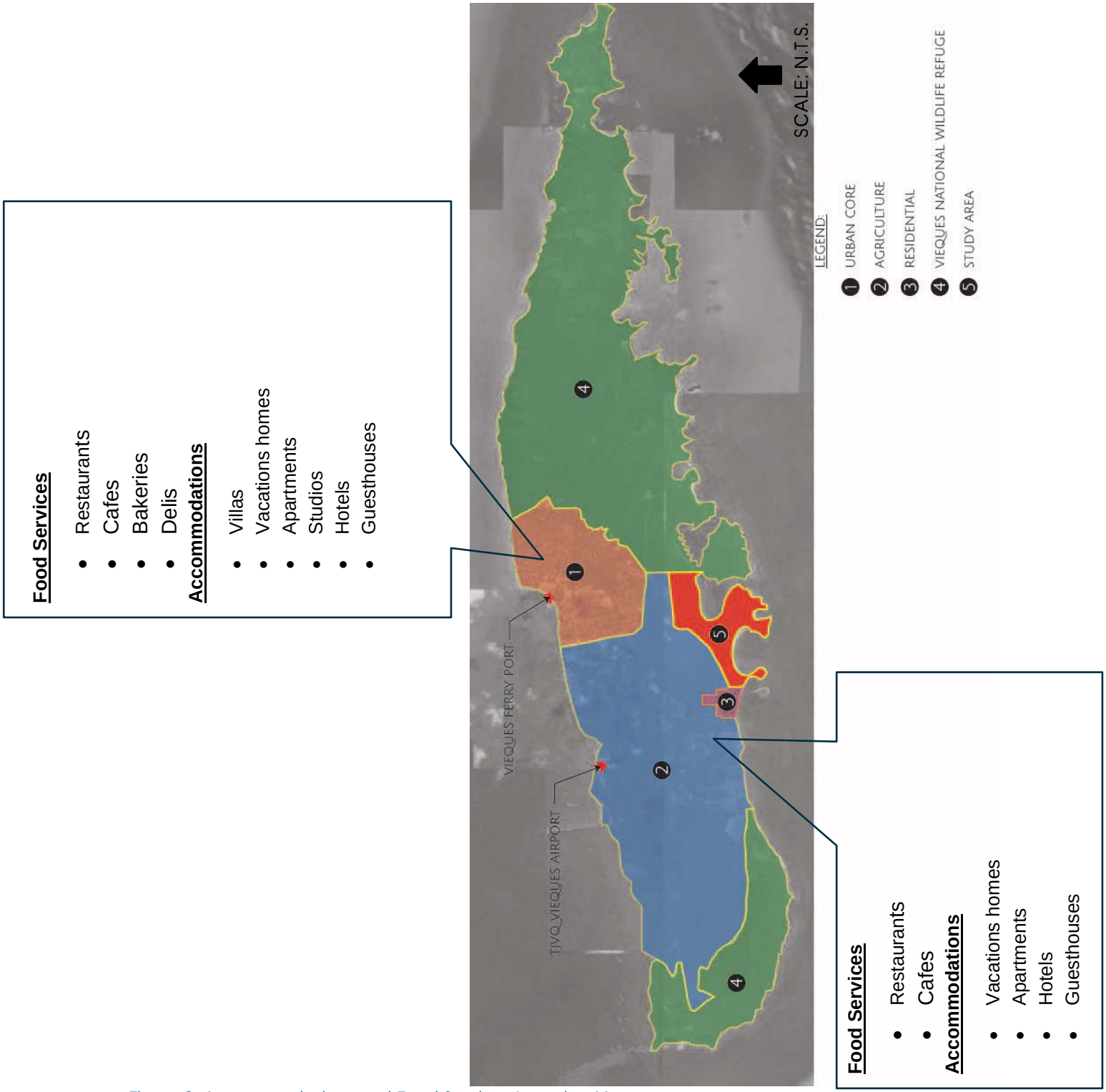

Figure 8: Accommodations and Food Services Location Map

4.2. SITE ANALYSIS – WATERSHED

There are two watersheds that feed Puerto Mosquito Bay, Watershed – East and Watershed – West (Figure 10).

4.2.1. Existing Land Use Zoning

There are three main land use classifications within the watersheds that support the stream corridors that flow into Puerto Mosquito Bay (Figure 9).

Agriculture:

This zone is characterized as rural and agricultural areas that are allowed to be developed. The areas are prime farmland if irrigated. Typical crops includes coffee, bananas, coconuts, papaya, fruit trees, and sugarcane. Development must be consistent with the retention of pastoral open spaces, and a bucolic character. It also needs to preserve environmentally sensitive areas. The vast majority of the stream corridors that outflow into the bay run through this agriculture land use zoning category.

Conservation:

Development is permitted as long as it protects natural and historic resources. Approximately, 25% of the stream corridor in the Watershed – West is located in the conservation zone. In the Watershed – East, about 60% can be found in the conservation area.

Residential:

This includes urban residential development that may consist of a full range of housing types, lot sizes, and densities. Currently, 8% of the stream corridor in the Watershed – East originates in this zone.

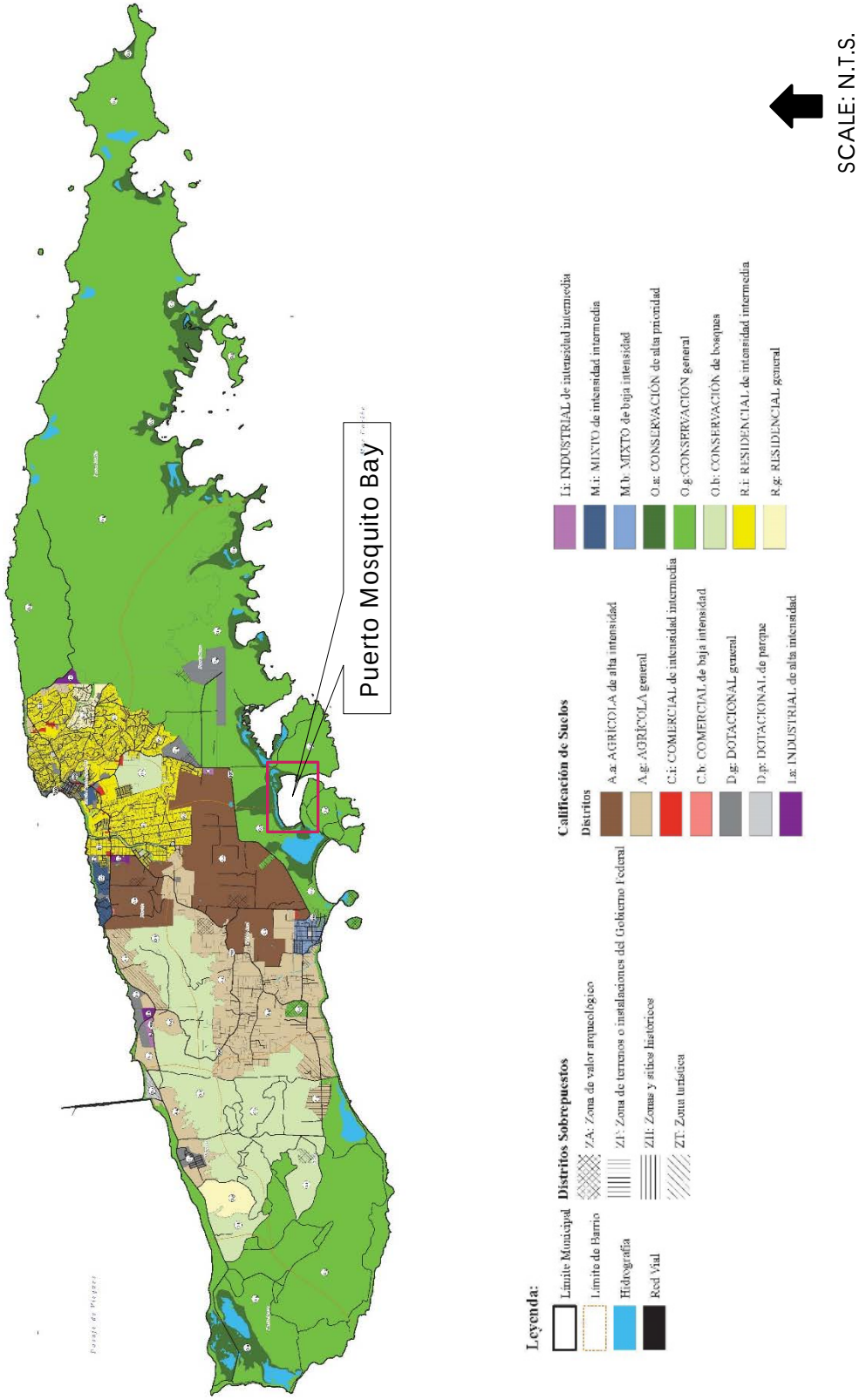

Figure 9: Vieques' Land Zoning Map

4.2.2. Existing Stream Corridor Condition

Existing stream corridor conditions appear to be unknown in the absent of physical inspection. According to the most recent waterbody quality assessment report for Puerto Mosquito Bay conducted by EPA for years 2012 and 2014, the overall status was not assessed. However, the 2010 report indicated the status was good. It could be interpreted that the water quality contribution from the existing stream corridors to the bay was in acceptable condition according to EPA's standards in the 2010 report, but one obvious recommendation is to initiate annual monitoring of these streams to ensure no negative changes in water quality.

4.2.3. Future Land Use

Changes to the existing land use could exacerbate current bio-physiological conditions of the streams in the two Puerto Mosquito Bay's watersheds. For instance, if in the future the agriculture zone that encompasses most of the stream corridors were to be developed, it would threaten the water quality and therefore the existence of dinoflagellates. An increase in impervious surfaces would contribute to sediment loading, erosion and pollution to the bay.

4.2.4. Conclusion

A comprehensive land use plan for Puerto Mosquito Bay's watershed and stream corridor pollution control methods for its streams must be developed as part of an integrated protective strategy for Puerto Mosquito Bay. Siting considerations, and planning for water pollution and stormwater control must be included in design guidelines. More specifically, it is important for management entities responsible for the bay to minimize any future development in the watershed, ensure proper use of low impact development techniques to minimize the impact of any new

development in the watershed, and to consider mitigating the existing impacts from urban and agricultural land uses within the watershed.

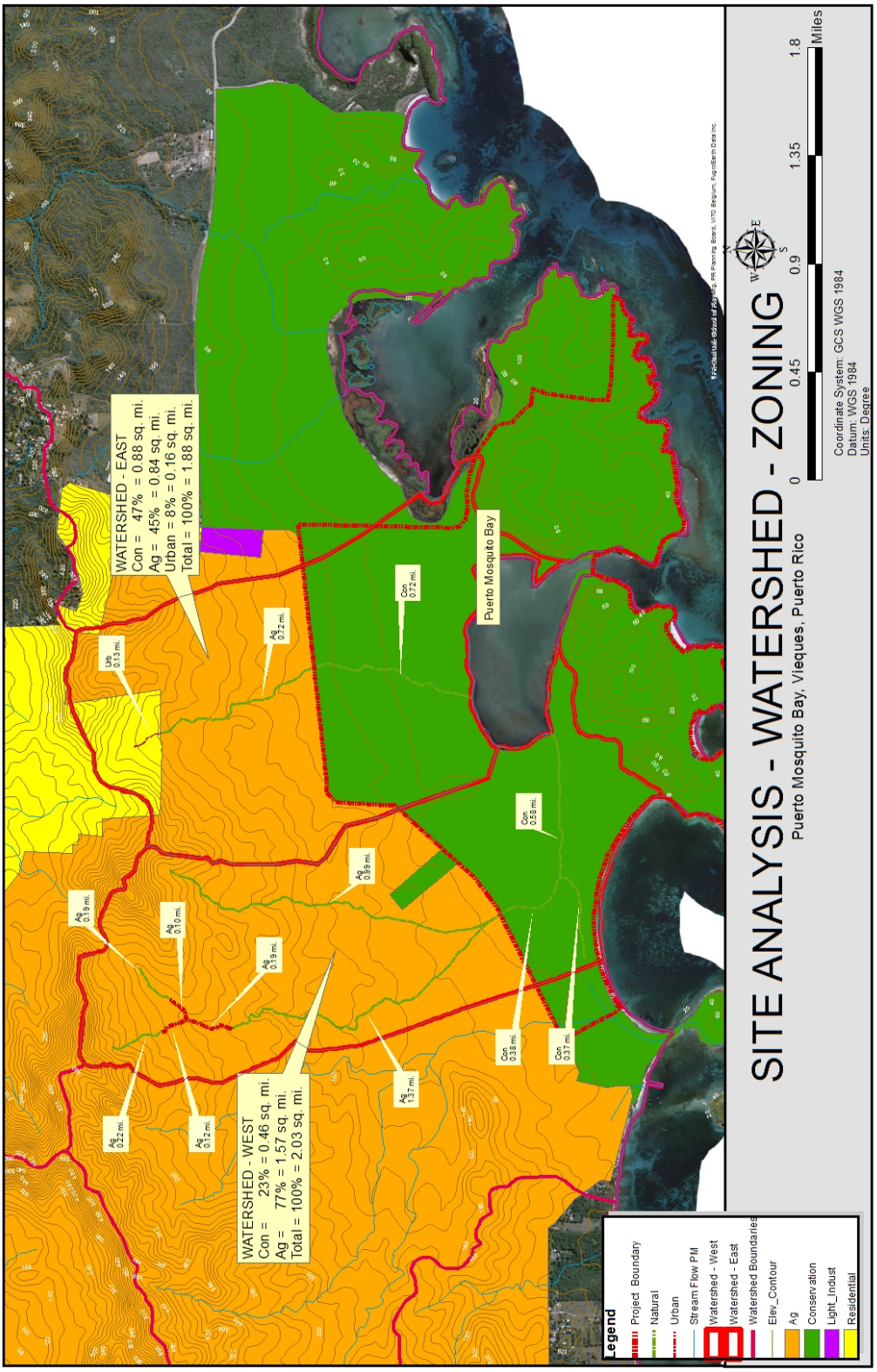

Figure 10: Site Analysis – Watersheds -Zoning and Stream Corridors

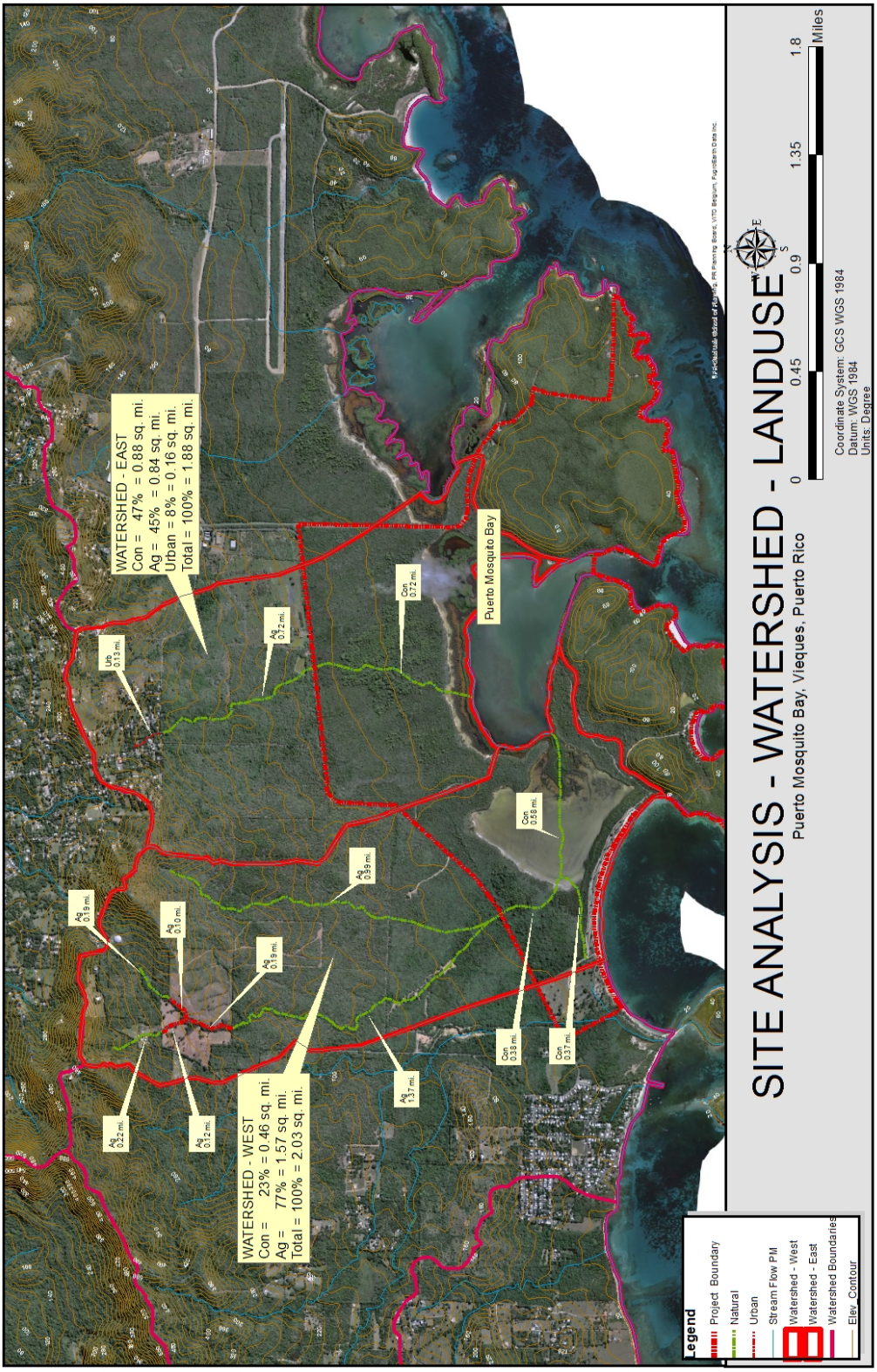

Figure 11: Site Analysis - Watershed - Land Use and Stream Corridors

4.3. SITE ANALYSIS – PARK SITE

4.3.1. Land Use and Access

Puerto Mosquito Bay is surrounded by land uses identified as conservation, preservation, rural, urban, and residential – tourism (low density). The land immediately surrounding the bay is classified as conservation area (Figure 10).

The primary means for arriving at the site is traveling on an unpaved road, approximately 2,600 feet off of PR997 heading southeast. A second unpaved road that provides access to the site is approximately 3,000 feet in length running the southwest off of a sandy path from Sun Bay's Beach. Both roads end at the edge of the bay where points of deployment for kayaks have been designated and modestly developed with parking, and boat launch.

4.3.2. Topography and Slope

The landform within the park site is composed of a series of hill summits on two rock island areas. Summits or convex landforms are described as high points of ground. Generally, the summits on both rock islands show contours in a concentric arrangement sloping at about 6%. Generally, speaking the higher the summit of a convex landform, the steeper its side slopes. In this particular case, the steep side slopes on the west side and east site are 6.4% and 5.8% respectively (Figure 12) and run from a high point of 25 feet to 0 feet at a distance of approximately 416 feet. This can cause erosion at the edges, and contributing to sediment loading to the bay. Conversely, on the north shore of the bay, the slope or gradient is relatively level with a 0.5% slope with the high point of 15 feet to 0 feet at a distance of 2640 feet. This

creates a low-lying area where frequent flooding and ponding occurs. A drainage divide on the east side of the bay allows for stormwater to be channeled into the salt marsh adjacent to the bay.

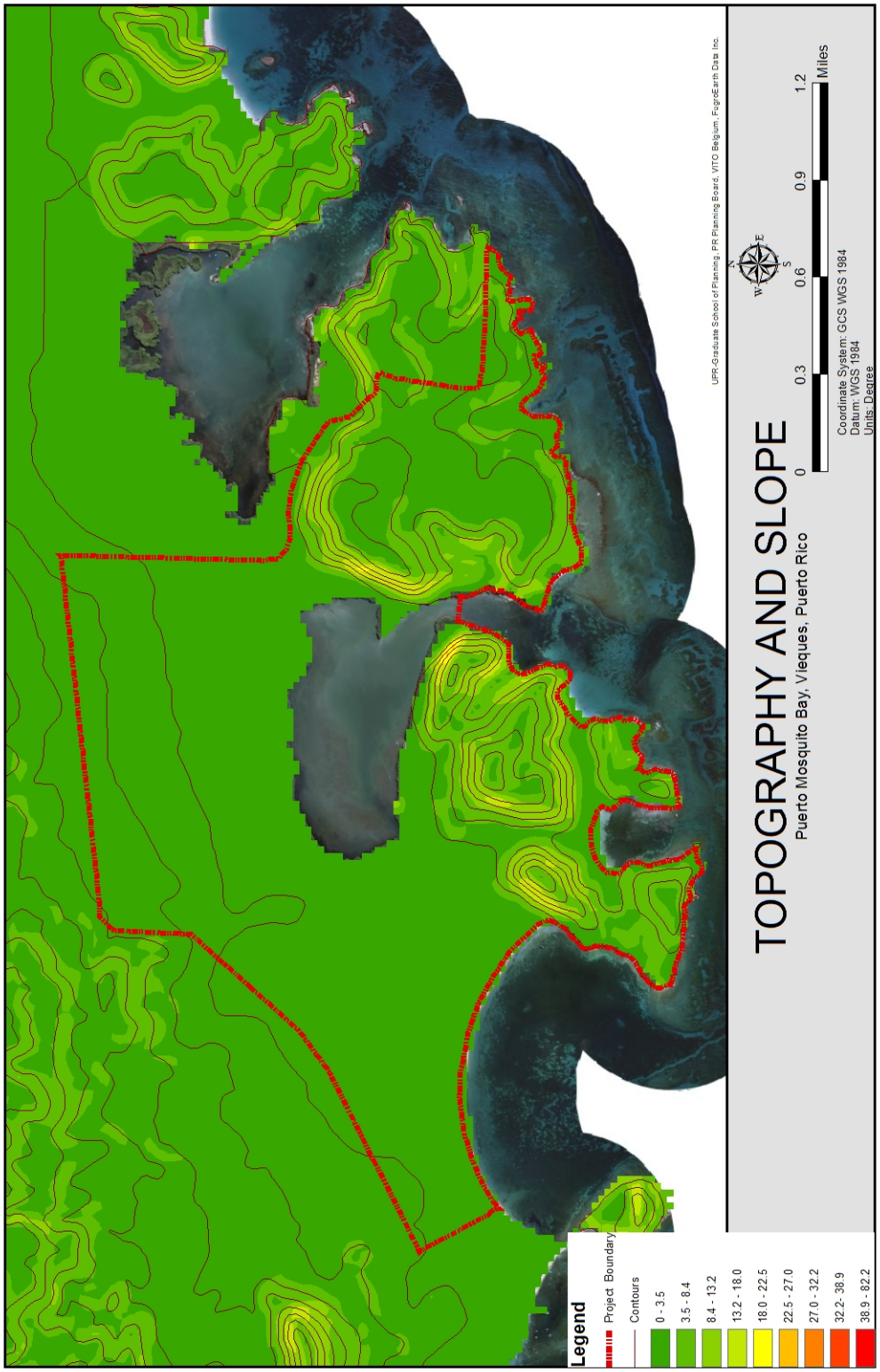

Figure 12: Topography and Slope Map

4.3.3. Hydrology

Water in the bay circulates through tidal fluctuations, freshwater runoff from creek that enters the bay and brackish or saline surface water that enters from a saline marsh to the west (Figure 13). There is some sheet flow runoff flowing from land area on the north side.

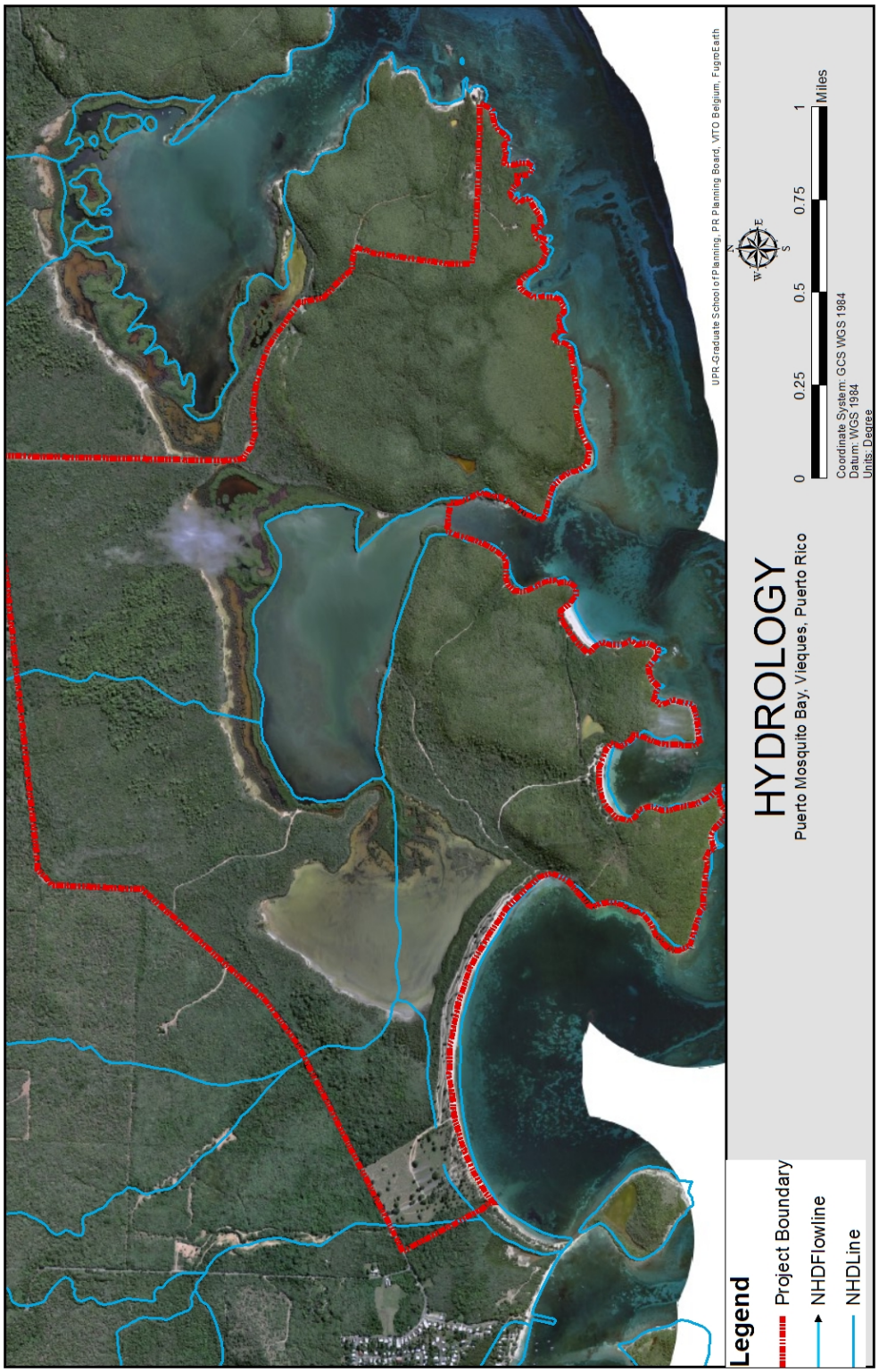

Figure 13: Hydrology Map

4.3.4. Soils

Soil composition at Puerto Mosquito Bay encompasses four main types: Tidal flats (Tf), Tidal swamp (Ts), Rock land (Rs), and Vieques loam, 5 to 12 percent slopes (VmC) (Figure 14). Tidal flats and tidal swamps are similar in their properties. They are both found in areas where the landforms are fairly level and wet (wetlands) and the elevations are between 0 and 10 feet. Slope is between 0 to 2 percent. Their natural drainage property is classified as very poorly drained, and therefore tend to flood and pond frequently. Based on the Hydrologic Soils Group, soils are rated by assigning a grade of either “A”, “B”, “C”, or “D”. An A soils exhibit the highest infiltration rate, whereas D soils have the lowest infiltration rate. Tidal swamp has a rating of C/D which indicates that it has a very low infiltration rate (0.00 – 0.15). They exhibit strong salinity levels – 16.0 to 32.0 mmhos/cm. However, the difference between them is the depth to the water table. Tidal flats have a depth of about 12 to 24 inches, whereas with tidal swamp is 0 inches.

Conversely, rock land soil is prevalent in ridges landforms. It has a steep slope of approximately 60 to 70 percent. Finally, Vieques loam’s soil is predominant in hillslopes where elevations between 10 to 100 feet dominate the landscape. Slope of 5 to 12 percent exhibits a well-drained surface which translates to low or no frequency of flooding or ponding. It also is non-saline to very slightly saline (0.0 to 2.0 mmhos/cm). Moreover, Vieques loam, 5 to 12 percent has a rating of B (0.15 - .30) which is considered moderate, based on the Hydrologic Soil Group rating system.

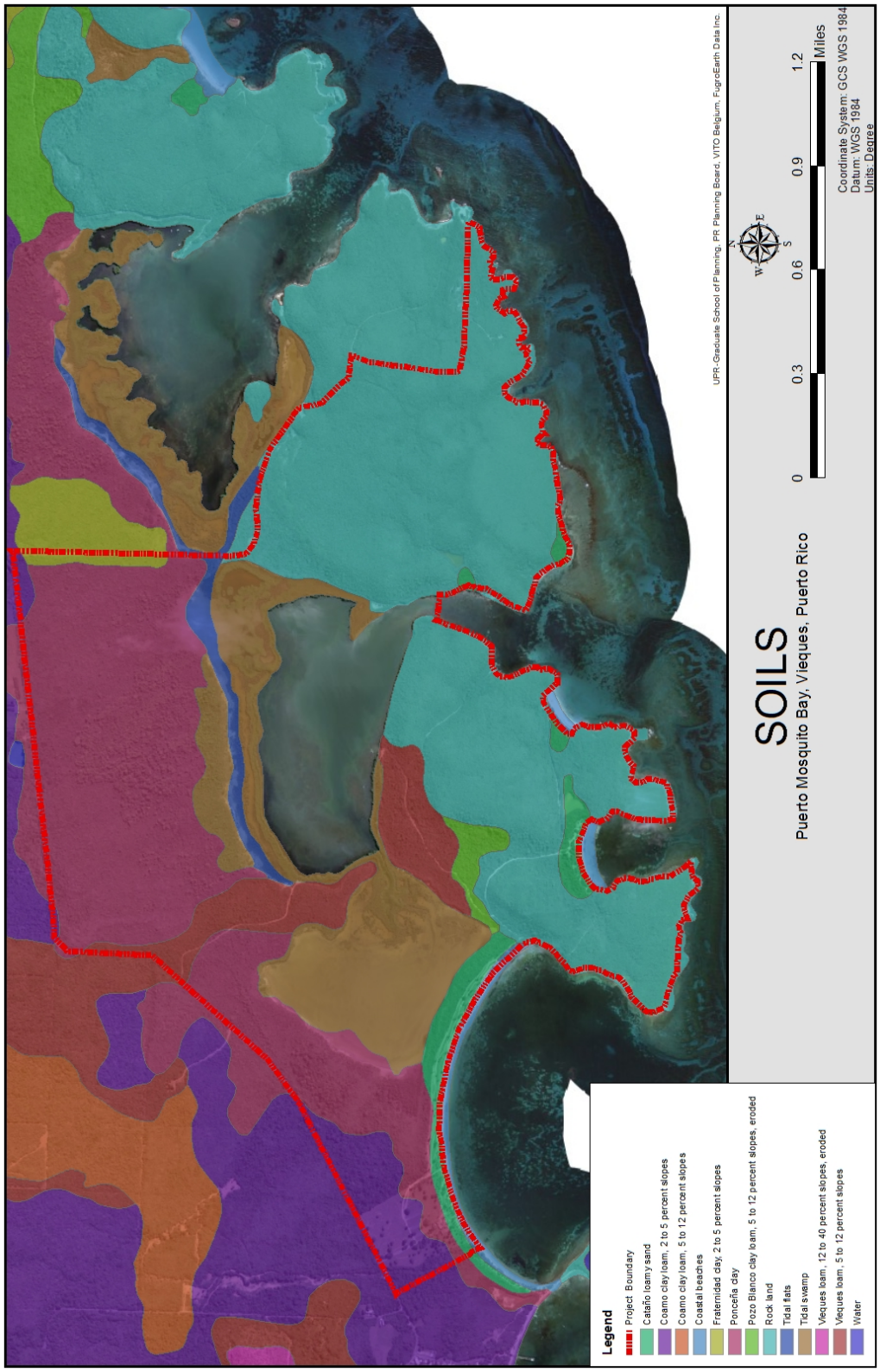

Figure 14: Soils Map

4.3.5. Vegetation

Puerto Mosquito Bay is bordered by red mangrove (*Rhizophora mangle)* - (Figure 15). Although, the majority of the mangrove forest is dominated by red mangrove, few white mangrove (*Laguncularia racemose*) are found along with the red. The fringing mangrove include wide lagoons and channels on which kayakers can navigate through.

Estuarine subtidal and intertidal wetlands dominate the landscape especially on the north side. The bay has a healthy cover of seagrass. “Seagrass habitats provide a variety of ecological functions in coastal marine ecosystems. Among these functions seagrasses are known for their high primary productivity via photosynthesis, the accumulation of sediments and nursery function for fish and invertebrates.” (Valdes-Pizzini & Sharer-Umpierre, 2014)

The upland located north of the bay is predominately cover by lowland dry riparian and semi deciduous forest.

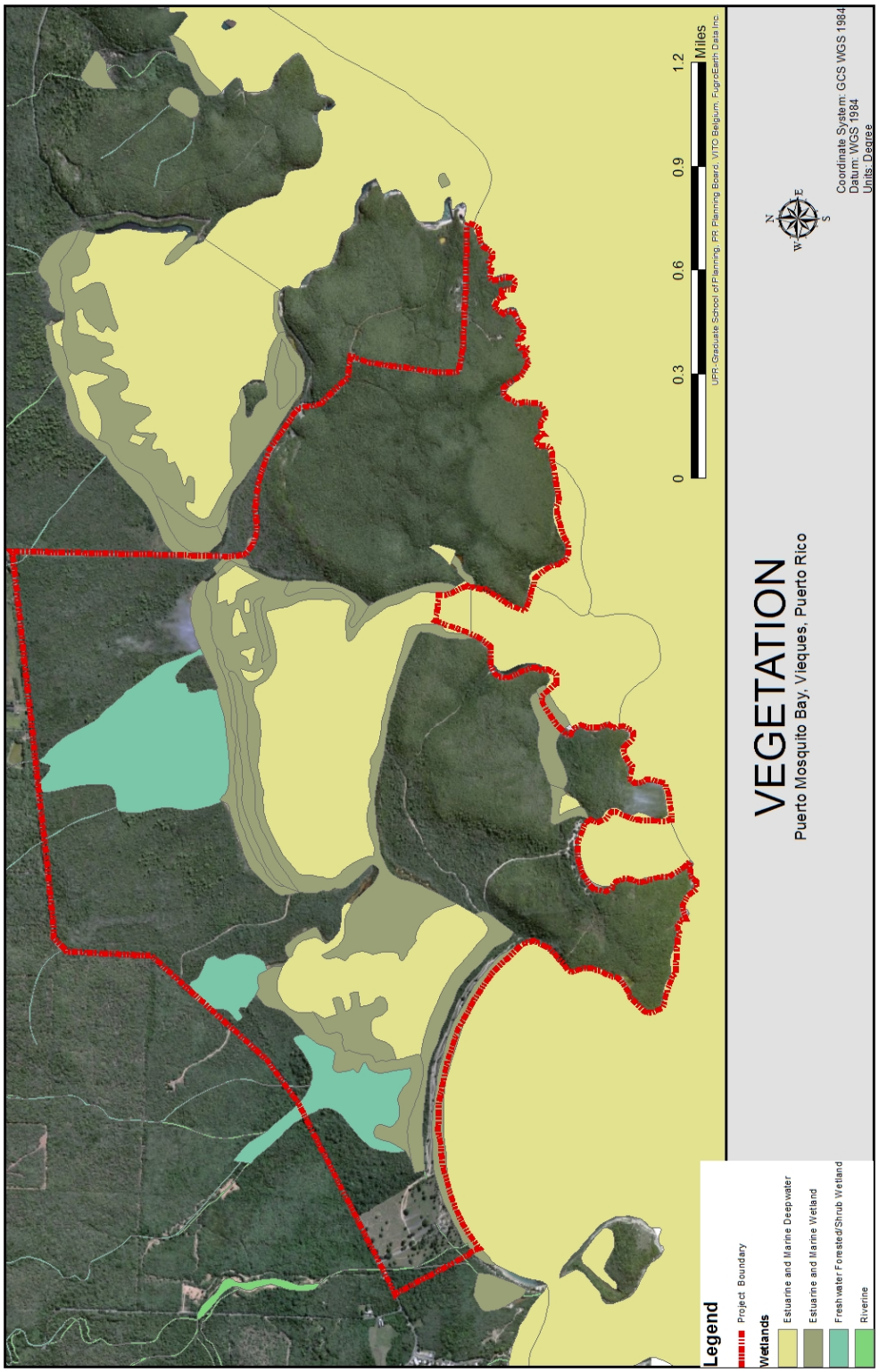

Figure 15: Vegetation Map

4.3.6. History/Cultural Site/Features

In addition to its bioluminescent properties as an ecotourism attraction, Puerto Mosquito is also valued as a conservation, educational and cultural resource for the island of Vieques. The Vieques Conservation and Historical Trust is the principal management agency for the bioluminescent bay. Its mission is to promote the island's precious natural and cultural resources, in particular, the ecology of the bay by conducting non-formal education activities, and facilitating scientific research (Figure 16).

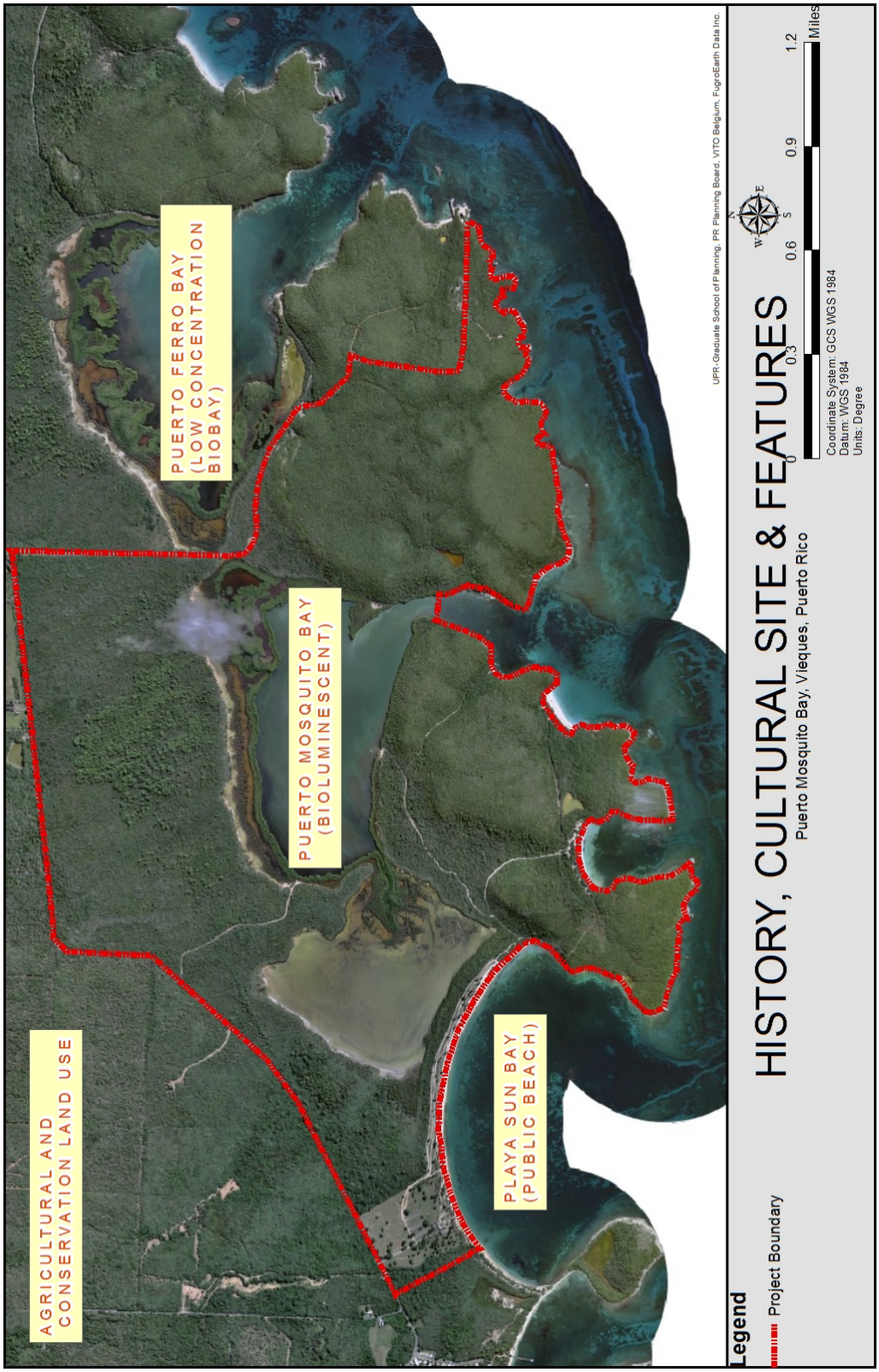

Figure 16: History/Cultural Site - Features Map

4.3.7. Existing Utilities and Services

Existing utilities and services include water distribution systems, wastewater collection systems, and electrical distribution systems. The water distribution main is located off of PR-997 connecting to wells located just north of the site. A force main runs through PR-996 with gravity and lateral lines connected to public restrooms at Playa Sun Bay's visitor center and nearby residential community (Figure 17).

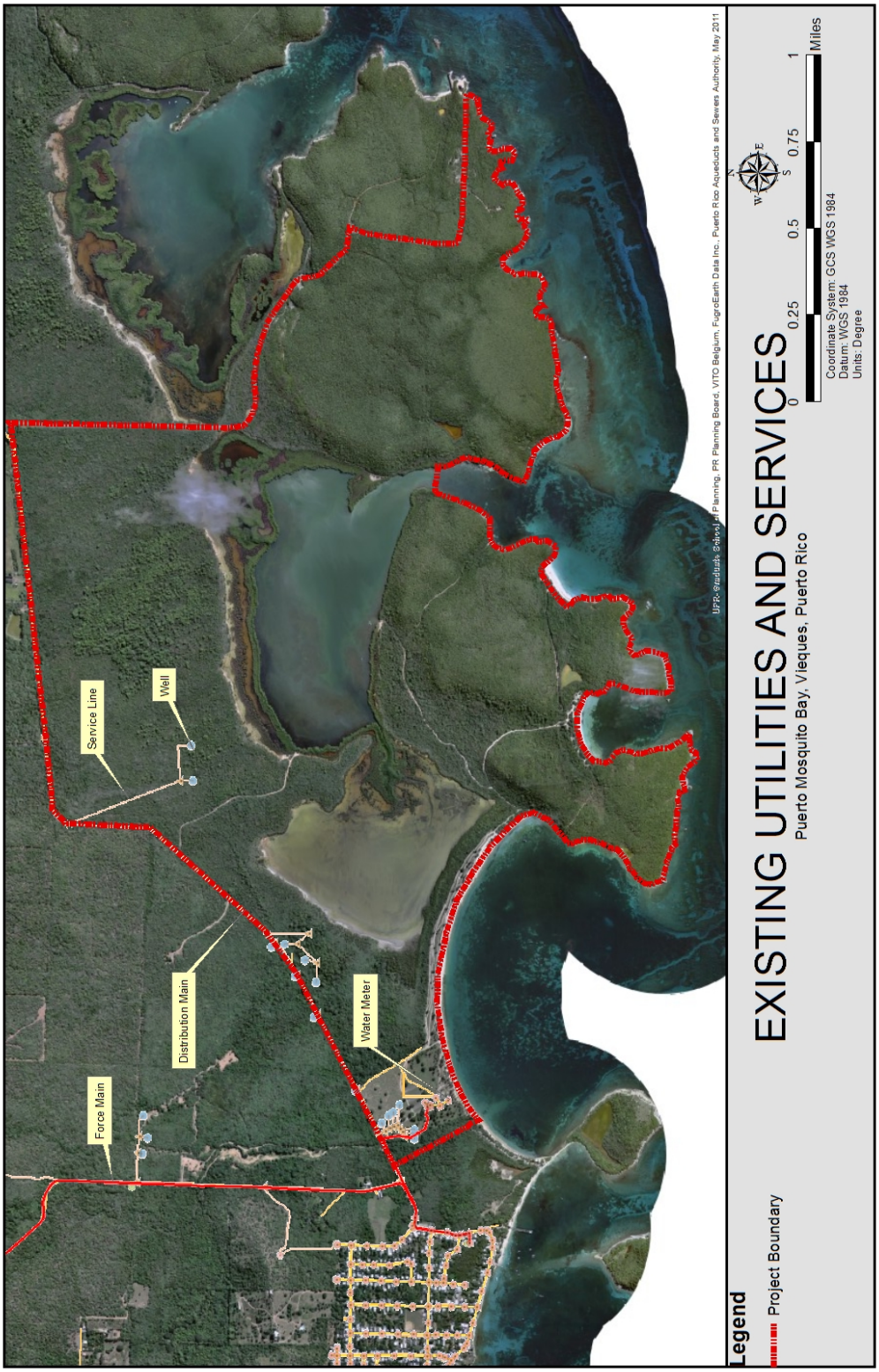

Figure 17: Existing Utilities and Services Map

4.3.8. Existing Structures

Several existing buildings, parking lot, pavilions located at the north side of Playa Sun Bay (public beach) are the only structures enclosed within the defined site limits (Figure 18).

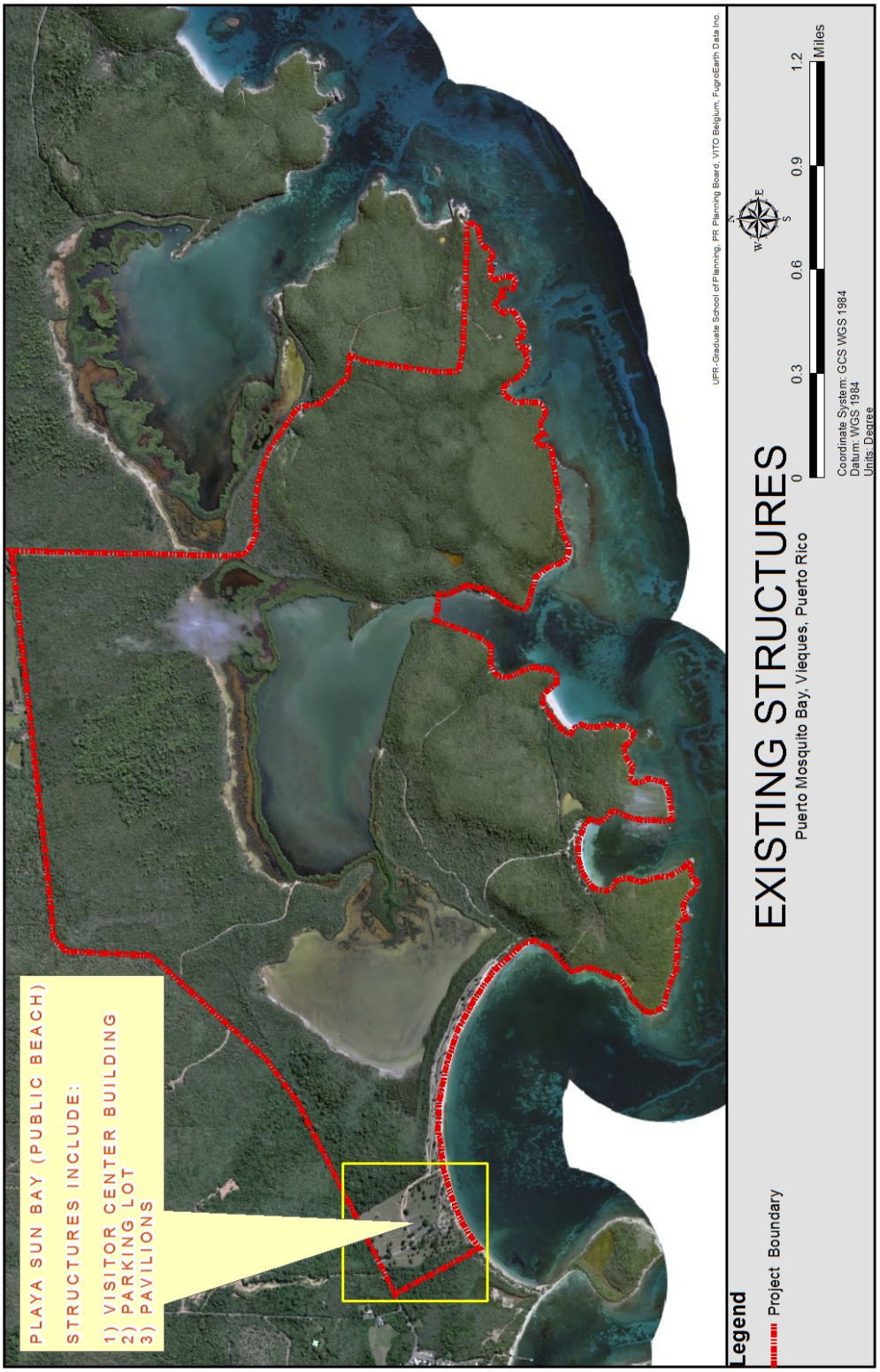

Figure 18: Existing Structures Map

4.4. SITE SYNTHESIS – PARK SITE

4.4.1. Opportunities (Figure 19)

4.4.1.1. Public Beach – Sun Bay Beach (1)

- Proximity to public beach (Playa Sun Bay).
- Proximity to residential subdivision.
- Connectivity to program elements.
- Good site for a sustainable development (e.g., eco-resort).
- Adjacent to primary road (Road 997).
- Convenient access to Isabel II (main town in Vieques).

4.4.1.2. Natural Area (2)

- Serves as erosion control.
- Stormwater detention
- Allows for water to percolate.
- Cleanse pollutants from storm runoff.
- Replenishes freshwater back to the aquifers.

4.4.1.3. Mangrove Stand (3)

- Provides wildlife habitat and refuge.
- Attenuates prevailing winds (NW direction).
- Provides food for dinoflagellates and other organisms.
- Reduces sediment loading.
- Minimizes erosion due in part to a terrain ≤ 2% slope.

4.4.1.4. Rock Island Area (4)

- Site contains high bearing soil capacity = good for low-impact sustainable development.
- Considered for ideal campground opportunities in the future.

4.4.1.5. Biobay Area (5)

- Potential for non-motorized water transportation (e.g., kayak, canoe).
- Night ecotourists' attraction should be protected, preserved and conserved for current and future generations.

4.4.1.6. Hypersaline Estuarine Lagoon Area (6)

- Filters pollution, sediment, and nutrients.
- Mangrove planting where feasible may improve water quality.

4.4.1.7. Rock Island Area (7)

- Provide access to beaches (Media Luna & Navio Beach).
- Should be considered for low-impact sustainable development.

- Good drainage and high soil bearing capacity.
- Provides 360° views of coastline.

4.4.2. Constraints (Figure 19)

4.4.2.1. Public Beach – Sun Bay Beach (1)

- Should make provision to protect critical stream corridor if development is proposed in this area.
- Adjacent to primary road (Road 997), increase in traffic may augment noise pollution (vegetative buffer may be needed to mitigate effect).

4.4.2.2. Natural Area (2)

- Existing conditions unsuitable for development.
- Wet soil, flat grade < 1%.
- Prone to flooding and ponding.

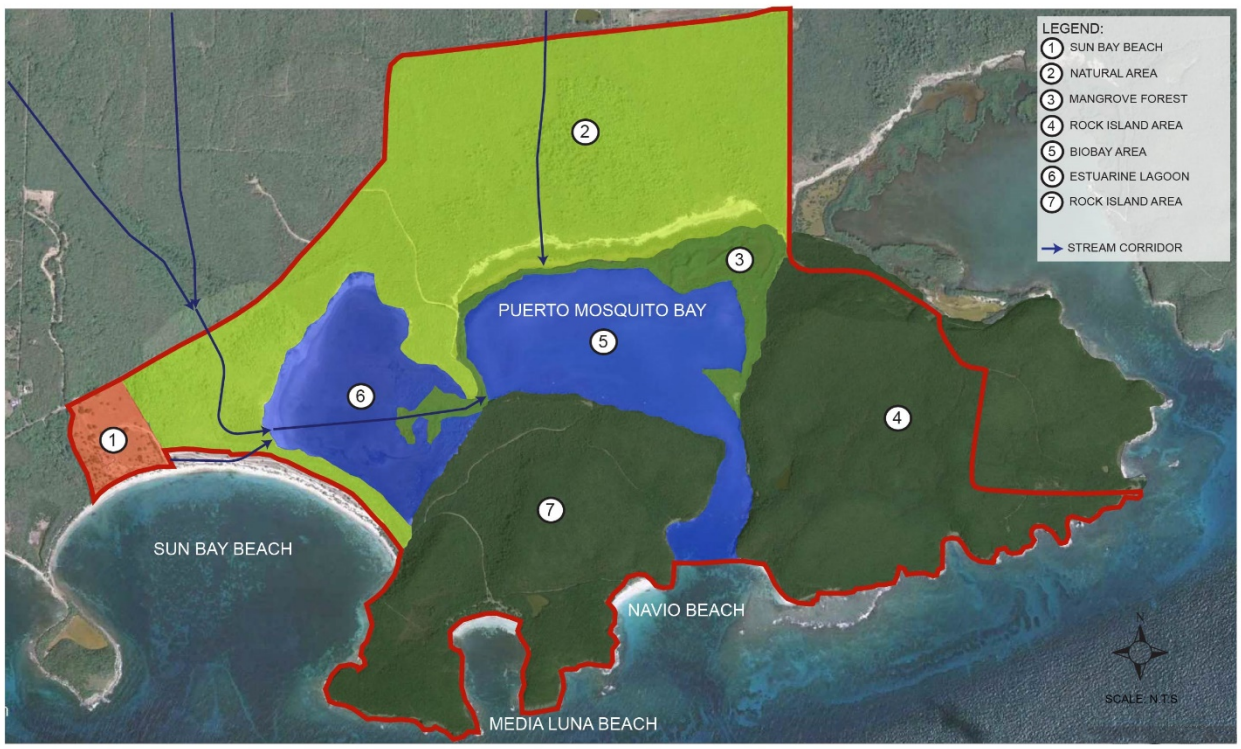

Figure 19: Opportunities and Constraints Map

4.5. PROGRAM DEFINITION FOR PARK SITE

4.5.1. Program Elements

4.5.1.1. Public Beach – Sun Bay Beach

- Visitor center (restrooms, ranger's office, classrooms, etc.)
- Playground (Tot-lot)
- Outdoor fitness area
- Pavilions (grills, picnic tables, potable water and electrical outlets)
- Outdoor showers
- Beach volleyball court
- Parking (permeable pavement)

4.5.1.2. Nature-based Recreation Park

- Primitive camping
- Cabin camping
- Kayaking
- Canoeing
- Trail system (nature trail, boardwalk)
- Lookout tower
- Interactive outdoor learning (biobay) – signage posting.
- Guided group tours to the Biobay at night

4.6. GOALS AND OBJECTIVES

4.6.1. Goal 1:

- Create a place that will facilitate beach goers to experience positive outcomes and provide them with a variety of aquatic-related activities in a clean and safe venue.

4.6.1.1. Objectives 1.1

- Build a new visitor center that will offer facilities such as restrooms, ranger's office, and classrooms.

4.6.1.2. Objectives 1.2

- Construct a new parking lot that provides better vehicular circulation with a drop-off area and landscaped islands.

4.6.1.3. Objectives 1.3

- Designate zones for different activities in order to mitigate potential activity conflict.

4.6.2. Goal 2:

- Design a nature-based park where ecotourists will be encouraged to engage in sustainable tourism.

4.6.2.1. Objectives 2.1

- Designate zones for various activities to minimize conflict of interactivity (e.g., primitive camping vs. cabin camping).

4.6.2.2. Objectives 2.2

- Designate zone for non-motorized aquatic transportation such as kayaks and canoes.

4.6.2.3. Objectives 2.3

- Develop a trail system that will accommodate all terrain (elevated boardwalk) with a lookout tower in the center for maximum 360° views.

4.6.2.4. Objectives 2.4

- Create a system of easy access to the bay for scheduled guided night tours (operated by the Vieques Conservation and Historical Trust – VCHT).

5. Design Exploration

5.1. Changes to Visitor Services on the Island

5.1.1. Overnight Accommodations

Cabins and cabanas will provide overnight accommodations, primarily for guests who will be participating in guided tours of the biobay as well as other events with prior arrangements.

5.1.2. Transportation

A shuttle will have scheduled trips to and from Puerto Mosquito Bay in coordination with programmed guided tours to the biobay.

5.2. Watershed Management Recommendations

5.2.1. Land Use

It is recommended that the existing agricultural land use designation should be changed to conservation use. Much of this zone designated as potential agricultural use is still currently forest and I recommend remaining forest be retained and any intensive agricultural areas be restored or managed with best management practices to minimize erosion, sedimentation, and nutrient runoff. Therefore, a comprehensive plan that incorporates watershed management strategies and a stream corridor protection approach should be developed in order to mitigate the ecological impacts affecting Puerto Mosquito Bay.

5.2.2. Stream Management

Stream management best practices might include three main methods or approaches to ameliorate stream corridor conditions (De Chiara & Koppelman, 1984).

1. *Stream Bank Stabilization* (Figure 20)
    - Stabilization through vegetation
    - Vegetative buffers along the streams to minimize pollution, erosion, and sedimentation.
    - Buffers entrap sediment, absorb pollutants and provide food and cover for fish and wildlife.

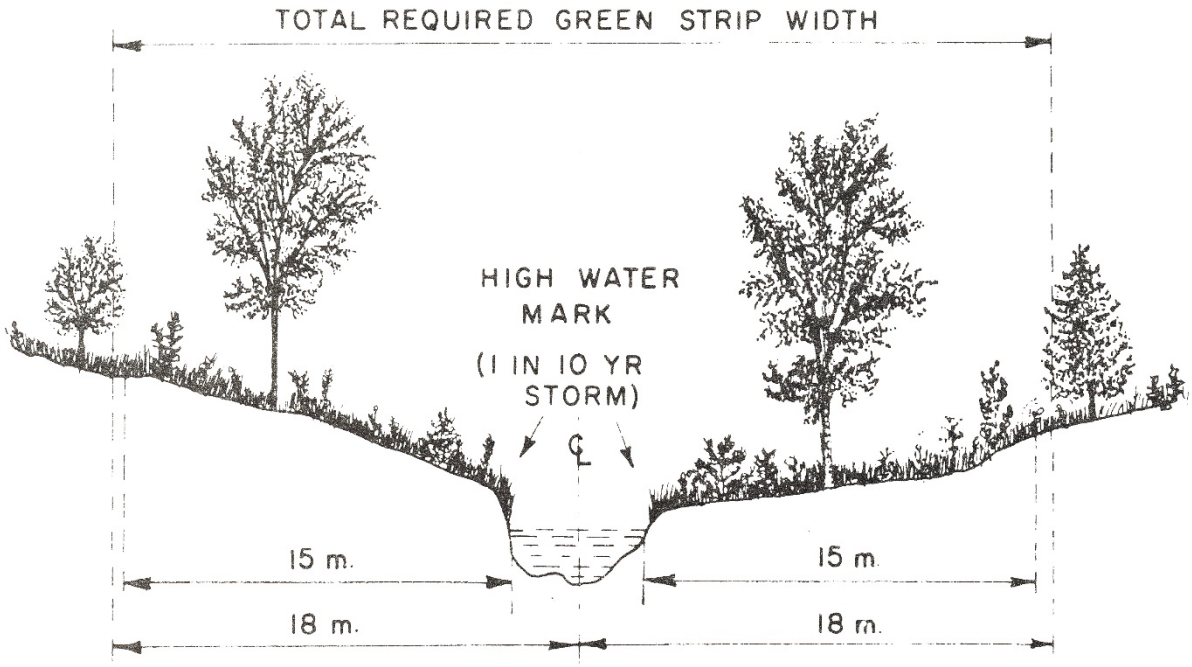

Figure 20: Stream Bank Stabilization and Protection

2. *Rehabilitation of Streams*

- Restore channelized streams by installing stones or long deflectors, gabions, and low dams.
- Sloping ripraps
- Improving water circulation by replacing undersized culverts.
- Removing construction debris and other obstacles preventing or clogging the natural flow of water.

5.3. PARK SITE MASTER PLAN

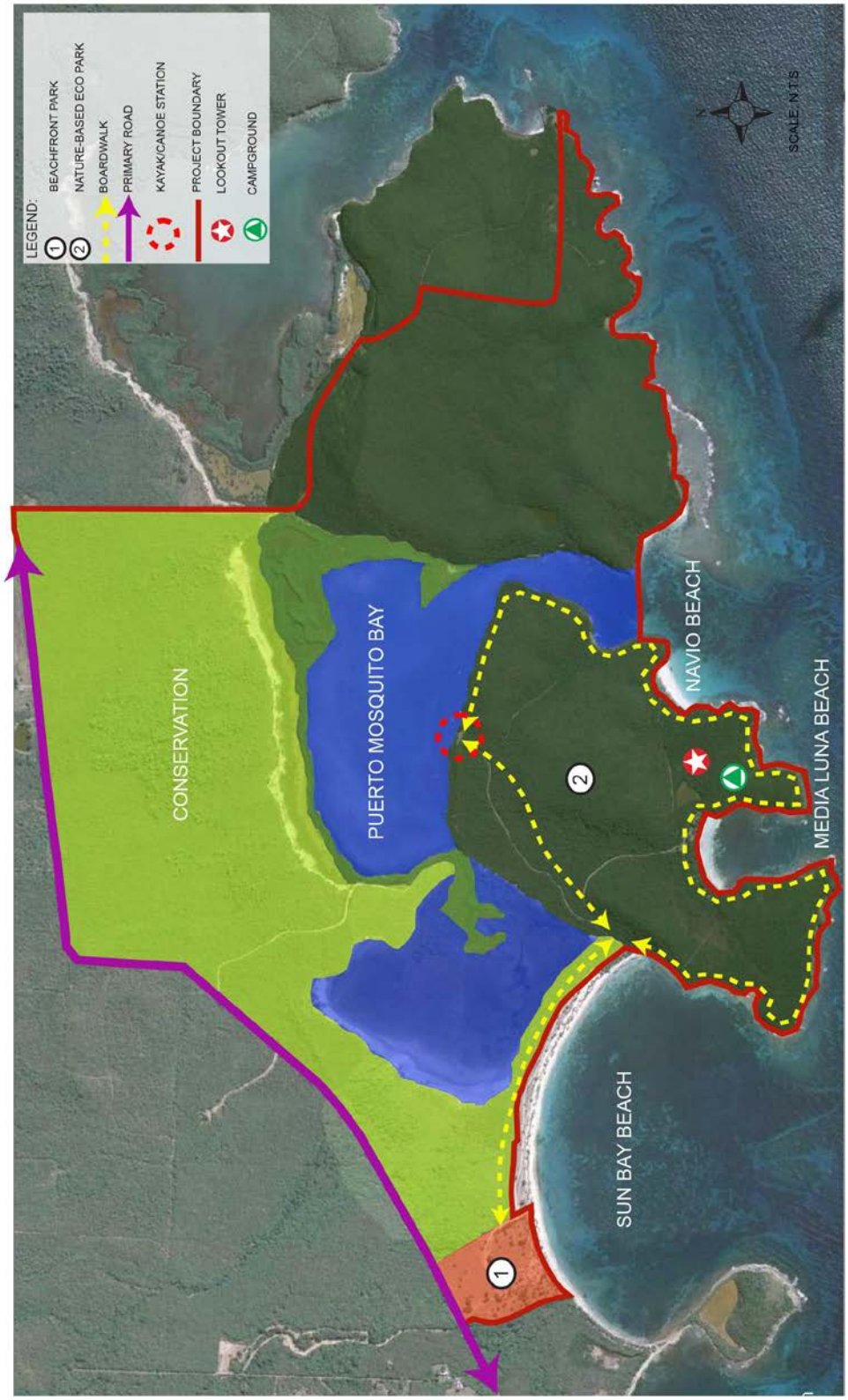

Figure 21: Master Plan

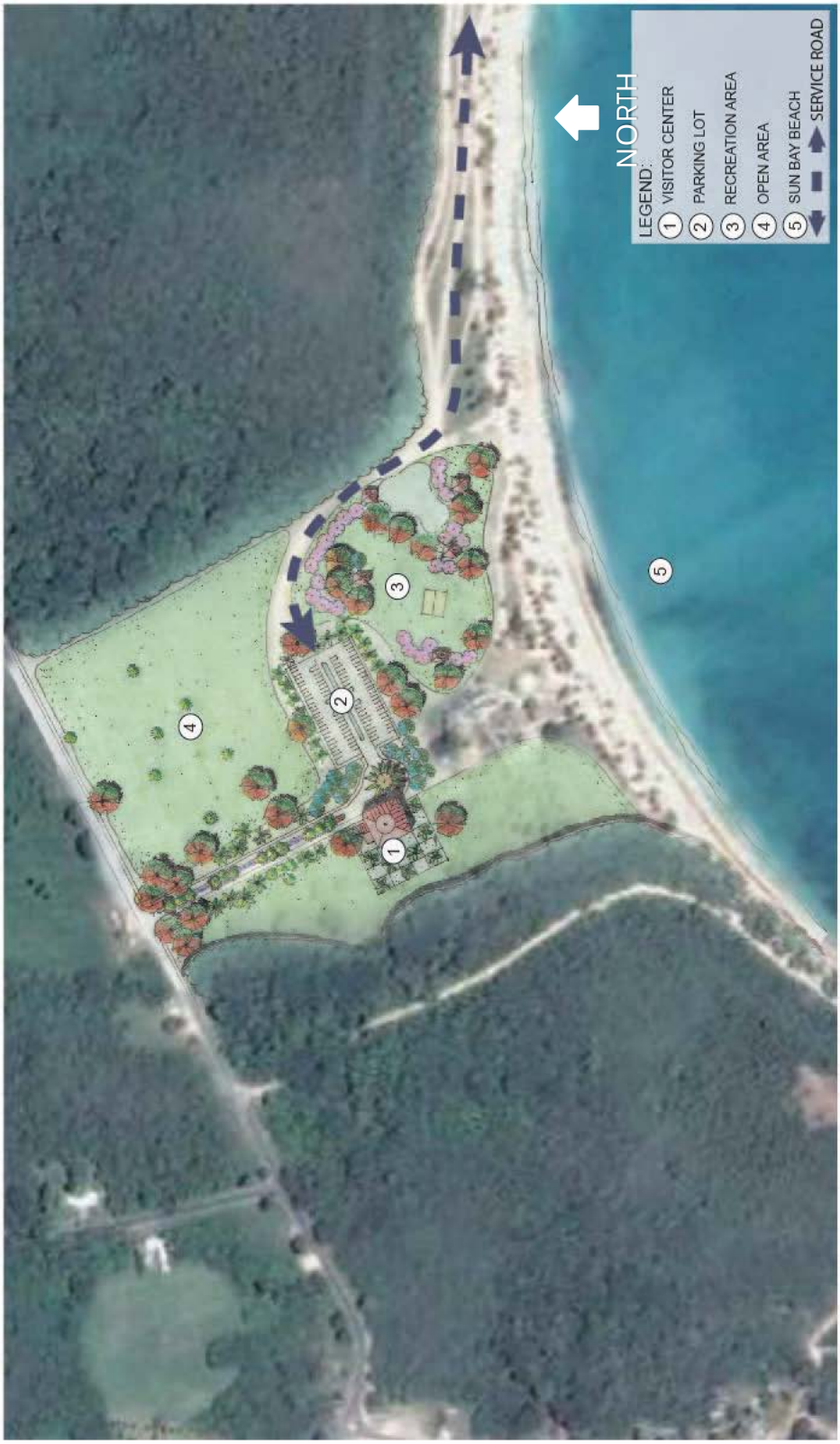

Figure 22: Beachfront Plan

Figure 23: Nature-base Eco Park Plan

6. Conclusion

In examining the ecological impacts of poor water quality that might be affecting Puerto Mosquito Bay, a watershed analysis was conducted. This analysis revealed that approximately 75% of the stream corridors that outfall to the bioluminescent bay are encompassed within agricultural land use zoning. A recent study found that the main cause for sediment loss from the ridge watersheds in Puerto Rico was the interactions of development, heavy rainfall events (primarily hurricanes), and steep mountainous slopes associated with the ridges (Yuan, Jiang, Taguas, Mbonimpa, & Hu, 2015). These results showed the potential implications of changes in land use/cover and sediment loading to the composition of the existing stream corridors. Based on the results from this study, stream corridors were highly susceptible to non-point and point source pollution that could ultimately threaten the water quality in the bioluminescent bay.

Further field study should be conducted to verify the extent of any damage to the stream corridors that may exist and the ramifications this might have downstream to the bioluminescent bay. This includes the need for annual monitoring of water quality in these streams.

Throughout this project, effective management strategies applicable to mitigating the ecological impacts were explored. Watershed, vegetation and ecotourism management strategies were identified from the literature and case studies to be applicable to the protection of this bioluminescent ecosystem.

Based on the information developed throughout the project, a master plan was designed to address the ecological impacts and implement the management strategies learned. The information presented from this project could be used by planners, managers, and decision makers as a framework for future land planning initiatives and as a catalyst of design ideas for conserving and

preserving the environment, culture and economic values this part of the region has to offer to future generations.

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Biographical Sketch

One of the most enlightening moments of my life was when I discovered Landscape Architecture. The skills, interests and career goals that I value are epitomized in this profession. Landscape Architecture has become an incipient passion that began in the fall of 1998 when I first toured the graduate studio in the Department of Landscape Architecture at the University of Florida (UF). I became more passionate about Landscape Architecture as I collaborated with landscape architects and allied professionals in multiple projects as a CADD Technician/GIS Analyst. One book in particular, *"Becoming a Landscape Architect: A Guide to Careers in Design"* by Kelleann Foster, RLA, ASLA, was a catalyst for my journey to become a landscape architect. I embarked on that journey when I was accepted in graduate school at the University of Florida. In the summer of 2014, I began my studies for the First-Professional Master's in Landscape Architecture degree.

List of Figures' Sources