PROGRAMA DEL
Estuario
de la Bahía de San Juan

San Juan Bay Estuary

CLIMATE CHANGE Adaptation Plan

San Juan Bay Estuary
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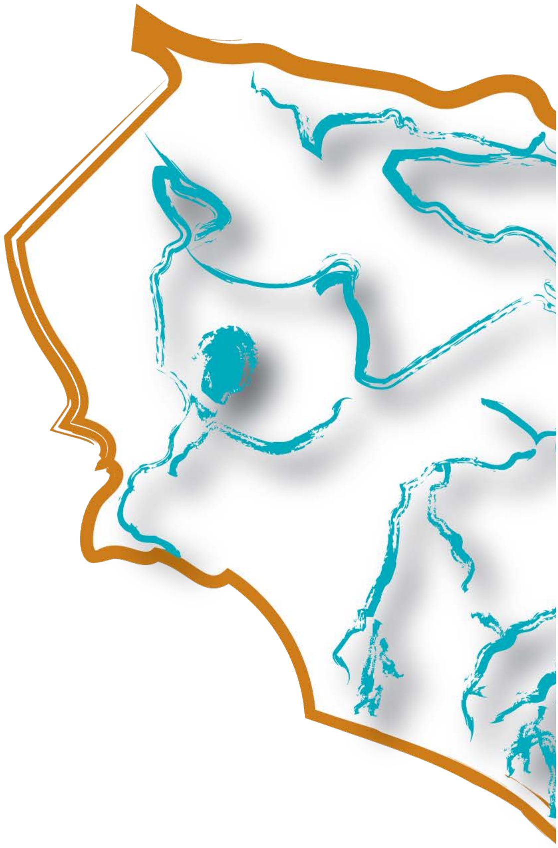
Adaptation Plan

Prepared by Jorge Bauzá-Ortega, PhD, QEP, Scientific Director, San Juan Bay Estuary Program



SAN JUAN BAY ESTUARY PROGRAM

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Contents

LIST OF FIGURES AND TABLES

FIGURES

TABLES

ACRONYMS

CariCOOS
Caribbean Coastal Ocean Observing System

CCMP
Comprehensive Conservation and Management Plan, San Juan Bay Estuary Program

CRE
Climate Ready Estuaries

DRNA
Puerto Rico Department of Natural and Environmental Resources (in Spanish)

IDS
Initiative for Sustainable Development (in Spanish)

IPCC
Intergovernmental Panel on Climate Change

JOBANERR
Jobos Bay National Estuarine Research Reserve

NASA
National Aeronautics and Space Administration

NEP
National Estuary Program

NOAA
National Oceanic and Atmospheric Administration

OPCA
Office for Environmental Compliance and Planning, Municipality of San Juan (in Spanish)

PRASA
Puerto Rico Aqueducts and Sewers Authority (Autoridad de Acueductos y Alcantarillados)

PRCCC
Puerto Rico Climate Change Council

PREQB
Puerto Rico Environmental Quality Board (Junta de Calidad Ambiental)

SEAS
Sargassum Early Alert System

SJBE
San Juan Bay Estuary

SJBEP
San Juan Bay Estuary Program

SRCP
Spill Response and Cleanup Plan

SSO
Sanitary Sewer Overflows

TNC
The Nature Conservancy

UPR
University of Puerto Rico

-CIMA
Marine Sciences Campus (in Spanish)

-ITES
Institute for Tropical Ecosystem Studies

-RCM
Medical Sciences Campus (in Spanish)

-RUM
Mayagüez Campus (in Spanish)

USGS
U.S. Geological Survey

USEPA
U.S. Environmental Protection Agency

INTRODUCTION:

Preparing for Climate Changes in the San Juan Bay Estuary System

Extreme climatological events, coastal erosion, and acidification of the oceans are some of the impacts caused by climate change. The San Juan Bay Estuary (hereafter the Estuary) is susceptible to these impacts, some of which are already causing evident changes in the Estuary's systems. These impacts compromise and may endanger the goals of the San Juan Bay Estuary Program (the SJBEP) to enhance, restore, and conserve the Estuary. Therefore, the SJBEP is developing a climate-change adaptation plan tailored to the particular challenges of the Estuary as a tropical system. The SJBEP has identified potential risks, analyzed the Estuary's vulnerability in the face of these risks, and developed a plan of action to deal with the effects of climate change.

This report summarizes the SJBEP's efforts to develop a plan for adapting to the foreseen effects of climate change. In pursuit of this objective, the SJBEP has followed the steps set out in the workbook *Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans* (hereafter, the Workbook), which is part of a pilot project designed by the Climate Ready Estuaries program (hereafter the CRE), under the U.S. Environmental Protection Agency's National Estuaries Program (the NEP). The Workbook is basically a tool intended precisely to help organizations such as the SJBEP identify climate change risks, carry out vulnerability studies, and develop a plan for adapting to the impacts caused by climate change.

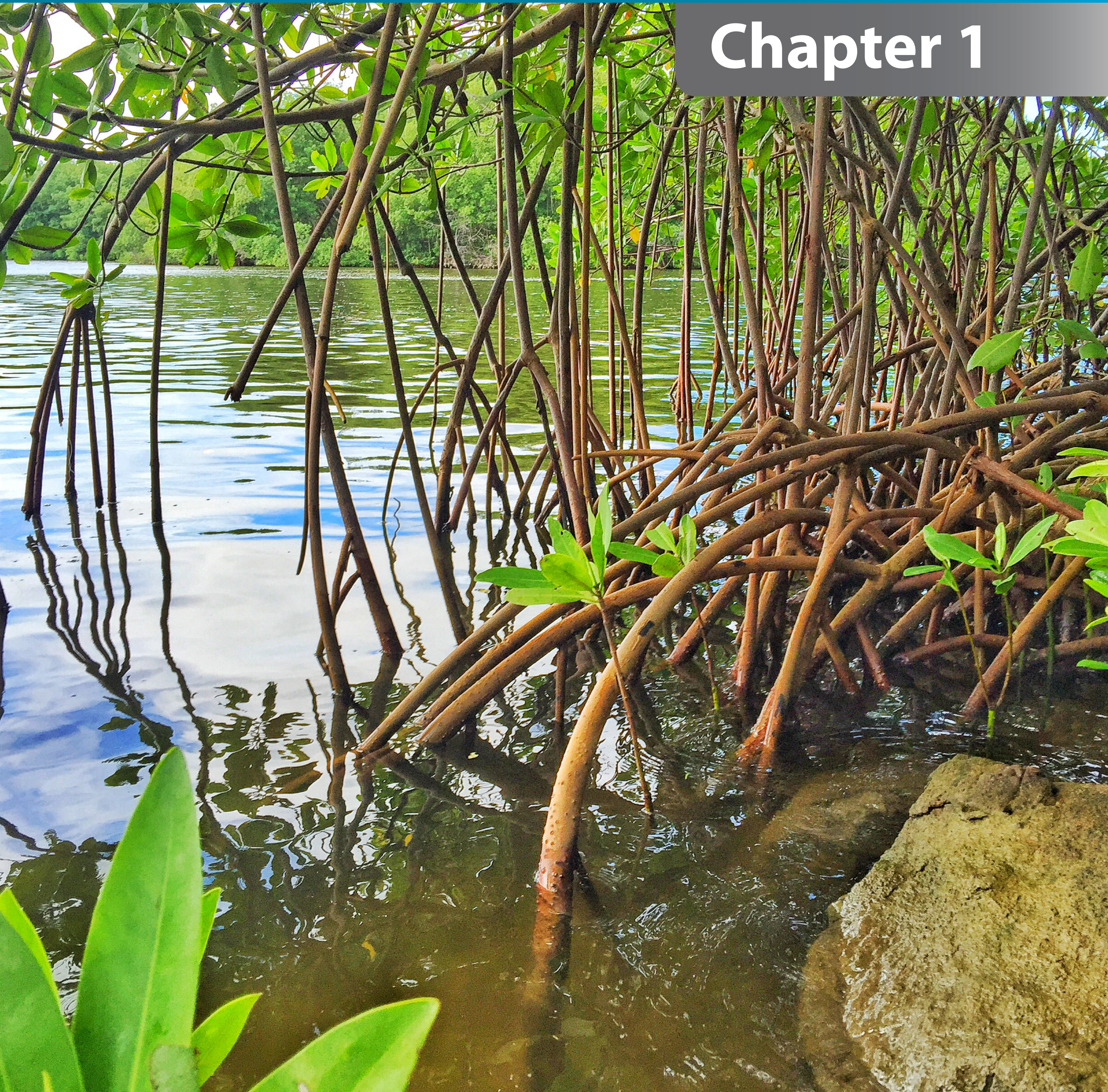
The principal goal of the CRE program (www2.epa.gov/cre) is to help organizations design effective plans for adapting to climate change impacts, especially impacts that make it difficult or impossible for the organizations to achieve their goals and objectives. In pursuit of this goal, the CRE provides coastal communities and NEP member programs with tools for assessing their areas' vulnerability to climate change, and it guides these communities and programs as they design and implement concrete adaptation strategies. The step-by-step method that the CRE suggests for the adaptation-plan design promotes participatory and interactive processes that bring together all members of a community. The SJBEP is one of the first NEP members (of 28 across the United States) to fully employ the Workbook as a tool for developing its climate-change adaptation plan.

This report consists of four chapters. The first chapter includes general background information about the Estuary, its bodies of water, and associated ecosystems and biological communities. The second chapter comments on climate changes in the Estuary, stressing those tendencies foreseen for the Caribbean and Puerto Rico. Much of this information has been compiled by the Puerto Rico Climate Change Council (the PRCCC) under the direction of Ernesto Díaz, Director of the Puerto Rican Department of Natural and Environmental Resources' Coastal Zone Management Program. The PRCCC is an association of more than 150 researchers, scientists, agency representatives, planners, and non-governmental organizations whose task is to assess how changes in temperature, precipitation, sea level, and other climatic parameters may affect Puerto Rico's infrastructure and natural resources (http://pr-ccc.org/). The SJBEP has been an active member of this organization since the PRCCC's founding in 2010.

The third chapter of the report explains, step by step, how the Workbook was used to develop the SJBEP's adaptation plan, which is discussed in the fourth and last chapter of the report.

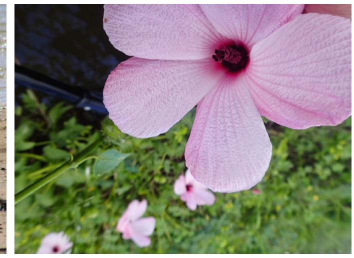
> *The San Juan Bay Estuary system is highly diverse, providing habitat to over 160 species of birds, over 300 species of plants, some 87 species of fish, and 20 different species of amphibians and reptiles. Of these species, at least 16 are considered endangered, threatened, endemic to Puerto Rico, and/or rare.*

Chapter 1



1 THE SAN JUAN BAY ESTUARY:

Ecosystems and Bodies of Water



An estuary is a coastal area in which freshwater from rivers, creeks, and rainwater runoff mixes with the salt water of the ocean.

The San Juan Bay Estuary (SJBE) system includes San Juan Bay, the Condado Lagoon, the San José Lagoon and Los Corozos, the Torrecilla Lagoon, and the Piñones Lagoon, plus the channels that interconnect these bodies of water, such as the San Antonio Channel, the Suárez Canal, and the Martín Peña Channel. Freshwater enters the system from the creeks and rivers of the watershed, which include the Río Piedras/Río Puerto Nuevo, the Juan Méndez, San Antón, and Blasina creeks, and the Malaria Canal. Finally, seawater enters the system through three openings: The El Morro inlet, the Boquerón inlet through the Condado Lagoon, and the Cangrejos opening (**Figure 1**). The areas of these bodies of water are shown in **Table 1**.

The SJBE system is highly diverse, providing habitat to over 160 species of birds, over 300 species of plants, some 87 species of fish, and 20 different species of amphibians and reptiles (**Figure 2**, page 5). Of these species, at least 16 are considered endangered, threatened, endemic to Puerto Rico, and/or rare.

The quality of the water and sediments in the SJBE system are intimately related both to the natural characteristics of the estuarine system (such as tides, currents, and the area's geology) and to human impacts. Human impacts include the dredging and filling of wetlands and bodies of water, the development of natural areas, and the discharge of domestic and industrial wastewater and trash. Obviously, the intensity and diversity of human activities that take place in the metropolitan area have influenced the quality of the water and sediments in the estuary in many ways, and in many cases have caused a deterioration in the functions and value of the estuary's bodies of water.

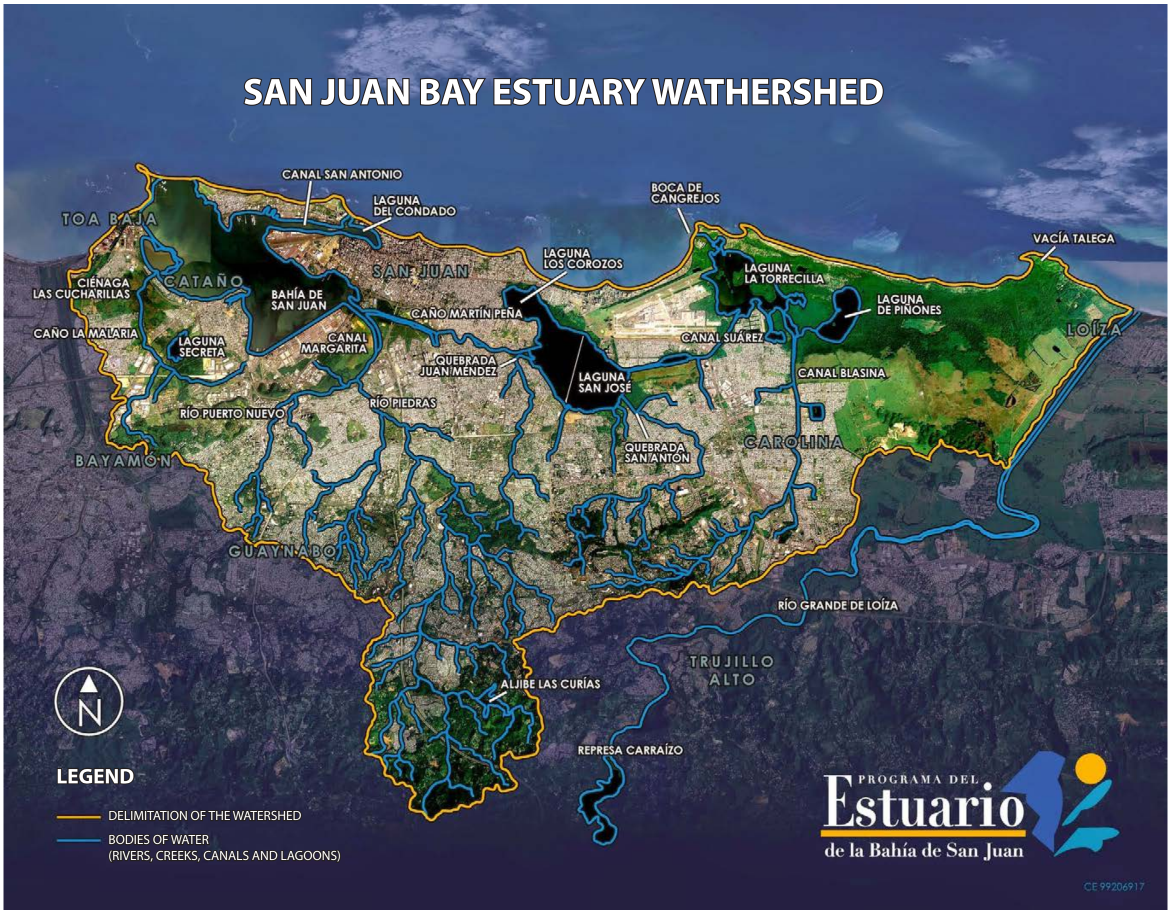


Figure 1. The San Juan Bay Estuary system encompasses eight municipalities: San Juan, Bayamón, Cataño, Toa Baja, Guaynabo, Carolina, Loíza, and Trujillo Alto, making it the most populated estuary of Puerto Rico.

Table 1: Geograhical Extension of Bodies of Water in the San Juan Bay Estuary

	Area (acres)	Linear Extension
San Juan Bay	3,280	6.5 miles (10.5 km)
San Antonio Channel	114	1.2 miles (2 km)
Condado Lagoon	102	
Martín Peña Channel	69	3.75 miles (6 km)
San José Lagoon	1,129	
Suárez Canal	63	2.4 miles (3.9 km)
La Torrecilla Lagoon	608	
Piñones Lagoon	236	

Figure 2. Emblematic species in the San Juan Bay Estuary (clockwise): brown pelican (*Pelecanus occidentalis*), red mangrove (*Rhizophora mangle*), leatherback turtle (*Dermochelys coriacea*) and the antillean manatee (*Trichechus manatus manatus*).

1.1 BODIES OF ESTUARINE WATER

San Juan Bay

San Juan Bay (**Figure 3**) is the most popular body of water in the SJBE system. It has approximately 6.5 miles (10.5 km) of highly developed coastline. This bay was described by the first settlers as one of the most beautiful ports in the New World. It is connected to the Atlantic Ocean by the El Morro inlet at the northern extreme of the bay. Today, more than eighty percent of the products shipped to and consumed in Puerto Rico and over a million cruise passengers a year arrive via the waters of San Juan Bay.

Figure 3. San Juan Bay

San Antonio Channel

The San Antonio Channel (**Figure 4**) connects San Juan Bay to the Condado Lagoon on the east. This channel is approximately 1.2 miles (2 km) long, and on its shoreline are located ports and marine-recreational facilities. In the early twentieth century, dredging and fill activities increased along this channel, intensifying in the 1950s. These activities transformed the San Antonio Channel from a narrow waterway with natural bends and meanders bordered by mangroves into a deep, straight canal bordered mainly by man-made structures. In spite of this human activity, the channel bottom has healthy beds of seagrasses that provide habitat to many species of marine creatures, including protected species such as the West Indian manatee, sea turtles, and dolphins.

Figure 4. San Antonio Channel

Las Cucharillas Marsh

Las Cucharillas Marsh (**Figure 5**) is a freshwater ecosystem that covers approximately 1,236 acres (500 ha) consisting mostly of herbaceous wetland, mangroves, and areas of open water. Ecologically, the marsh contains the highest diversity of waterfowl documented in the SJBE system. Moreover, Las Cucharillas Marsh plays a very important role in flood protection/control and water-quality improvement in the estuary and the urban communities within the system.

Figure 5. Las Cuharillas Marsh

Condado Lagoon

The Condado Lagoon (**Figure 6**) covers an area of about 102 acres and is joined to the Atlantic Ocean in the area known as El Boquerón, just east of Fort San Gerónimo. This body of water is also one of the most diverse areas within the SJBE system in terms of its marine flora and fauna. Coral communities, mangroves, sandy beaches, and seagrass beds all interact in the Lagoon. The lagoon's recreational value is as great as its ecological richness, as it is used by thousands of tourists and residents alike, who enjoy its sandy beaches and practice water sports such as windsurfing, kayaking, and paddle boarding. In 2013, through the Condado Lagoon Estuarine Reserve Act (Law 112-2013), the Puerto Rican legislature designated the Condado Lagoon as the first estuarine/marine reserve in the metropolitan area.

Figure 6. Condado Lagoon

Martín Peña Channel

For many years, the Martín Peña Channel (**Figure 7**, next page) has been severely impacted by intense residential development and lack of an adequate infrastructure for handling the area's wastewater and solid domestic waste. This is especially true along the eastern segment of the channel, where in the past, construction rubble, cast-off domestic appliances, domestic waste, and other components were used as fill to create land for the construction of housing and other structures along its shore. In order to make the western half of the channel navigable for public transportation, the part of the channel between "downtown" Hato Rey—Greater San Juan's banking and insurance district—and Old San Juan was dredged. This segment of the channel is bordered by healthy mangroves and thus was designated as a nature reserve. The channel is approximately 3.75 miles (6 km) long and connects San Juan Bay to the San José Lagoon.

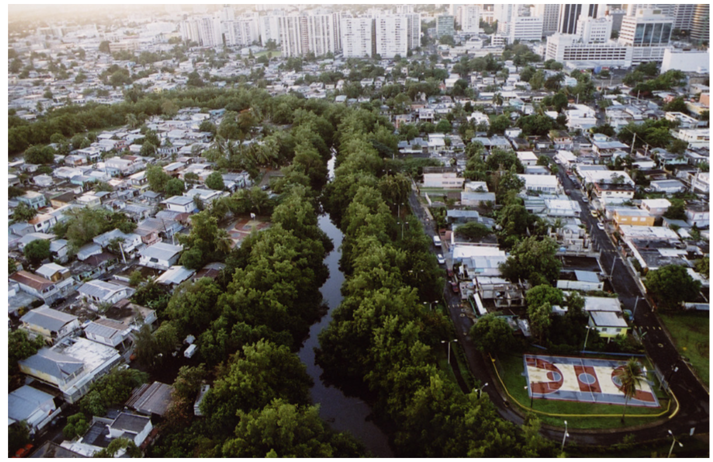


Figure 7. Martín Peña Channel

San José Lagoon

The San José Lagoon (**Figure 8**) is located in the center of the SJBE system and occupies approximately 1,129 acres (about 450 ha). At the present time, this lagoon has limited connection to the Atlantic Ocean through San Juan Bay, unlike in the past, since today the eastern segment of Martín Peña Channel is clogged by aquatic debris, sediment, and aquatic weeds. Thus, the San José Lagoon is one of the bodies of water in the SJBE least directly influenced by tides. In fact, the only exchange of water between this lagoon and the Atlantic Ocean occurs through the Suárez Canal. On the other hand, the San José Lagoon is bordered by healthy mangroves and supports some of the best recreational fishing in the SJBE, specifically for "catch and release" of the *sábalo*, or Atlantic tarpon, which puts up a fierce fight and is a great challenge to the sport fisherman.

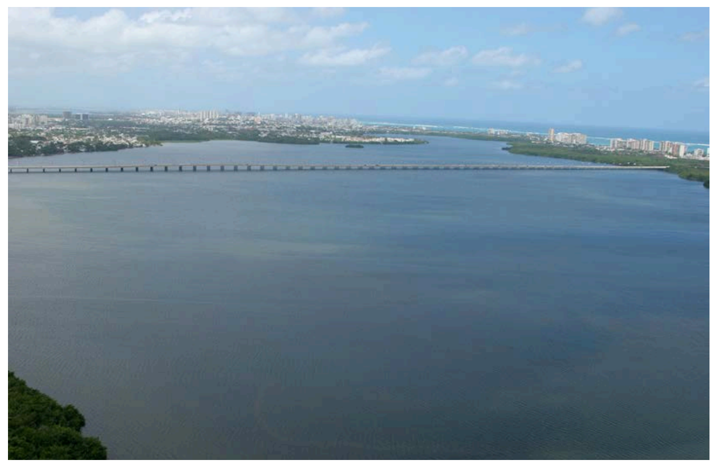


Figure 8. San José Lagoon

Suárez Canal

The Suárez Canal (**Figure 9**), 2.4 miles (3.9 km) long, connects the San José Lagoon with La Torrecilla Lagoon to the east. Most of its length is fringed by mangroves, but there are also herbaceous wetlands adjacent to the waterway. Its current dimensions are the product of dredging carried out between 1962 and 1967, as the Suárez Canal was originally relatively narrow and shallow. This waterway is the main means of water exchange and turnover of the San José Lagoon, a point often overlooked. In just one tour through the Suárez Canal, a visitor can observe most of the species of herons present in the SJBE and other native birds feeding and perching on the mangrove trees.

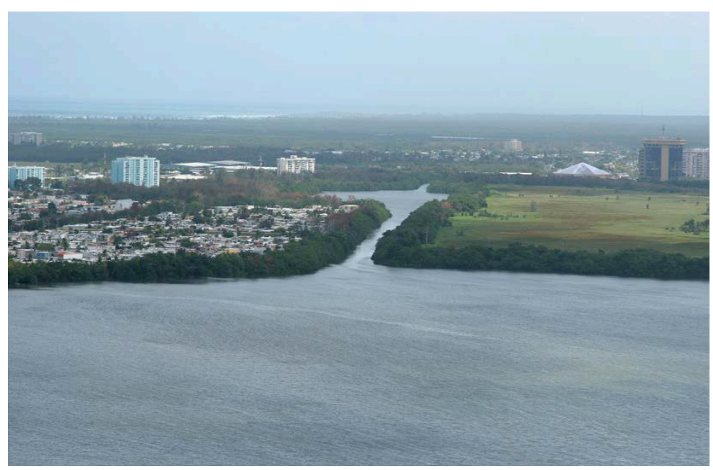


Figure 9. Suárez Canal

Torrecilla Lagoon

The Torrecilla Lagoon (**Figure 10**) receives water from the Atlantic Ocean through a narrow strait in Boca de Cangrejos.

This lagoon has an area of some 608 acres (246 ha) and is bordered almost entirely by stands of mangrove. The Torrecilla Lagoon is located on an important flood plain and has almost all the types of emerging wetlands found in Puerto Rico. Along with the Piñones Forest, it contains the largest mangrove forest in Puerto Rico.

Figure 10. Torrecilla Lagoon

Piñones Lagoon

The Piñones Lagoon (**Figure 11**) lies east of the Torrecilla Lagoon, within the Piñones State Forest Nature Reserve. The Piñones and Torrecilla lagoons, along with the area of Vacía Talega-Torrecilla Alta, contain approximately 5,500 acres (2,223 ha) of mangrove forest and just over 5,000 acres (2,056 ha) of herbaceous wetlands.

1.2 FRESHWATER RIVERS, CREEKS, AND CANALS

The main freshwater sources of the SJBE system are the Río Piedras/Río Puerto Nuevo system, which discharges into the southwestern part of San Juan Bay; the Juan Méndez and San Antón creeks, which discharge into the San José Lagoon; the Blasina Canal, which discharges into the Torrecilla Lagoon; and the Malaria Canal, which discharges into the northwest part of San Juan Bay.

Figure 11. Piñones Lagoon

Malaria Canal

The Malaria Canal (**Figure 12**) was constructed by the U.S. Army Corps of Engineers in the 1930s to drain Las Cucharillas Marsh as a way of controlling the mosquitoes that transmit malaria; hence the name. Malaria is a disease caused by a microorganism of the genus *Plasmodium* that is transmitted through mosquito bites. The word used in Spanish for the disease, *paludismo*, comes from the Greek *palus*, which means "swamp," and it was long thought, mistakenly, that draining wetlands was good public-health policy. But the Malaria Canal was built also to drain the wetlands on which Fort Buchanan was constructed. Regarding the water quality of the canal, it has been negatively affected by discharges of untreated sewage and wastewater, mainly from septic tanks in adjacent communities. Another point to mention here is that the Puerto Rico Department of Natural and Environmental Resources (DNRA) operates a pumping station on the Malaria Canal for flood control in surrounding communities

Figure 12. Malaria Canal

such as Juana Matos in Cataño.

Blasina Creek

Blasina Creek (**Figure 13**) is a freshwater creek that runs some 3.7 miles (6 km) from Highway PR-3 to the creek's discharge point on the south segment of the Torrecilla Lagoon. Its watershed of some 8.5 square miles (22 km2) (www.recursosaguapuertorico.com/Lagunas-San-Juan-2.html) receives rainwater runoff from the municipalities of Trujillo Alto and Carolina. Often, unauthorized discharges of untreated wastewater are detected, which severely impact the water quality of this system.

Figure 13. Blasina Creek

San Antón Creek

The San Antón Creek (**Figure 14**) is one of the freshwater sources of the San José Lagoon. This creek, which begins in Trujillo Alto, is fed by runoff from the municipalities of San Juan and Carolina. Part of the creek is channeled, and connects with the southeastern part of the San José Lagoon, where it is bordered by mangroves. Cleaning and maintenance of the creek are of crucial importance to prevent flooding events upstream.

Figure 14. San Antón Creek

The Río Piedras/Río Puerto Nuevo System

The Río Piedras/ Río Puerto Nuevo system (**Figure 15**) is the main source of freshwater into San Juan Bay. The system runs for 9.9 miles (16 km), receiving runoff from some 24 square miles of surface area (62 sq km). In 2010-2011 the U.S. Army Corps of Engineers dredged the lower portion of the Río Puerto Nuevo as part of a flood-control project. At present, the USACE plans to continue this canalization upstream. It is expected that the modifications proposed will significantly alter the hydrology, sedimentation rates, and pollutant discharges in both the Río Piedras/Río Puerto Nuevo system and its outlet into San Juan Bay.

Figure 15. The Río Piedras/Río Puerto Nuevo System

1.3 HABITAT, ECOSYSTEMS, AND WILDLIFE

Mud flats, herbaceous wetlands, mangrove swamps, seagrass beds, coral communities, rocky shorelines, and sandy beaches are some of the ecological habitats that foster the biodiversity of the SJBE system.

Mud Flats, marshess, and mangroves

Mud flats are areas of fine-grain sediments, without emergent wetland vegetation, that are alternately flooded and exposed by tidal action. Mud flats are important feeding grounds for birds and other wildlife. For example, in the late eighties the mud flats around the Constitution Bridge, at the mouth of the Martín Peña Channel near San Juan Bay, furnished habitat for the most diverse and abundant populations of native and migratory birds in the SJBE. Sadly, these mud flats were destroyed by the dredging activity carried out for the construction of the AcuaExpreso in the western section of the Martín Peña Channel. However, there are still isolated mud flats in some areas of the Martín Peña Channel and among the mangrove stands that border La Torrecilla and Piñones lagoons.

Figure 16. Secret Lagoon

Herbaceous wetlands, or marshes, provide critical breeding and feeding grounds for a variety of fish, birds, invertebrates, and other wildlife. They also function as natural filters of sediments and pollutants such as pesticides, fertilizers, and excessive nutrients. The main wetlands within the SJBE system are located in Las Cucharillas Marsh (west of San Juan Bay), in the area of Torrecilla Alta, and, on a smaller scale, along the Suárez Canal.

Figure 17. Mangrove stands

The most extensive freshwater wetland within the SJBE is Las Cucharillas Marsh, a freshwater emergent wetland that covers some 500 acres (200 ha) of the SJBE watershed. Land use in Las Cucharillas Marsh includes merchandise storage and distribution facilities and residential communities. Within this marsh there is a lagoon known by locals as "Laguna Secreta," Secret Lagoon (**Figure 16**). This freshwater lagoon was created to receive the fine sediments produced by the dredging of the San Juan Bay navigational channels. With the passing of time, Laguna Secreta metamorphosed from an impact zone to a natural system, considered today a "hot spot" for waterfowl- and migratory bird-watching. Finally, the importance of Las Cucharillas Marsh in terms of flood protection for adjacent communities and water-quality improvement is as great as its ecological value.

Mangrove stands (**Figure 17**) provide feeding, mating, nesting, and resting areas for birds and reptiles. In addition, the organic detritus of the mangrove trees is an important food source for crabs, mollusks, shrimp, fish, and other species. The mangrove species in the SJBE include the red mangrove (*Rhizophora mangle*), the black mangrove (*Avicennia germinans*), the white mangrove (*Laguncularia racemosa*), and the buttonwood mangrove (*Conocarpus erectus*). Another tree found in the SJBE (specifically in Torrecilla Alta) that is adapted to water-saturated soils (hydric) and creates unique swamps is the dragon's blood tree, or *Pterocarpus officinalis*. We should note that the largest mangrove forest in Puerto Rico (approximately 2,750 acres) is located within the SJBE: the Bosque Estatal de Piñones, or Piñones State Nature Reserve.

Benefits of the Mangrove Forest

Mangroves provide a wide range of benefits, including protecting the shoreline, serving as breeding grounds for fish and crustaceans of commercial and recreational importance, providing areas for relaxation, wildlife observation, and scientific research. Furthermore, mangroves improve the water quality of our coasts, since the mangroves' roots serve as natural traps that catch sediments that arrive with coastal runoff. By trapping these sediments, the mangroves allow cleaner water to enter the bodies of water, thereby benefiting all the associated marine and estuarine communities. In addition, the trapped sediments also immobilize pollutants such as pesticides, metals, and excess nutrients that would otherwise reach the ocean.

Mangroves act as natural living barriers that protect us from coastal erosion, heavy swells, hurricane waves, and, as we saw in 2004, tsunamis. It has been demonstrated that the wave generated by a tsunami may be reduced by as much as 75% if it passes through a 200-yard belt of mangrove forest. Not to mention that mangroves are a more cost-effective, aesthetic, and lasting alternative for coastal erosion control than concrete seawalls and other hard-armored barriers.

Finally, the submerged roots of the red mangrove are the living nurseries of the tropical oceans. To be more specific, between 80 and 90 percent of the fish and shellfish of the Caribbean and Gulf of Mexico spend part of their juvenile stage looking for protection and food among the submerged roots of the red mangrove.

Submerged aquatic vegetation and seagrass beds

Submerged aquatic vegetation and seagrasses (**Figure 18**) have been documented in San Juan Bay, the Condado Lagoon, San Antonio Channel, and La Torrecilla Lagoon. The species of seagrasses reported in the SJBE system include turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), paddle grass (*Halophila decipiens*), and shoalweed or Halodule wrightii (Rivera-Herrera, 1996). The benefits of seagrasses on coastal processes should not be overlooked. They provide nutrients, protection, and habitats that support coastal fisheries. They also provide a forage area for endangered marine species such as the green sea turtle (*Chelonia mydas*) and the West Indian manatee (*Trichechus manatus*).

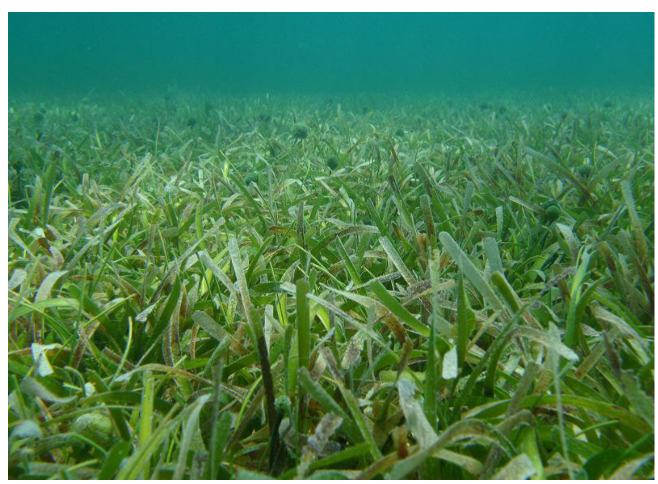


Figure 18. Turtlegrass (*Thalassia testudinum*)

Seagrasses

Seagrasses are plants that reproduce by producing flowers and seeds. That is, they are Angiosperms (such as orchids and roses) that returned to the ocean about 100 million years ago. Also, they function as underwater corridors that connect mangrove forests in the littoral zone with deeper-water ecosystems such as coral reefs.

Seagrasses provide countless benefits and services. They are a source of food and shelter for over 154 aquatic species, including endangered species such as the West Indian manatee, the green sea turtle, and the seahorse (*Hippocampus sp.*). They produce large amounts of oxygen and absorb nutrients such as nitrates and phosphates, translating into healthier, cleaner water. In addition, they stabilize sediments and lessen the erosion caused by tides and currents. In summary, abundant and healthy seagrasses mean cleaner water, higher aquatic biodiversity, and healthier ecosystems.

Coral Communities

Coral communities and their associated habitats are found in San Juan Bay and the Condado Lagoon. They are also found along the SJBE watershed's coastline at a distance of approximately .25 to 1 mile (0.4 to 1.6 km) offshore, where diverse substrates composed of natural rock outcroppings, reef incrustations, and cemented sand offer habitats to a wide variety of aquatic fauna. It is important to mention that all the living resources associated with these ecosystems depend closely on the well-being of the estuary watershed.

Sandy Beaches

Areas of sandy beach (**Figure 19**) within the SJBE system are limited to the perimeter of La Esperanza Peninsula, the eastern shore of Isla de Cabras, La Puntilla, and the Condado Lagoon. There do, however, exist other areas of sandy beach associated with the SJBE watershed, including the area of the Condado, Ocean Park, Isla Verde, Piñones, and Vacía Talega. The Condado and Isla Verde areas have many hotels important to the tourist industry and are among the most visited public beach areas on the island. The fauna and flora of sandy beaches are adapted to high energy (waves) and to moving substrate (sand). Although we don't necessarily see them during a trip to the beach, fauna include polychaete worms, bivalves (clams), crustaceans, starfish, and many other creatures. Sea birds regularly visit sandy beaches in search of food, and some of these sandy beaches are important nesting grounds for the leatherback sea turtle (*Dermochelys coriacea*), hawksbill sea turtle (*Eretmochelys imbricata*), and green sea turtle (*Chelonia mydas*). At the present time, the DRNA has documented sea-turtle nesting activity on Isla de Cabras and in Ocean Park, Isla Verde, and Piñones.

Figure 19. Sandy beaches in the San Juan Bay Estuary.

A CORAL RESTORATION EFFORT

In 2008, the SJBEP placed 45 artificial reefs (modules of Taíno Reefs®) on the bottom of the Condado Lagoon to create an underwater corridor.

The purpose of this project was to increase the biodiversity of aquatic species on the sandy bottom and create an interpretative underwater trail.

The artificial reef structures imitate the ocean floor and provide habitat for marine creatures.

Within two years of construction, 49 species of fish had been documented and the number of fish in this part of the lagoon had doubled.

In addition, some 2,500 colonies of coral now grow on the trail's surface.

The interpretative underwater trail links meadows of sea grasses and other fragmented marine communities on the bottom of the Condado Lagoon, creating an underwater ecological corridor.

In addition to its ecological benefits, the underwater trail provides recreational and educational opportunities, as it allows visitors—with proper equipment—to observe fish and other marine creatures in their natural environment.

Figure 20. Artificial reefs placed in the Condado Lagoon as part of the SJBEP Coral Reef Restoration Project.

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The case of the San Juan Bay Estuary is very particular: over seventy percent of the estuary's watershed is developed and paved over. This situation translates into higher temperatures than for the rest of the island.

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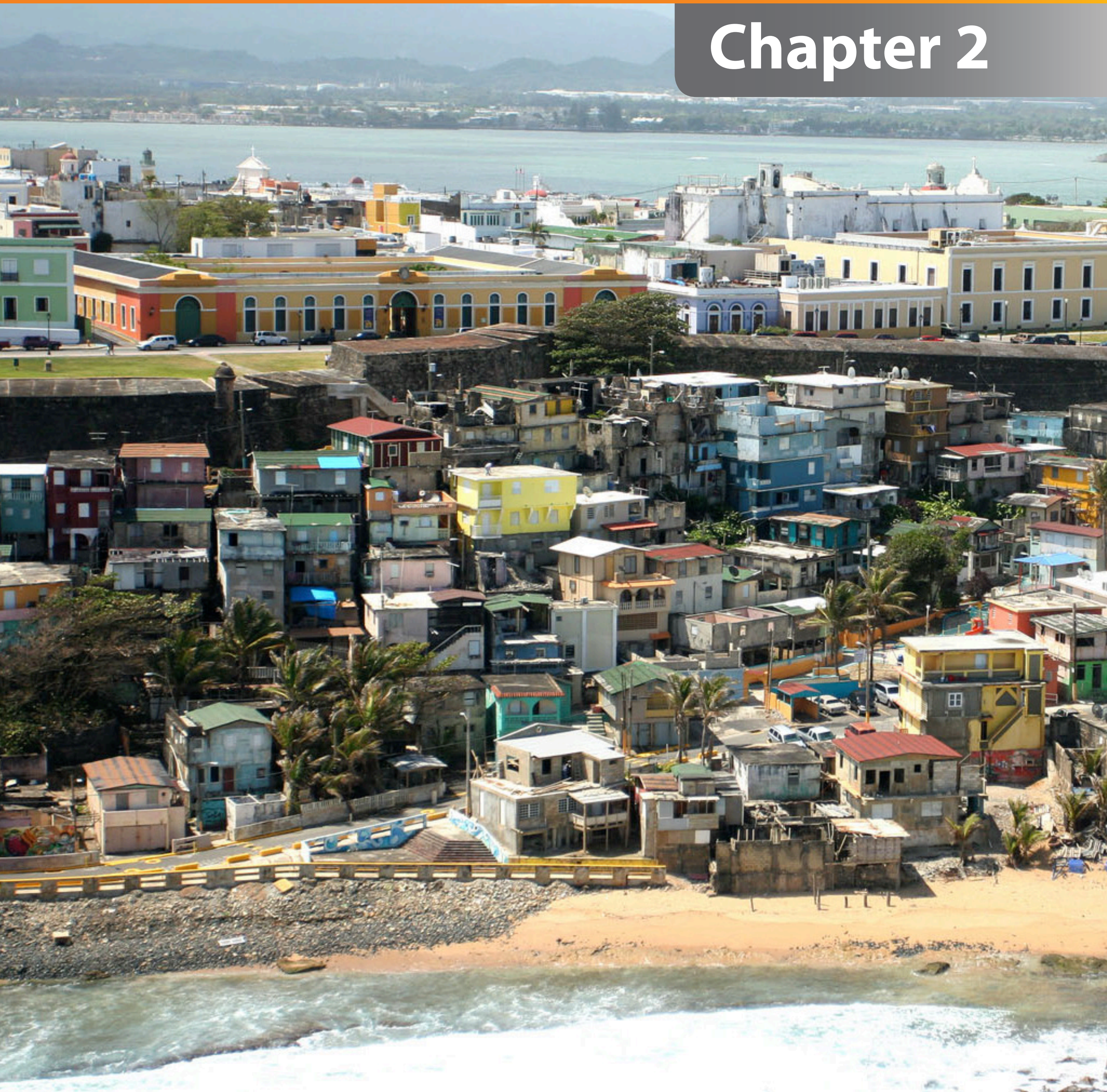
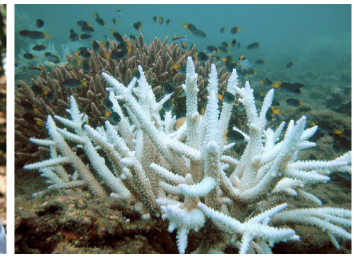
Chapter 2



2 CLIMATE CHANGE

in the Caribbean and Puerto Rico: Impacts and Projections



2.1 CLIMATOLOGY

Temperature and Precipitation

Predictions of climate change impacts and consequences are usually based on mathematical models on a global scale and are probably not as accurate on a smaller scale, as for Puerto Rico and the San Juan Bay Estuary. Therefore, there is a good deal of uncertainty in the projections and/or predictions that we can make. Nonetheless, it is a documented fact that the temperature of the earth's surface has risen over the last few years. In 2012, Puerto Rico experienced the warmest month in its entire recorded climatic history (Méndez-Lázaro et al., 2015). According to the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA), the years 2014-2015 have been the warmest since reliable record-keeping began in 1880, and the Intergovernmental Panel on Climate Change (IPCC) reports that world temperatures have risen 0.74 degrees Centigrade (1.33 degrees Fahrenheit) since 1906. The Caribbean region is no exemption to this tendency, as it has experienced a temperature increase of 0.6°C (1.0°F) (PRCCC, 2013). Predictions as to how much the surface temperature may rise in the future have a degree of uncertainty, and this is due to a number of causes (Hawkins and Sutton, 2009), but we do know that this increase will continue, even if all current greenhouse-gas emissions are reduced today. The fact is that climate change has always existed, since the genesis of our planet 4.6 billion years ago; the problem is how we accept and adapt culturally to its consequences.

The case of the San Juan Bay Estuary is very particular: over seventy percent of the estuary's watershed is developed and paved over (**Figure 21**). This situation translates into higher temperatures than for the rest of the island, as heat is absorbed and re-emitted from solid surfaces such as buildings, parking lots, paved streets, etc., a phenomenon known as the "urban heat-island effect." Therefore, the San Juan Bay Estuary watershed will unquestionably, on a regional scale, have higher temperatures than the rest of the island. To illustrate: the estimated temperature increase for Puerto Rico over the last century-plus (from 1900 to the present) has been between 0.012°C and 0.014°C per year, while for the San Juan metropolitan area it has been 0.022°C per year —

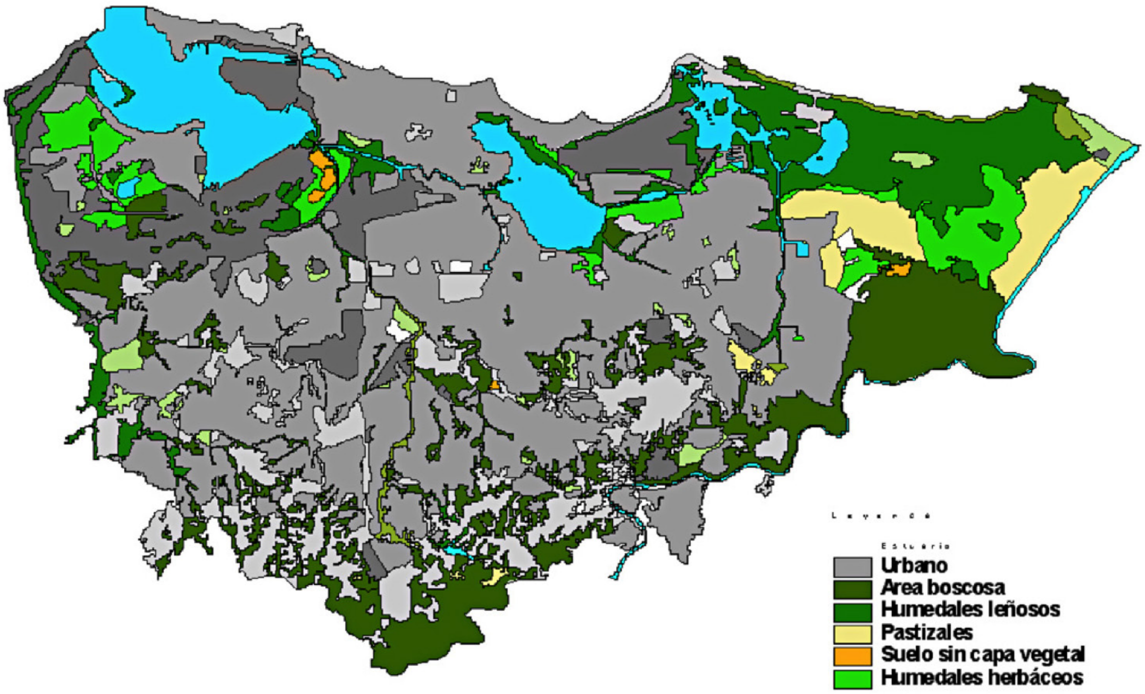


Figure 21. Land-use and paved area map for the San Juan Bay Estuary watershed.

almost double (PRCCC, 2013). With respect to the ocean, the temperature in the Caribbean watershed rose 1.5°C during the last century (IPCCC, 2013). An analysis done by Dr. Mark Jury as part of the PRCCC's efforts agrees with the 2013 IPCCC report, which shows an increase in the sea surface temperature (**SST**) of 0.008°C per year.

An event of extreme or extraordinary precipitation is an intense rainfall that occurs infrequently, and is spoken of, for example, as a "hundred-year event". To put it another way, this is a rainfall event whose intensity and quantity has a 1% probability of occurring in any given year. These are the accepted statistics, but the fact is that these precipitation events have been observed to be occurring recently with much higher frequency.

On the other hand, rainfall has decreased in San Juan over the last hundred years. According to Méndez-Lázaro's studies (2010), a decrease of between 0.0012 and 0.0032 mm/day of rainfall has been documented in the northern part of Puerto Rico. Méndez-Lázaro's observations agree with the USGS reports (from riverine water-level stations), which state that river discharges have fallen by approximately 1.27 mm/year. Although total rainfall has decreased, the frequency of extreme events, or intense rainfall (**Figure 22**), have increased fifteen percent for San Juan over the last sixty years (PRCCC, 2013). And this phenomenon is occurring not just in San Juan but over the entire island of Puerto Rico, where extreme rainfall events increased some 37% in the period 1958–2007 (PRCCC, 2013).

Figure 22. Extreme rainfall event in San Juan.

Sea Level Rise

Geological studies show that sea levels began to rise about 18,000 years ago. But the concern today is the average annual rise of 1 to 2 mm observed over the last hundred years, ten times faster than the increase over the last three thousand years. Moreover, and to be more precise, the sea level rise documented globally in the 1990s was 3.1 mm per year, much faster than the rise documented beginning in the 1960s, at 1.8 mm per year. This sea level rise translates into an increase of between 0.09 and 0.88 meters above current sea level for the next century (IPCC, 2013).

The rise in sea level is caused by the thermal expansion of the ocean due to an increase in the average ocean temperature. This expansion of the ocean due to temperature changes is known as "steric" sea level rise. To illustrate this, an increase of 1°C in the surface temperature of the ocean translates into a 2-meter rise in sea level. In fact, thermal expansion is greater in warm waters (like ours) than in the cold waters typical of temperate zones. In other words, the rise in sea level due to a given increase in temperature will be greater for Puerto Rico and other tropical zones than for the rest of the planet. But the sea level also rises due to melting of the polar ice caps, with a resulting increase in the volume of sea water. This is known as "eustatic" sea level rise, and will impact both tropical and temperate latitudes equally.

Locally, Dr. Jorge Capella has performed a detailed study on sea-level changes using data obtained from tide gauges located on Puerto Rico's south coast (Isla Magüeyes station, with an observation period of 56.7 years) and north coast (San Juan station, with an observation period of 49.4 years). The island's south coast exhibits an increase of 1.35 mm/year, similar to the north, which has risen 1.64 mm/year (**Figure 23**). Dr. Capella's conclusion is that the sea level will continue to rise at about 1.4 mm/year, and possibly faster. Likewise, Prof. Aurelio Mercado (personal communication) studied sea-level tendencies in Puerto Rico, but his analysis concentrates on the last few years, since 2010. Prof. Mercado makes an amazing and disturbing find: The sea is rising much faster than previously thought, some 13.43 mm/year for the San Juan tide gauge and 12.05 mm/year for Isla Magüeyes. Although the 2013 PRCCC report recommends that we should be preparing for a rise of between 0.5 and 1.0 meters by 2100, we can see that the situation may be more critical.

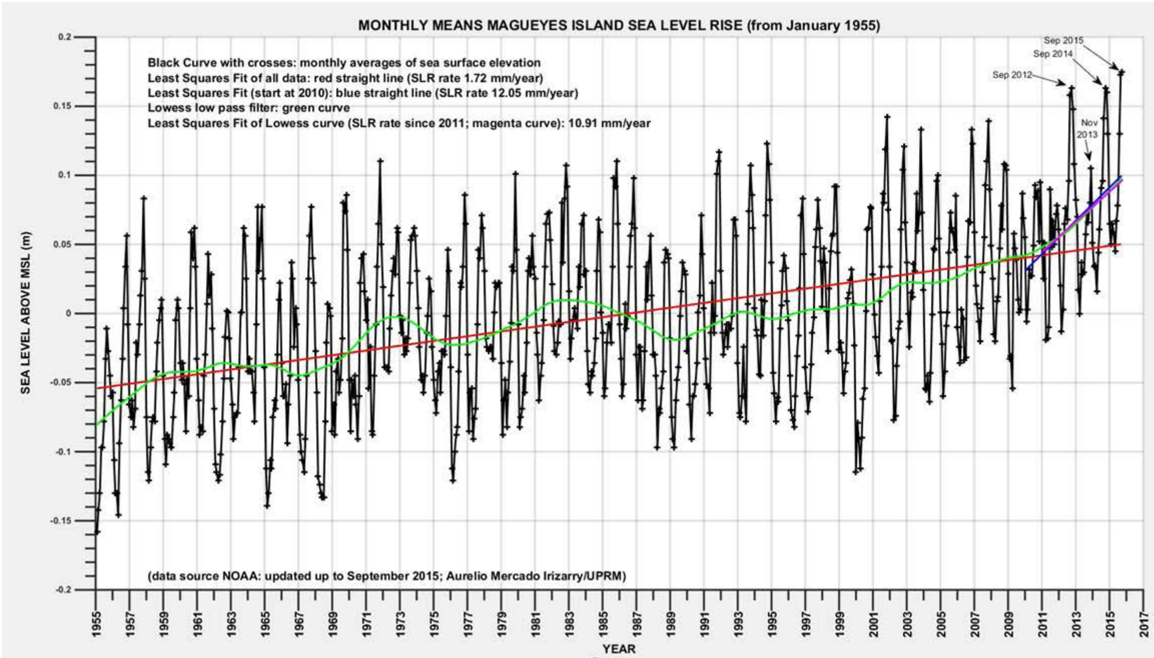
As we mentioned, the increase in the planet's surface temperature is not the only factor responsible for sea-level rise. There are other geological and climatological processes that increase or decrease sea levels. For example, when a storm approaches, the sea level rises due to a decrease in atmospheric pressure—the so-called inverted barometer effect. To be more precise, an increase of one centimeter of sea level occurs for each drop of one millibar of atmospheric pressure. This rise is short-lived, since once the hurricane passes, sea level returns to its normal state.

Sea-level changes relative to the coastline also occur due to movements in the earth's crust. These are called "tectonic changes." For example, the coastline of Tomaco, in Colombia, fell some two meters in 1979 due to an earthquake. The same thing has been observed along some Mediterranean coastlines. The coast may not only fall, but may also be lifted during an earthquake, as occurred on the Yakutat Bay beach in Alaska. There, in 1899, the coast was suddenly lifted some 14 meters above sea level.

Sea Level Changes

Eighteen thousand years ago, the sea level was some 130 meters (about 425 feet) lower than today. At that time, Puerto Rico, Vieques, Culebra, and the American and British Virgin Islands were all connected. You could walk to Vieques island with no need for a boat or bridge. This phenomenon was a consequence of the Wisconsin Glaciation (the Würm Glaciation in Europe), which was the last large-scale glaciation our planet has experienced. During glaciations, the shoreline extends and the sea retreats due to the large amount of water stored in glaciers and polar ice caps.

During the period known as the Holocene Transgression, the sea level began to rise due to the melting of the polar ice caps. It was this sea-level rise that gave birth to the San Juan Bay Estuary. This process continues today, but it has been accelerated by recent climate change. During rises in the sea level, the coastline migrates inland, a phenomenon known as "transgression."



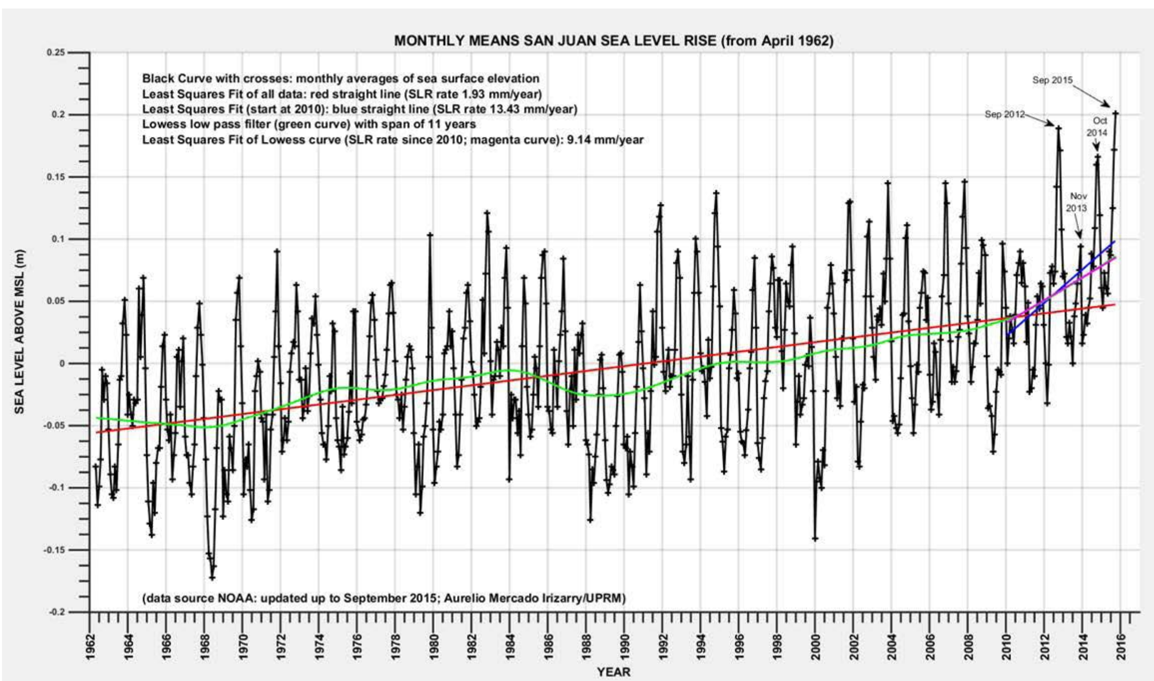


Figure 23. Data of sea level rise in Puerto Rico.

Humans intervene in other ways in sea-level changes, as when ground¬water or oil is extracted from along the coast. For example, in the twentieth century the shorelines of Venice have sunk some 30 cm due to ground subsidence produced by groundwater extraction. A similar phenomenon has occurred along the coasts of Galveston, Texas, Los Angeles, California, and Bolívar, Venezuela, where the apparent rise in sea levels is due to land subsidence as a consequence of oil drilling activities. In summary, whether because of groundwater or oil extraction, the mechanism is the same: a subsidence of the coastline as a result of extracting underground liquid.

In a kind of reverse of that mechanism, the deposition of large amounts of sediment at the mouth of rivers also contributes to coastal land subsidence and an apparent rise in sea levels. This is because the coastline literally sinks under the weight of the accumulated sediment. These changes in sea level due to long-term sediment accumulation are known as "isostatic adjustments." Isostatic adjustments are changes in the earth's crust caused by loading and unloading (increased or decreased weight on the surface) due to deposition, erosion, ice accumulation, etc. One example is the San Juan Bay Estuary. Comparison of historical photographs with photographs taken today of the San Juan Bay Estuary show an increase of about twelve percent in the mangrove coverage between Piñones and Las Torrecillas zones. It is believed that this increase is due to, among other things, the phenomenon of isostatic adjustment. In other words, as part of the coastline sank due to sediment deposition through time by the Río Grande de Loíza, seawater penetrated inland, flooding new areas and creating good conditions for the growth of mangroves. Deposits of sedimentary rock and the remains of shells and other organisms in the mountainous regions of Puerto Rico and the formation (by subsidence) of flooded coastal valleys creating lagoons and estuaries are clear evidence of drastic changes in sea level even without direct human intervention.

Storms and hurricanes

According to the PRCCC (2013), the number of hurricanes striking Puerto Rico has decreased over the period from 1730 to 2005 (Nyberg et al., 2007). But oddly enough, hurricanes of greater intensity (**Figure 24**) are expected by the end of the century (Kunkel et a., 2008; Knutson et al., 2010)—in other words, hurricanes with stronger winds (an expected increase from 5% to 11%) and with greater precipitation (an increase of 28% is expected) due to the increase in sea surface temperature (SST). The reason for this intensification is that an increase of 2°C in the SST (climatic models show) increases the velocity of hurricane winds by 5% to 12%. It is evident that the expected increases in hurricane intensity will affect coastal ecosystems, as well as people's life and property.

Ocean acidification

Since the beginning of the Industrial Revolution, the concentration of CO_2 in the atmosphere has risen from 280 ppm to a current level of 385 ppm. Over just the last five years, there has been the equivalent of an annual increase in the partial concentration by volume of approximately 0.75%, and it is expected that this concentration will continue to rise at about 1% per year. More than half of this CO_2 is absorbed

Figure 24. Hurricanes in the Caribbean area.

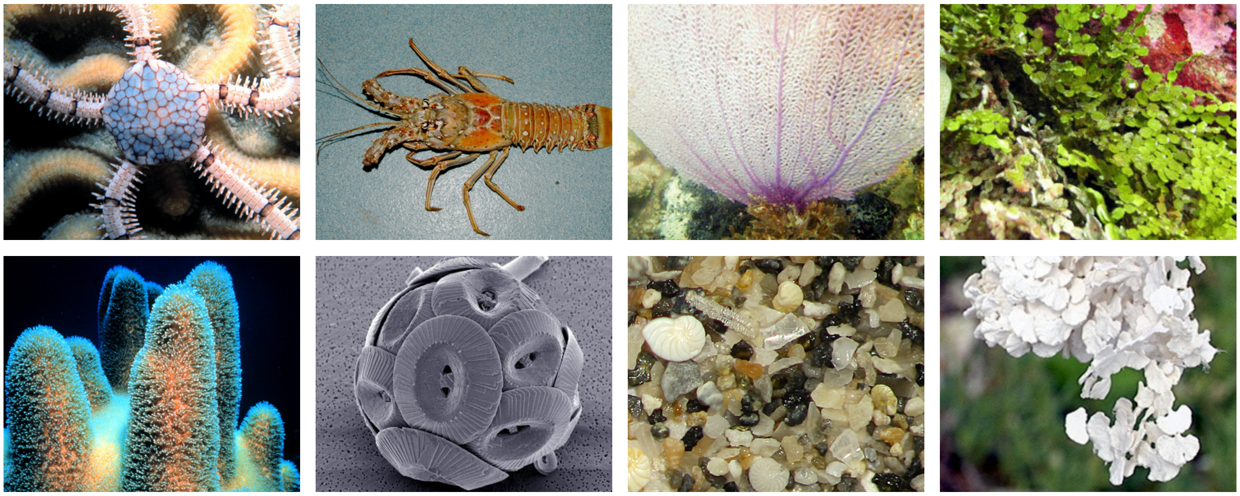


Figure 25. Example of calcifying organisms (clockwise): brittle star (*Ophionereis reticulata*),Caribbean lobster (*Panulirus argus*), venus fan (*Gorgonia ventalina*), green macroalgae (*Halimeda opuntia*, alive), green macroalgae (*Halimeda opuntia*, dried), Foraminifera, microalgae (*Coccolithus pelagicus*), and pillar coral (*Dendrogyra cylindrus*).

by the oceans, and if we continue with current levels of CO_2 emission, the oceans' pH will decrease between 0.3 and 0.4 units by the end of this century (in comparison to pre-industrial levels). In fact, the ocean's pH has already decreased from 8.16 to 8.05 in the past decades (IPCC 2013). Coral reefs, marine plankton, crustaceans, and other species that produce calcium carbonate will be severely impacted by ocean acidification due to the dissolution of their shells and a reduction in the availability of carbonates in seawater (**Figure 25**). We must keep in mind that the ocean will never be truly acidic, as the chemistry of its water buffers drastic changes in pH. Thus, the term "ocean acidification" refers to the process by which the ocean's pH is reduced, not to the fact that the ocean will be a body of acid water in the future.

2.2 VULNERABILITY OF OUR COASTAL ECOSYSTEMS

Sandy beaches and dunes

Bruun's Law (Bruun, 1962) states that for every centimeter of increase in sea level, a beach will retreat approximately one meter (depending on the beach's degree of inclination). This translates into the eventual disappearance of recreational beaches due to sea level rise (**Figure 26**, next page). Moreover, during hurricane events and heavy swells the sand may be transported out of the beach circulation cell and be lost to the beach berms and dunes forever.

A reduction in beach surface area will negatively affect coastal habitats and their associated fauna and flora. For example, Fish et al. (2005) have indicated that a rise of 0.5 meters in sea level in the Caribbean will reduce sea turtles' nesting zone by as much as thirty-five percent. This "coastal squeezing" will negatively affect other coastal species, as well, such as the blue land crab (*Cardisoma guanhumi*), the ghost crab (*Ocypode cuadrata*), and marine birds that nest and feed along the coast.

In addition, an increase in the temperature of the sand on beaches will influence the proportion of females to males among baby turtles, as the sex of the sea turtle hatchling is determined by the sand temperature during the second third of the incubation period: At higher temperatures more females are produced and at lower temperatures, more males (Ackerman, 1997). The disproportionate ratio of the sexes may eventually affect the sea-turtle population as a whole.

Due to ocean acidification, the calcium carbonate shells,

Figure 26. Areas of coastal erosion in Condado, Isla Verde and Loíza.
© El Nuevo Día (bottom right image)

spines, and skeletons that constitute the biogenic sand of many tropical beaches may dissolve and be lost. This loss may even extend to the eolianites, or coastal rock formations made of sand cemented with calcium carbonate, that act as natural barriers against heavy swells. The weakening and disappearance of these eolianites may expose the ecological communities living on the coast to coastal erosion. As can be seen, sea level rise, ocean acidification, intense hurricanes, higher temperatures, and other stressors may impact and directly or synergically jeopardize coastal ecosystems and their inhabitants.

Mangroves and wetlands

Some mangroves in the Caribbean have adapted to sea level rise by depositing peat, which accretes and thereby raises the mangrove forest faster than the sea level rises. Mangrove peat is composed mainly of refractory or persistent root residue rather than leaves and wood, which decompose more rapidly. There is evidence of vertical accretion of as much as 10 meters in mangrove forests established from 7,000 to 8,000 years ago. These deposits of mangrove peat may keep pace with rises in sea level, particularly in mangroves located on riverbanks, allowing these forests to survive rises in sea level. As evidence of this possibility, radiocarbon dating of cores taken in red mangrove forests in Belize, Honduras, and Panama and comparison of sea-level curves for the Atlantic Ocean show a link between the production and accumulation of peat and a rise in sea level during the Holocene (McKee et al., 2007). However, anthropogenic impacts may alter this dynamic, compromising the mangrove swamp's natural ability to adapt to sea-level changes.

Not all mangrove forests produce sufficient peat to accrete at a rate faster than sea-level rise. In that case, one response by the mangroves might be migration inland. Evidence of this response can be found in the Florida Everglades, where mangrove forests have migrated inland over the last fifty years as a result of sea-level rises. But mangrove stands can migrate inland only when there is available space—space not taken up by highways, housing developments, and other kinds of infrastructure. If the mangroves are unable to migrate, the wetland area will begin to shrink and disappear. Or there may be an alteration of the mangrove zonation and species composition—for example, displacement of the white mangrove (*Avicennia germinans*) by the red mangrove (*Rhizopora mangle*), which is better able to adapt to rises in sea level.

The mangrove forests most susceptible to rises in sea level are those located on emergent shelf reefs on keys and small islands made of carbonate (such as those in La Parguera and

Guánica). Due to the energy regime, nutrient dynamics, and mangrove productivity, the amount of peat accumulation in these mangroves is very small, insufficient to keep pace with sea-level rise, unlike mangrove stands along riverbanks, which have high rates of vertical accretion due to their own high productivity and the contribution of sediments from the watershed.

Coral communities

Coral bleaching is a phenomenon in which intracellular algae known as zooxanthellae (*Symbiodinium*, also known as zooxanthellae) are expelled from the coral's tissue with the resultant loss of the coral's pigmentation (**Figure 27**). But this is more critical than just losing the coral's color, since with this loss the coral colony stops growing or in many cases dies, as the zooxanthellae are needed for coral calcification and the colony's growth. At least in the Caribbean, corals die once they bleach out because opportunistic algae eventually overgrow and suffocate the coral polyps. Indeed, the Caribbean star coral (*Orbicella annularis*, formerly *Montastrea annularis*) may become extinct within the next few decades as a result of bleaching (Hernández-Pacheco et al., 2011).

Figure 27. Coral bleaching.

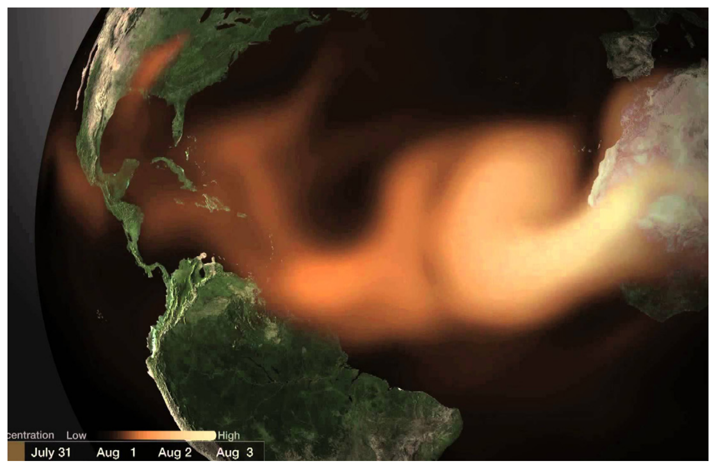


Figure 28. Sahara dust cloud reaching the Caribbean area. © NOAA

Bleaching usually occurs when the ocean temperature rises 3°C to 4°C above normal, under conditions of extreme calm. But in addition to contributing to bleaching, high surface temperatures stimulate the propagation of infectious diseases such as the "white plague," which, along with bleaching, has caused the loss of up to eighty percent of coral coverage in some places in the Caribbean (Miller et al., 2006; 2009). To this stressor may be added others such as sediment deposition, wastewater discharge, fertilizers, and natural events such as hurricanes. All of these stressors compromise the coral's health and its resilience to adapt to climate change.

Ocean acidification could also affect the rate of calcification in coral colonies. It is estimated that rates of calcification of coral reef may decrease by up to sixty percent by the twenty-first century. Also, a drop in pH (which could be up to 0.4 units by the end of this century) weakens the coral and makes it more susceptible to erosion and disease. And while the expected increase in rainfall intensity will lower the surface salinity, increased sedimentation and pollutant loads will further impact the coral reefs.

One of the most overlooked climate change impacts to coral communities is the "Sahara dust" from Africa (**Figure 28**). In April and May, Sahara dust may be observed from space crossing the Atlantic toward the Caribbean. But it is not only dust and sand that is being transported by the trade winds from Africa; "hitching a ride" are fungus, bacteria, and over 150 species of pathogens. The most compelling evidence of the damage done by pathogens carried by Sahara dust is the fungus *Aspergillus sydowii*, which infects Gorgonian corals such as the sea fan. Sahara dust also carries nutrients that enter the coastal waters and cause eutrophication and harmful algae blooms. Since the sixties, much less rainfall and thus more desertification has been recorded in Africa, and this in turn has increased the amount and intensity of dust clouds over the Sahara.

Seagrasses

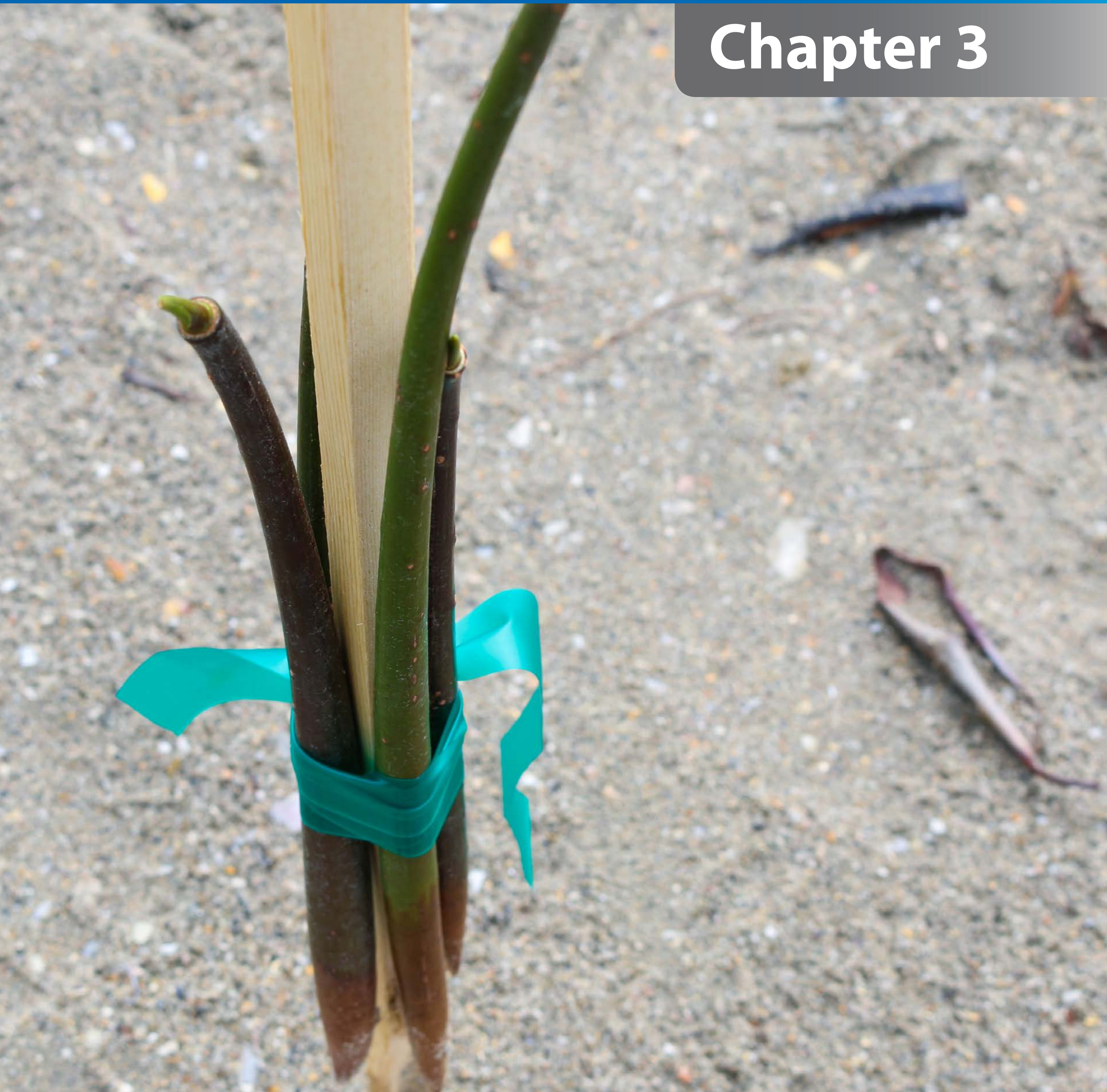
The projected increase in the intensity of hurricanes will affect all tropical marine communities, including seagrasses. Waves and strong currents resulting from strong winds can uproot and shred seagrass beds. In addition, strong wave action re-suspends sediments from the sea floor, thereby reducing the water column's transparency. This, in turn, translates into less light for photosynthesis and more abrasion by the suspended sediment. Thus, seagrasses will be affected by the same stressors and drivers as for coral communities. Last but not least, an increase in rainfall would generate more runoff, with its high content of sediments, nutrients, and pollutants.

TO SUMMARIZE...

The combination of natural and anthropogenic impacts—the full interaction of which cannot be fully gauged—weakens these ecosystems' resilience in the face of climate change. Therefore, it is of vital importance that we preserve the good health of the SJBE system's ecosystems so that they can adapt to new and emerging environmental conditions. One approach in the restoration and rehabilitation of these ecosystems is removing existing anthropic stressors, as these ecosystems have considerable ability to tolerate and survive climatic changes so long as their ability to resist and adapt to other impacts is not compromised. Lastly, it is very important to understand the interconnectedness and the biological, physical, and chemical interactions that occur among ecosystems, since these ecosystems' resilience to climate change will depend on how healthy these interactions are between the mangroves, the seagrasses, and the coral reefs.

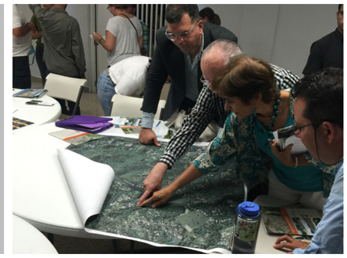
“A rise in sea level will cause freshwater wetlands to become salinized, and their structure and function to change.”

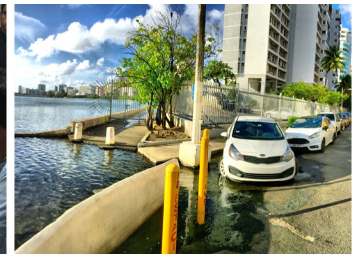
Chapter 3



3 THE WORKBOOK

Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans





The manual *Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans* (hereafter, the Workbook) is a tool to help identify risks, carry out a vulnerability assessment, and develop an adaptation plan in the face of impacts resulting from climate change.

It also allows an organization such as the SJBEP to develop a step-by-step plan of action for climate change impacts such as those described in earlier pages. This tool has been developed by the Climate Ready Estuaries Program (CRE) under the U.S. Environmental Protection Agency's National Estuaries Program (NEP).

The Workbook guides organizations through ten defined steps (**Figure 29**), which, once completed, allow the organization to develop, implement, and monitor adaptation actions. The first five steps are aimed at assessing the estuary's vulnerability to climate change; that is, determining what risks the estuary will or may face. Once all possible foreseeable risks are identified, those of highest priority are noted. These are the risks that have important consequences and are currently impacting the estuary. The next steps (6 through 10) are then aimed at designing, implementing, and monitoring concrete actions—the tasks the SJBEP will perform in order to mitigate climate-change impacts.

The following chapter will describe the process followed and the results obtained by the SJBEP in implementing the Workbook steps.

The workbook is available for public access. To download a copy, click here or visit :

http://www.epa.gov/sites/production/files/2014-09/documents/being_prepared_workbook_508.pdf

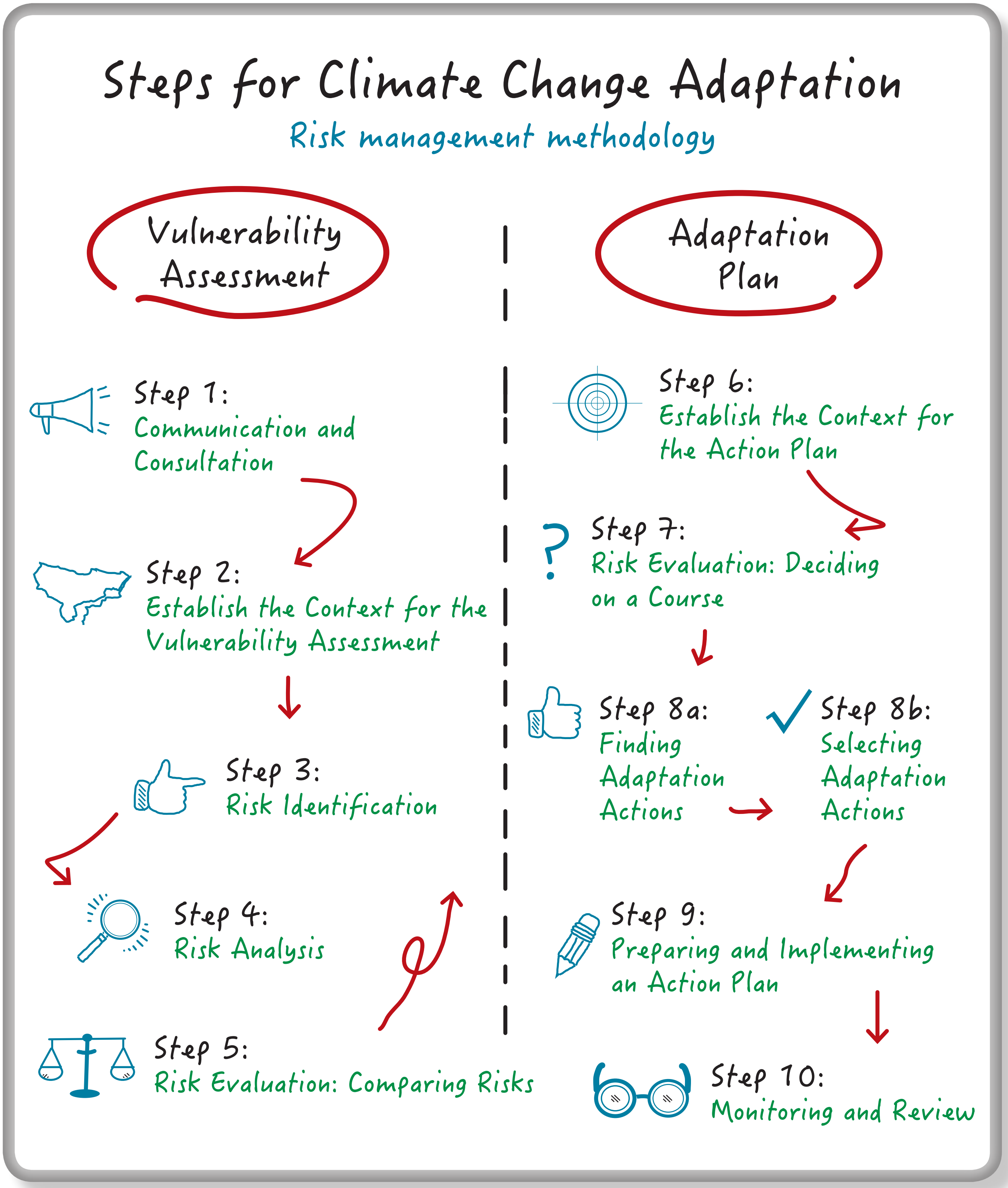
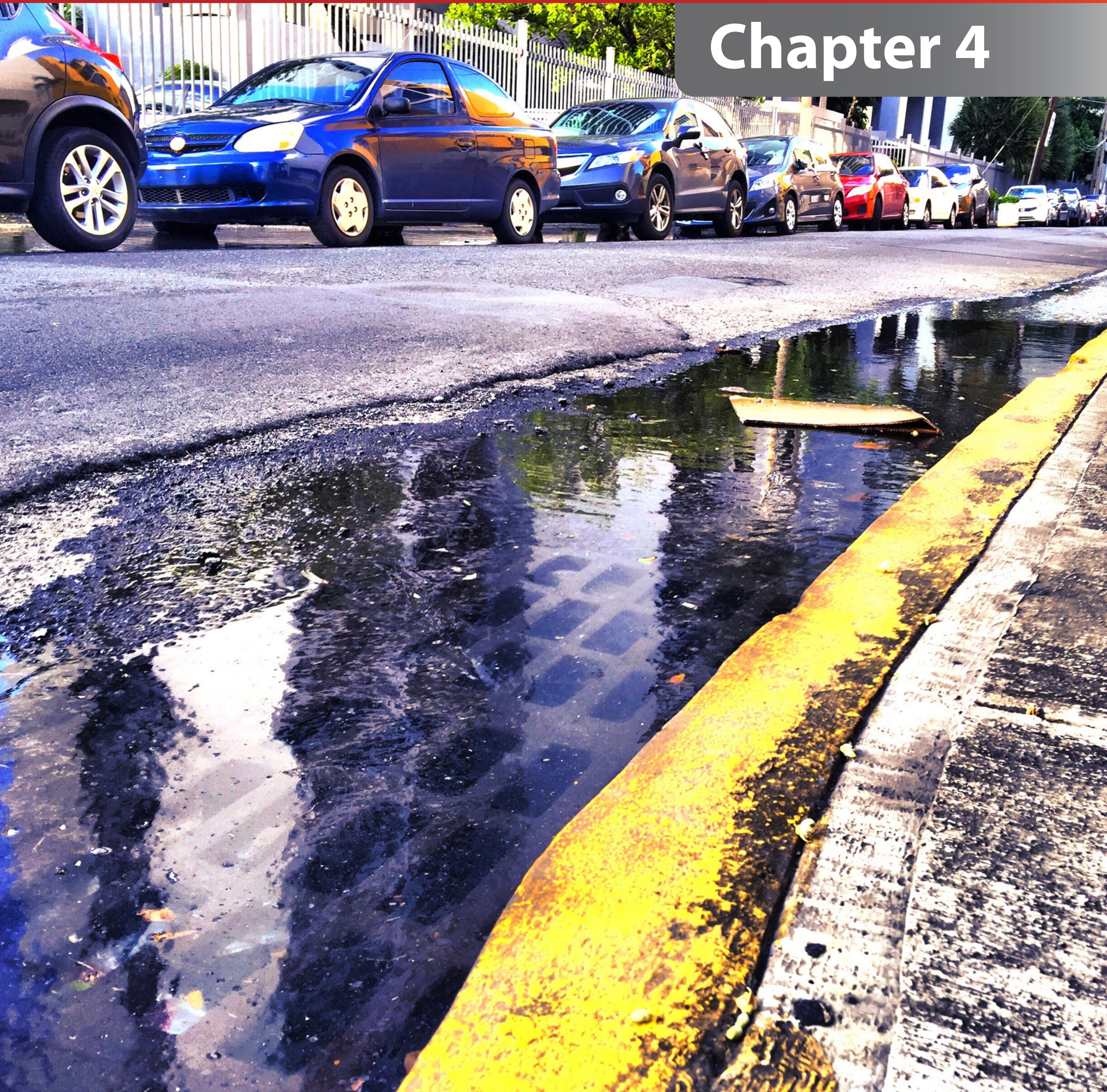


Figure 29. Step-by-step application of a risk management methodology to climate change adaptation, as proposed in the manual *Being Prepared for Climate Change: A Workbook for Developing Risk-Based Adaptation Plans.*

We invite you to watch CRE's short video about our Climate Change Vulnerability Assessment Project and other related efforts, by clicking on the image above (digital version) or scanning the QR Code below (print version).

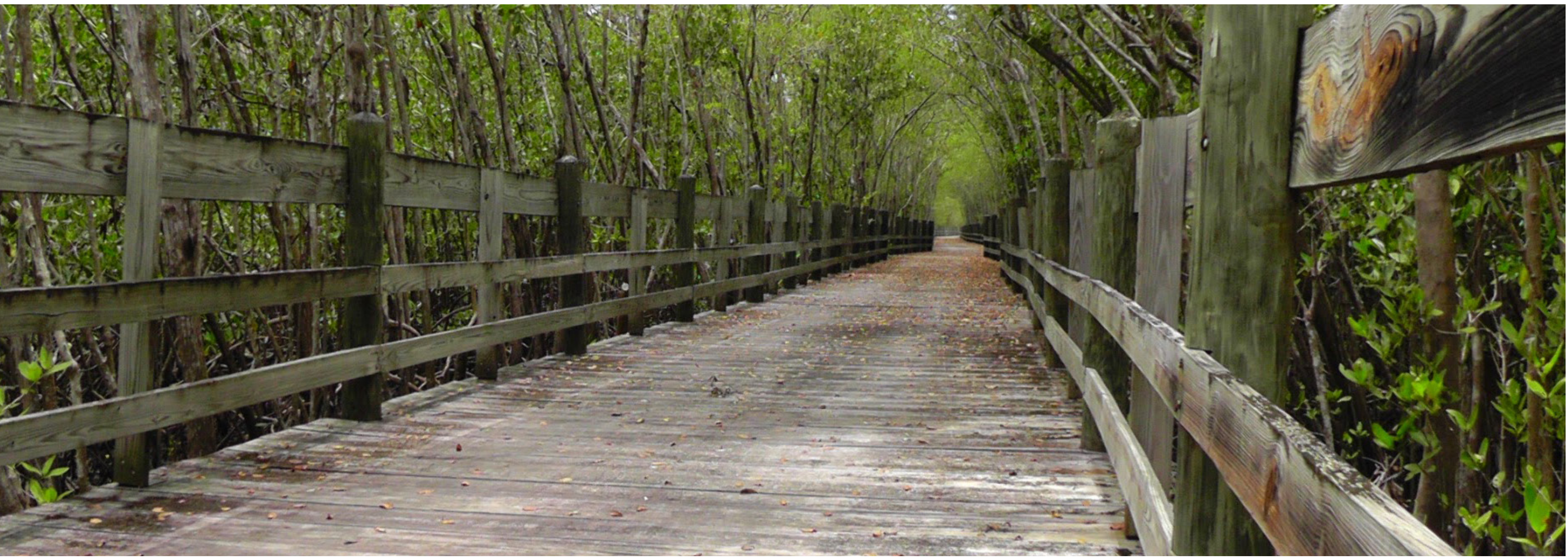
> *An increase in the intensity and amount of rainfall will cause flooding and episodes of more intense rainwater runoff, particularly at entries to already saturated rainwater sewers.*

Chapter 4



4 STEPS FOR ACTIONS:

San Juan Bay Estuary Climate Change Adaptation Plan



STEP 1:
Communication and Consultation

The objective of this first step is to select citizens, groups, agencies, and other interested parties and involve them in a vulnerability analysis and the subsequent development of an adaptation plan, and to inform the public of the importance of developing such a plan. But perhaps even more important, during this step valuable information is compiled and an attempt is made to elicit hitherto unshared knowledge from the participants in the analysis. Citizens, groups, and agencies interested in the subject are invited to take part. Some of the participants prefer to take an active part during the entire process, while others, in only some of the ten steps; some wish only to be kept informed, and of course some of those invited prefer not to participate at all.

To implement this step, a list was made of key persons representing state and federal environmental agencies and members of the marine and recreational industries. (For a list, see Step 3.) Meanwhile, a series of participatory

Figure 30. Promotional flyer of a participatory workshop in Loíza.

workshops was developed for environmental-justice communities such as, for example, the Piñones community in Loíza and the communities adjacent to the Martín Peña Channel (**Figure 30**). During these workshops and conversations, we first offered a general, easy-to-understand presentation of issues related to climate change, its causes and consequences. Then the session was opened up to questions and answers, suggestions, and concerns. During this period, some citizens voiced their concern over flash flooding in their community; others agreed that coastal erosion is impacting many recreational and commercial activities.

STEP 2:
Establishing the Context for the Vulnerability Assessment

The objective of this step is to list the goals (in this case, the SJBEP's specific goals) that would be compromised should certain climate-change impacts occur. This step is very important for the vulnerability assessment that follows, as it set the limits of this analysis; that is, how far we want to go with the adaptation plan. In the particular case of the SJBEP, the goals were set at the Program's founding in 1992. They respond to the mission of the Federal Clean Water Act and its Section 310, which created the National Estuary Program.

The goals chosen were the following:

- Controlling or eliminating **non-point sources of pollution**.
- Controlling or eliminating **point sources of pollution**.
- Maintaining the biological integrity of the SJBE and reintroducing native species.
- Preserving, improving, and restoring the SJBE's hydrological and physical characteristics.
- Protecting and propagating fish, shellfish, and other native species.
- Actively supporting recreational activities in the SJBE's bodies of water.
- Controlling or eliminating invasive species.

STEP 3:
Risk Identification

The objective in this step is to create a list of risks, resulting from climate change stressors, that could prevent the SJBEP from achieving the goals mentioned in Step 2. During this step, it is important that all possible foreseeable risks be identified. Risks are those consequences resulting from climate-change stressors, and stressors are the climate changes themselves. For example, a stressor is a rise in sea level resulting from global warming and a risk associated with this stressor is coastal erosion. Another stressor is an increase in rainfall events or in the intensity of rainfall, and an associated risk is an overflow of the sewage system. That is, when intense downpours occur (stressor), then more sewage-system overflows (risk) may occur, causing untreated sewage to reach the estuary's water. This risk in turn threatens our ability to achieve the goal of controlling or eliminating dispersed or point sources of pollution within the SJBE system. This is the type of analysis performed in Step 3; the objective of this step is to create, with the help of the community, a list of potential risks.

However, in order to create the list of risks, one first has to do a cross-analysis. In other words, one must present the SJBEP's goals (Step 2) and compare them with the stressors.

Non-point (or sometimes "dispersed") **sources of pollution** are those that have no specific point of origin—pollutants associated with rainwater and runoff, for example. That is, those pollutants carried by rainwater down gutters, from parking lots, highways, vehicle repair shops, residential and commercial roofs, etc.

Point sources of pollution, on the other hand, are those that have a specific, identifiable origin, such as pollutants that can be observed flowing from a sewage pipe.

For example:

1. **Choose a SJBEP goal** (Step 2)**:**

    √ Controlling point sources of pollution

2. **Choose a stressor** (See list, Step 3)**:**

    √ Warmer water temperatures

3. **Identify the risks** (such as that warmer water temperatures can affect control of point sources of pollution)**:**

    - √ Warmer water temperatures can increase the solubility and availability of some pollutants
    - √ Dissolved oxygen decreases in warmer water
    - √ Greater growth of undesired algae and/or microorganisms

Finally, the stressors selected for doing this analysis were the following:

- Warmer summers
- Warmer water temperatures
- More-frequent droughts
- More-intense rainfall
- Rise in sea level
- Effects of CO_2, including ocean acidification

A workshop-conversation/discussion was held in the regional offices of the USEPA on September 12, 2012. Twenty-two scientists attended (**Appendix 1**), representing academia, environmental organizations, the private sector, state and federal agencies, and so on. Some of the agencies and organizations attending the workshop were the Puerto Rico Department of Natural and Environmental Resources (DRNA), NOAA/National Marine Fisheries Services, the University of Puerto Rico, the Jobos Bay National Estuarine Research Reserve (JOBANERR), the Puerto Rico Tourism Company, the Puerto Rico Environmental Quality Board (PREQB), the U.S. Geological Survey (USGS), the Caribbean Coastal Ocean Observing System (CariCOOS), the DRNA's Program for Coastal Zone Management, the Puerto Rico Conservation Trust, the Nature Conservancy, Vicente & Associates, Inc., La Regata (a sailing magazine), and the ENLACE Project.

During the workshop a total of 68 risks associated with climate change were identified. Some risks were repeated because they threaten the achievement of more than one program goal. **Table 2** (next page onwards) presents those risks identified by the workshop participants.

STEP 4:
Risk Analysis

It is difficult to develop an adaptation plan that takes into account all the risks identified in Step 3. Thus, it is important to do a more detailed analysis of each individual risk. The objective is to understand the nature of the risk, its impacts and consequences, the probability that it will occur, and its spatial extension (how much of the estuary will be impacted) in order to begin to prioritize the risks on the basis of those specific criteria. In summary, the risks were analyzed according to the following criteria:

Probability of the risk's occurring: Here, we determine whether the risk is already occurring today, or whether, on the contrary, there is little probability that it will actually occur. The qualitative scale consists of three levels: (A) low probability; (B) medium probability; and (C) high probability.

Consequences of the impact: The consequence is the effect the risk will have, the intensity of its impact. For example, if the consequence is low, that means that there is little impact and it will not significantly impact the estuary. If, on the contrary, the consequence is high, then the impact will be severe or significant.

Spatial scale of the impact: The spatial scale is the area that will be impacted by the risk—for example, whether the impact is on a small structure such as a dock or a sewage-treatment plant, or covers a greater area such as, for example, a wildlife refuge or sub-watershed, or, finally, the impact is extensive, affecting the estuary's entire watershed.

Time scale of the impact: This criterion refers to when the impact is expected to occur. For example, in a few decades, over the next 15 to 30 years, or already occurring.

We assigned the range of impacts and scales letters, in which ***C*** is high and ***A***, low. The risks as they were finally evaluated are set forth in **Table 3** (after Table 2, page 35).

Step 5 continues on page 39, after tables 2 and 3.

Table 2: Risks due to Climate Change Identified in Workshops

GOAL	STRESSOR: Warmer summers
Controlling non-point sources of pollution	• Increase in runoff from more-intense precipitation and increasing sedimentation rate in the estuary's bodies of water. • Increase in concentration of ground pollutants due to increase in the rate of evapotranspiration within the watershed. • More episodes of eutrophication and hypoxia in estuarine bodies of water. • Shift of the forest structure and species in the upper watershed toward more drought-tolerant species.
Controlling point sources of pollution	Increased discharges of heated water from thermoelectric power plants' cooling systems into San Juan Bay due to an increased demand for energy.
Maintaining the biological integrity of the SJBE system and reintroducing native species	• Increased death of coral communities due to coral bleaching and disease. • More-intense storms and hurricane events. • Increased levels of nutrients in the estuary due to decomposition of aquatic vegetation (eutrophication).
Protecting and propagating fish, shellfish and other native species	• Increased death of fishes, crustaceans, and amphibians as they exceed the limit of their biological tolerance for dissolved oxygen and other environmental parameters. • Increased stopover time of migratory birds during the winter.
Preserving, improving, or restoring the SJBE's hydrological and physical characteristics	• May cause more-intense storms and hurricane events. • Higher demand for freshwater for human consumption and for other uses, leading to a reduction in the volume of surface and underground water and creating a deficit and/or ecological imbalance.
Controlling or eliminating invasive species	Increased metabolic and physiological activity of invasive species such as the green iguana and the caiman, leading to greater herbivore action and predation.
Actively supporting recreational activities in the SJBE's bodies of water	Increase in recreational activities and use of bodies of water all year round, which will increase pollutants and aquatic debris.
GOAL	**Warmer water temperatures**
Controlling non-point sources of pollution	• May cause greater solubility of pollutants and thereby increase pollutants in SJBE. • Increased abundance, survival, and transmission of parasites and pathogenic bacteria.
Controlling point sources of pollution	Greater dispersion and migration of species such as the caiman.
Maintaining the biological integrity of the SJBE system and reintroducing native species	• Less dissolved oxygen due to increased water temperature, with more-frequent episodes of mass fish mortality due to asphyxiation and physiological stress. • More events of eutrophication and hypoxia in estuarine bodies of water. • Increased death of coral communities due to coral bleaching and disease. • Drop in populations of dinoflagellates and other microorganisms.

Continues on next page

Table 2 (*continued*): Risks due to Climate Change Identified in Workshops

GOAL	STRESSOR: More-frequent droughts
Controlling non-point sources of pollution	Increased concentration of pollutants due to a decrease in water volume.
Controlling point sources of pollution	• Increased concentrations of pollutants in bodies of water as dilution is reduced due to reduced water flow.
Maintaining the biological integrity of the SJBE system and reintroducing native species	• Reforestation and planting in the watershed will be less successful. • More-frequent droughts and more-intense rainfall will create changes in the salinity of the estuary, affecting the distribution of species. • Increase in Sahara dust carrying pathogens and other compounds may stimulate the rapid and uncontrolled growth of microorganisms and increase "red tide" events.
Protecting and propagating fish, shellfish and other native species	More-frequent droughts and more-intense rainfall will create changes in the salinity of the estuary, affecting the distribution of species.
Preserving, improving, or restoring the SJBE's hydrological and physical characteristics	• A reduction in the base flow of rivers and streams, loss of depth, and therefore warmer water. • Lower water table and reduced aquifers, causing subsidence along the coastline and intrusion of saltwater. • More-frequent droughts and more-intense rainfall will create changes in the salinity of the estuary, affecting the distribution of species.
Actively supporting recreational activities in the SJBE's bodies of water	Increase in recreational activities and use of bodies of water all year round, which will increase pollutants and aquatic debris.
GOAL	**More-intense rainfall**
Controlling non-point sources of pollution	• Increased amounts of rainwater runoff. • May cause septic tanks and sewage-collection systems to fail and/or overflow. • More flooding by rainwater in urban areas. • Flood-control facilities such as retention ponds and wastewater treatment plants may fail and/or overflow. • Greater runoff from impervious surfaces carrying oils and grease, pesticides, and other pollutants.
Controlling point sources of pollution	• More incidents of flooding/overflow of combined sewage systems and sewage-collection systems. • Treatment plants will become overloaded and have to be halted due to excess flow of sewage to be treated.
Maintaining the biological integrity of the SJBE system and reintroducing native species	• Spread of herbaceous emerging freshwater wetlands. • Greater vegetation coverage and tree growth in the upper watershed.
Preserving, improving, or restoring the SJBE's hydrological and physical characteristics	• Erosion of riverbanks and streambeds. • Greater runoff from impervious surfaces carrying oils and grease, pesticides, and other pollutants. • Increased number of trees, vegetation cover, and aquatic weeds, which can obstruct SJBE canals and other waterways. • Changes in the geomorphology of the coastline.

Table 2 (*continued*): Risks due to Climate Change Identified in Workshops

GOAL	STRESSOR: More-intense rainfall (*continued*)
Controlling or eliminating invasive species	• Increased dispersion of species such as the tilapia in estuarine bodies of water. • Dispersion of caimans to the upper watershed.
Actively supporting recreational activities in the SJBE's bodies of water	• Increased public-safety risk due to increased pollution and bacterial presence. • Closure of recreational facilities due to bad weather.
GOAL	**Rise in sea level**
Controlling non-point sources of pollution	• Higher sea level may create obstructions and backflow at points of stormwater discharge, causing pollutant-laden water to overflow and impact higher areas of the watershed. • Higher extreme tides, which will flood new areas along the coastline. • May reduce the thickness of the estuary's surface layer of freshwater. • Erosion of the coastline, causing loss of beaches, wetlands, and marshes. • Changes in the pattern of currents and circulation in estuary lagoons.
Controlling point sources of pollution	• May obstruct sewage-treatment plant gravity inflow point. • May obstruct discharge points for stormwater runoff. • Greater infiltration (due to rise in the water table) into sewage-treatment systems. • Seawater may reach treatment/disposal sewer systems. • Higher sea level may create obstructions and backflow at points of stormwater discharge, causing pollutant-laden water to overflow and impact higher areas of the watershed.
Maintaining the biological integrity of the SJBE system and reintroducing native species	• Migration inland of wetlands, including mangrove stands. • Freshwater wetlands may become salinized and their structure and function may change. • Changes in the zonation of mangrove species; e.g., the red mangrove may displace other species.
Protecting and propagating fish, shellfish and other native species	Loss of nesting areas for aquatic birds, sea turtles, and other marine creatures.
GOAL	**Effects of CO_2, including ocean acidification**
Maintaining the biological integrity of the SJBE system and reintroducing native species	Increased death of corals and other calcifying organisms.
Protecting and propagating fish, shellfish and other native species	Calcification of coral colonies growing on artificial reefs may be affected.
Preserving, improving, or restoring the SJBE's hydrological and physical characteristics	Dissolution of beach rocks and eolianites, weakening the natural barrier against high waves, storm surges, and swell along the coastline.

Table 3: Analysis and Characterization of Risks

Risk	Probability A=low B=medium C=high	Consequences A=low B=medium C=high	Spacial Scale A=limited B=regional C=widespread	Time Scale A=decades away B=10-15 years C=now occurring
More-intense rainfall will increase the amount of stormwater runoff.	C	C	C	C
Increase in runoff from more-intense precipitation; increased sedimentation in the estuary's bodies of water.	C	B	C	B
Increase in ground pollutants due to increase in the rate of evapotranspiration.	A	A	B	A
More episodes of eutrophication and hypoxia in estuarine bodies of water.	B	C	A	B
Increased concentrations of pollutants in bodies of water as dilution is reduced due to reduced water flow.	B	B	B	A
Increase in rain may cause septic tanks and sewage-collection systems to fail and/or overflow.	C	C	C	C
Shift in the structure of forests and in species in the upper watershed toward more drought-tolerant species.	B	A	B	A
Loss of topsoil in the watershed and greater erosion, increasing sedimentation in the estuary's bodies of water.	B	C	C	A
Increase in the intensity and amount of rainfall will cause more events of flooding in urban areas.	C	C	C	C
Increased discharges of heated water from thermoelectric power plants into San Juan Bay due to an increased demand for energy.	A	B	A	A
Higher water temperatures may cause greater solubility of pollutants and higher concentrations of pollutants in the SJBE.	A	B	A	A
Obstruction of discharge points and stormwater drain outlets.	C	C	C	B
Increased death of coral communities due to coral bleaching and disease.	C	B	B	B
Spread of herbaceous emerging freshwater wetlands.	B	A	B	A
Greater vegetation coverage and tree growth in the upper watershed.	A	B	C	A
Migration inland of wetlands, including mangrove stands.	B	B	B	A

Table 3 (*continued*)**: Analysis and Characterization of Risks**

Risk	Probability A=low B=medium C=high	Consequences A=low B=medium C=high	Spacial Scale A=limited B=regional C=widespread	Time Scale A=decades away B=10-15 years C=now occurring
Increased death of coral and other calcifying organisms.	B	B	B	A
Flood-control facilities such as retention ponds and wastewater treatment plants may fail and/or overflow.	B	B	A	A
Changes in the zonation of mangrove species; e.g., the red mangrove may displace other species.	B	A	B	A
Increased death of coral communities due to coral bleaching and disease.	B	B	A	A
Reduced populations of dinoflagellates and other microorganisms.	A	A	B	A
Increase in Sahara dust carrying pathogens and other compounds may stimulate the rapid and uncontrolled growth of microorganisms and increase "red tide" events.	B	B	C	A
Increased death of fishes, crustaceans, and amphibians as they exceed the limit of their biological tolerance for dissolved oxygen and other environmental parameters.	B	B	B	A
Loss of nesting areas for aquatic birds, sea turtles, and other marine creatures.	C	C	A	B
An increase in water temperatures may increase the abundance, survival, and transmission of parasites and pathogenic bacteria.	A	C	B	A
Increased stopover time of migratory birds during the winter.	A	A	A	A
Higher demand for freshwater for human consumption and for other uses, leading to a reduction in the volume of surface and underground water and creating a deficit and/or ecological imbalance.	C	B	C	B
A reduction in the base flow of rivers and streams, loss of depth, and therefore warmer water.	B	B	B	B
Dissolution of beach rocks and eolianites, weakening the natural barrier against high waves, storm surges, and swell along the coastline.	A	B	A	A
Higher sea level may create obstructions and backflow at points of stormwater discharge, causing pollutant-laden water to overflow and impact higher areas of the watershed.	C	C	C	B

Continues on next page

Table 3 (*continued*): Analysis and Characterization of Risks

Risk	Probability A=low B=medium C=high	Consequences A=low B=medium C=high	Spacial Scale A=limited B=regional C=widespread	Time Scale A=decades away B=10-15 years C=now occurring
Changes in the pattern of currents and circulation in estuary lagoons.	B	B	B	A
Increased metabolic and physiological activity of invasive species such as the green iguana and the caiman, leading to greater herbivore action and predation.	B	B	A	A
Greater dispersion and migration of species such as the caiman.	B	B	A	A
Dispersion of caimans to the upper watershed.	B	B	A	A
Erosion of riverbanks and streambeds.	B	B	B	A
Increase in recreational activities and use of bodies of water all year round, which will increase pollutants and aquatic debris.	C	B	B	B
Closure of recreational facilities due to bad weather.	A	A	A	A
More incidents of flooding/overflow of combined sewage systems and sewage-collection systems.	C	C	C	C
Loss of beaches for beachgoers and impact on hotel and recreational facilities along the coast.	C	C	B	C
Rise in sea level will cause greater infiltration (due to rise in the water table) into sewage-treatment systems.	A	B	B	A
Increased public-health risks due to increased bacteriological contamination.	B	B	A	A
Rise in sea level will cause seawater to reach combined sewage-runoff systems.	C	C	C	B
Calcification of coral colonies growing on artificial reefs will be affected.	B	B	B	A
More-frequent droughts will increase the concentration of pollutants due to a decrease in water volume.	B	B	B	A
Use of dams such as Las Curias will compromise freshwater reaching San Juan Bay via the Río Piedras.	A	A	A	A
Higher sea level may create obstructions and backflow at points of stormwater discharge, causing pollutant-laden water to overflow and impact higher areas of the watershed.	C	C	C	B
Reduction in the availability of potable water; possible rationing.	B	B	B	C

Table 3 (*continued*): Analysis and Characterization of Risks

Risk	Probability A=low B=medium C=high	Consequences A=low B=medium C=high	Spacial Scale A=limited B=regional C=widespread	Time Scale A=decades away B=10-15 years C=now occurring
More-intense rainfall will cause treatment plants become overloaded and have to be halted due to excess flow of sewage to be treated.	B	B	A	B
Rise in sea level may obstruct sewage-treatment plant gravity inflow point.	B	B	A	B
Rise in sea level may reduce the depth of freshwater surface layer in the estuary.	A	B	C	A
Increase in the intensity and amount of rainfall will cause flooding and episodes of more intense runoff, particularly at entries to already saturated stormwater drains.	C	C	C	C
Warmer summers due to global warming will cause an increase in the level of nutrients in the estuary due to decomposition of aquatic vegetation (eutrophication).	A	B	C	A
Installation of desalinizing plants in the estuary.	A	A	A	A
Increased water temperatures will cause eutrophication and hypoxia (low oxygen concentrations) in estuarine bodies of water.	B	B	A	A
Rise in sea level will cause erosion of the coastline, causing the loss of beaches, wetlands, and marshes.	C	C	B	C
Increase in distribution of species such as tilapia in estuarine bodies of water.	A	A	A	A
Warmer summers due to global warming will cause more-intense storms and hurricanes.	B	C	C	A
Increase in the intensity and amount of rainfall will increase the number of trees, vegetation cover, and aquatic weeds, which can obstruct SJBE canals and other waterways.	B	B	B	A
More-frequent droughts will cause a drop in the base flow of water in rivers and creeks and a loss of water depth, causing warmer water.	C	C	B	C
More-frequent droughts will lower the water table, causing subsidence along the coast, coastal erosion, and intrusion of salt water.	A	B	B	A
Rise in sea level will cause freshwater wetlands to become salinized and their structure and function will change.	B	B	B	B
Rise in sea level will lead to higher tides, flooding new areas along the coast.	C	C	B	C
More-frequent droughts or greater rainfall amounts will lead to changes in the distribution of salinity in the estuary, thereby affecting the distribution of species.	B	B	B	A

STEP 5:
Risk Evaluation: Comparing Risks

Step 5 completes the vulnerability assessment, and consists of reviewing the risks identified and analyzed in the prior steps. The objective is to create a matrix in which the risks are organized on the basis of the probability they will occur and the consequences of their impacts. Then those risks with a high probability of occurrence (or that are already occurring) and whose impacts are high—the combination producing what are known as "red risks"—are prioritized and an adaptation plan is designed for them.

The risks selected are those with a classification of C (high, widespread, already occurring) for the criteria discussed in the workshop and those emphasized and presented in the conversations with the community and participating groups. It is important to note that the other risks are not neglected, as they can be reevaluated in future efforts. That is, a risk with low impact and low probability of occurrence at this point may become a red risk at a later moment. Therefore, implementation of the plan involves ongoing/constant assessment.

The **red risks** (28 in total) were the following:

1. More-intense rainfall will increase the amount of rainwater runoff.
2. More-intense rainfall will cause septic tanks and sewage-collection systems to fail and/or overflow.
3. More-intense rainfall will cause more events of flooding in urbn areas.
4. Warmer water will cause greater solubility of pullutants and thereby increase pollutants' availability in the SJBE.
5. More-intense rainfall will cause flood-control facilities such as retention ponds and wastewater treatment plants to fail and/or overflow.
6. Warmer water will cause increased abundance, survival, and transmission of parasites and pathogenic bacteria.
7. A rise in sea level will create obstructions and backflow at points of stormwater discharge, causing pollutant-laden water to overflow and impact higher areas of the watershed.
8. More-intense rainfall will cause erosion of riverbanks and streambeds.
9. A rise in sea level will cause higher tides that will flood new areas of the coastline.
10. More-intense rainfall will cause more incidents of flooding/overflow of combined sewage systems and sewage-collection systems.
11. A rise in sea level will cause greater infiltration (due to rise in the water table) into sewage-treatment systems.
12. A rise in sea level will cause seawater to reach combined sewage-runoff systems.
13. More-frequent droughts will increase the concentration of pollutants due to a decrease in water volume.
14. More-intense rainfall will cause treatment plants to become overloaded and be halted due to excess flow of sewage to be treated.
15. Rise in sea level will obstruct sewage-treatment plant gravity inflow.
16. Rise in sea level will reduce the depth of the estuary's surface layer of freshwater.
17. More-intense rainfall will cause flooding and episodes of more intense runoff, particularly at entries of already saturated stormwater drains.
18. Warmer summers due to global warming will cause an increase in the level of nutrients in the estuary due to decomposition of aquatic vegetation (eutrophication).
19. Warmer water temperatures will cause eutrophication and hypoxia (low oxygen concentrations) in estuarine bodies of water.
20. Rise in sea level will cause erosion of the coastline, causing loss of beaches, wetlands, and marshes.
21. Warmer summers will cause more-intense storms and hurricanes.
22. More-intense rainfall will increase the number of trees, vegetation cover, and aquatic weeds, which can obstruct

SJBE canals and other waterways.

23. More-frequent droughts will cause a drop in the base flow of water in rivers and creeks and a loss of water depth, causing warmer water.

24. More-frequent droughts will lower the water table, causing subsidence along the coast, coastal erosion, and intrusion of salt water.

25. Rise in sea level will cause freshwater wetlands to become salinized and their structure and function will change.

26. More-frequent droughts or greater rainfall amounts will lead to changes in the distribution of salinity in the estuary, thereby affecting the distribution of species.

27. A rise in sea level will reduce nesting areas for aquatic birds, sea turtles, and other marine creatures.

28. A rise in sea level and consequent erosion will reduce beaches for beachgoers and impact hotel and recreational facilities along the coast.

STEP 6: Establishing the Context for the Action Plan

This step is aimed at examining the SJBEP's opportunities, limitations, and resources for developing an adaptation plan based on the vulnerability assessment and risk analysis completed in the first five steps. During this step, contact is made again with all the collaborators, participants, and organizations interested in continuing to take part in the process. The objective is to identify which risks the SJBEP can work on directly and which can be worked on with the help of other entities. All the organizations that took part in the workshop (Step 3) showed interest in continuing to work on the adaptation plan in all its phases.

The SJBEP is committed to incorporating the adaptation plan's actions into future work plans and to requesting funds for that purpose from both Section 320 of the CWA and external grantors. It is important to make clear that one of the limitations on implementation of an adaptation plan is precisely the availability of funding. Therefore, the SJBEP will commit resources to developing proposals to be sent to other interested agencies and offices. Not all risks can be addressed simultaneously in an adaptation plan; therefore, those measures that can be implemented with the resources currently available to the SJBEP and its collaborators will be chosen to be worked on first.

STEP 7: Deciding on a Course of Action

The objective of this step is to decide on the concrete actions to be taken for each of the red risks identified in Step 5. That is, the SJBEP decides which risks will be mitigated and which risks it will accept, transfer, or avoid. According to the Workbook, there are four possibilities:

MITIGATE: This action entails taking concrete, defined actions to develop an adaptation plan that will reduce the risk's probability and consequences. The risks selected for mitigation are those to which the SJBEP will assign resources for development of adaptation plans.

TRANSFER: This action is selected when there is another organization or agency, outside the SJBEP, that plans to mitigate, is mitigating, or plans to take action to reduce the risk.

ACCEPT: This action is selected when the risk is accepted, since at this time it is not possible to mitigate it and develop an adaptation plan. No action is taken, but it is possible that mitigation and development of an adaptation plan might be attempted when there is more information or there are more resources in the future.

AVOID: This action is administrative in nature. It is selected when a decision is made to change the SJBEP's goals and objectives to prevent the risk from successfully threatening the implementation of its actions; for example, eliminating the programs to plant red mangrove trees, since a rise in sea level would keep the mangroves from thriving.

Table 4 (on next page) shows the actions selected for each of the red risks. This analysis is the result of a participatory-interactive process with the collaborators mentioned above.

Table 4: Actions Selected for Each of the Red Risks

RISK	ACTION
More-intense rainfall will increase the amount of rainwater runoff.	TRANSFER
More-intense rainfall will cause septic tanks and sewage-collection systems to fail and/or overflow.	TRANSFER
More-intense rainfall will cause more events of flooding in urban areas.	TRANSFER
Warmer water will cause greater solubility of pollutants and thereby increase pollutants' availability in the SJBE.	ACCEPT
More-intense rainfall will cause flood-control facilities such as retention ponds and wastewater treatment plants to fail and/or overflow	ACCEPT
Warmer water will increase the abundance, survival, and transmission of parasites and pathogenic bacteria.	MITIGATE
A rise in sea level will create obstructions and backflow at points of stormwater discharge, causing pollutant-laden water to overflow and impact higher areas of the watershed.	MITIGATE
More-intense rainfall will cause erosion of riverbanks and streambeds.	MITIGATE
A rise in sea level will cause higher tides that will flood new areas of the coastline.	ACCEPT
More-intense rainfall will cause more incidents of flooding/overflow of combined sewage systems and sewage-collection systems.	MITIGATE
A rise in sea level will cause greater infiltration (due to rise in the water table) into sewage-treatment systems.	ACCEPT
A rise in sea level will cause seawater to reach combined sewage-runoff systems.	ACCEPT
More-frequent droughts will increase the concentration of pollutants due to a decrease in water volume.	ACCEPT
More-intense rainfall will cause treatment plants to become overloaded and be halted due to excess flow of sewage to be treated.	TRANSFER
Rise in sea level will obstruct sewage-treatment plant gravity inflow point.	TRANSFER

Table 4 (*continued*): Actions Selected for Each of the Red Risks

RISK	ACTION
Rise in sea level will reduce the depth of the estuary's surface layer of freshwater.	ACCEPT
More-intense rainfall will cause flooding and episodes of more intense runoff, particularly at entries to stormwater drains, which will already be saturated.	TRANSFER
Warmer summers due to global warming will cause an increase in the level of nutrients in the estuary due to decomposition of aquatic vegetation (eutrophication).	MITIGATE
Warmer water temperatures will cause eutrophication and hypoxia (low oxygen concentrations) in estuarine bodies of water.	MITIGATE
Rise in sea level will cause erosion of the coastline, causing the loss of beaches, wetlands, and marshes.	MITIGATE
Warmer summers will cause more-intense storms and hurricanes.	ACCEPT
More-intense rainfall will increase the number of trees, vegetation cover, and aquatic weeds, which can obstruct SJBE canals and other waterways.	ACCEPT
More-frequent droughts will cause a drop in the base flow of water in rivers and creeks and a loss of water depth, causing warmer water.	ACCEPT
More-frequent droughts will lower the water table, causing subsidence along the coast, coastal erosion, and intrusion of salt water.	ACCEPT
Rise in sea level will cause freshwater wetlands to become salinized and their structure and function will change.	ACCEPT
More-frequent droughts or greater rainfall amounts will lead to changes in the distribution of salinity in the estuary, thereby affecting the distribution of species.	ACCEPT
A rise in sea level will reduce nesting areas for aquatic birds, sea turtles, and other marine creatures.	MITIGATE
A rise in sea level and consequent erosion will reduce beaches for beachgoers and impact hotel and recreational facilities along the coast.	MITIGATE

STEP 8a:
Finding Adaptation Actions

The objective of this step is to identify and select a series of potential adaptation actions to mitigate the risks identified in Step 7. **Table 5** (next page onwards) shows the risks (from Step 7) to be mitigated and the potential actions to reduce the probability and consequences entailed by the risk.

STEP 8b:
Selecing Adaptation Actions

The objective of this step is to select, on the basis of certain specific criteria, the adaptation action(s) the SJBEP will be able to implement with its available resources. During Step 8a, several adaptation actions were identified, but not all were feasible. Therefore, each of the actions was further evaluated using the following criteria:

Risk reduction potential: Whether the action will actually reduce the probability and consequences of the risk.

Feasibility and effectiveness: Whether the action is achievable in a reasonable period of time and with the organization's resources, whether it has been implemented successfully in other places, what permits may be needed, and whether it is acceptable to the community.

Cost and cost effectiveness: Whether the costs justify the benefits, whether long-term maintenance is feasible, and whether, for example, the action generates economic benefits.

Ancillary costs and benefits: Whether the action creates positive side effects that may help with other non-climate problems, whether it mitigates more than one climate change risk, whether it is sustainable over the long term.

Equity and fairness: Does this action align with the SJBEP's ethics and principles, does it cause harm to low-income communities or minority groups, or does it disproportionately benefit a single social sector?

Robustness: Given inherent uncertainty about the future, is the action flexible and adaptable to potential changes? Is the action positive even if climate changes do not occur as expected; in other words, does the action produce other social and economic benefits?

Table 6 (on page 46) shows the results of our ranking after the analysis of criteria for judging the positive effects of adaptation actions. For each action, a ranking from 1 (low) to 5 (high) was assigned. Actions with the highest scores were then incorporated into the Workbook's Step 9.

The three actions with the highest scores were chosen. These were:

1. Restore and enhance coastal dunes impacted by extraction of sand and other causes. (27 points)

2. Implement a plan for frequent maintenance of stormwater and sewage collection systems. (27 points)

3. Begin an educational campaign aimed at restaurants on proper management and disposal of oils and grease. (26 points)

It is very important to keep in mind that the adaptation actions that were not selected will be considered for implementation in the future. The goal in implementing the selected actions is to reduce the probability of occurrences and the consequences of their impact at the present time. That is to say, to remove the risks from the list of red risks.

Table 5: Potential Adaptation Actions

Risk to be Mitigated	Potential Adaptation Action	Will reduce probability of occurrence? Y/N	Will reduce consequences and impacts? Y/N
Warmer water will increase the abundance, survival, and transmission of parasites and pathogenic bacteria.	Create a comprehensive monitoring program for pathogens that incorporates a system for rapid dissemination of findings.	**N**	**Y**
A rise in sea level will create obstructions and backflow at points of stormwater discharge, causing pollutant-laden water to overflow and impact higher areas of the watershed.	• Replace pavement and hard pipes with permeable surfaces or perforated pipes so that runoff can infiltrate the soil. • Design discharge points with valves allowing flow in one direction only, to prevent return.	**N**	**Y**
More-intense rainfall will cause erosion of riverbanks and streambeds.	Reforest riparian corridors and eliminate or replace hard-armored channelization in selected segments of rivers and creeks.	**Y**	**Y**
More-intense rainfall will produce more incidents of flooding/overflow of combined sewage systems and sewage-collection systems.	• Implement a plan for frequent maintenance of stormwater and sewage collection systems. • Begin an educational campaign aimed at restaurants on the proper management and disposal of oils and grease. • Replace pavement and hard pipes with permeable surfaces or perforated pipes so that runoff can infiltrate the the soil.	**Y**	**Y**
Warmer summers will cause an increase in the level of nutrients in the estuary due to decomposition of aquatic vegetation (eutrophication).	Improve the circulation of estuarine bodies of water and eliminate discharges and disposal of sewage, sediments, aquatic debris, and other types of pollutants that are already impacting the estuary.	**N**	**Y**
Warmer water temperatures will cause eutrophication and hypoxia (low oxygen concentrations) in estuarine bodies of water.	Improve the circulation of estuarine bodies of water and eliminate discharges and disposal of sewage, sediments, aquatic debris, and other types of pollutants that are already impacting the estuary.	**N**	**Y**

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Table 5 (*continued*): Potential Adaptation Actions

Risk to be Mitigated	Potential Adaptation Action	Will reduce probability of occurrence? Y/N	Will reduce consequences and impacts? Y/N
Rise in sea level will cause erosion of the coastline, causing loss of beaches, wetlands, and marshes.	• Restore and enhance coastal dunes impacted by extraction of sand and other causes. • Deploy artificial reefs designed to buffer wave action, redirect/dissipate currents, and deposit sand.	**Y**	**Y**
A rise in sea level will reduce nesting areas for aquatic birds, sea turtles, and other marine creatures.	• Restore and enhance coastal dunes impacted by extraction of sand and other causes. • Deploy artificial reefs designed to buffer wave action, redirect/dissipate currents, and deposit sand.	**Y**	**Y**
A rise in sea level and consequent erosion will reduce beaches for beachgoers and impact on hotel and recreational facilities along the coast.	• Restore and enhance coastal dunes impacted by extraction of sand and other causes. • Deploy artificial reefs designed to buffer wave action, redirect/dissipate currents, and deposit sand. • Beach nourishment.	**Y**	**Y**

Table 6: Analysis of Adaptation Actions Using Ranking Criteria 1 (low) to 5 (high)

: Highest score, incorporated to Step 9

Adaptation Actions	Risk Reduction Potential	Feasibility and Effectiveness	Cost and cost-effectiveness	Ancillary costs and benefits	Fairness and Social Justice	Robustness	Total
Create a comprehensive monitoring program for pathogens that incorporates a system for rapid dissemination of findings.	1	3	3	3	4	3	17
Replace pavement and hard pipes with permeable surfaces or perforated pipes so that runoff can infiltrate the soil.	5	3	3	5	5	3	24
Design discharge points with one-way valves or flappers allowing flow in one direction only, to prevent return.	4	3	3	4	5	3	22
Reforest riparian corridors and eliminate or replace hard-armored channelization in selected segments of rivers and creeks.	4	3	3	4	4	3	21
Implement a plan for frequent maintenance of stormwater and sewage collection systems.	5	4	3	5	5	5	**27**
Begin an educational campaign aimed at restaurants on the proper management and disposal of oils and grease.	3	4	5	5	5	4	**26**
Improve the circulation of estuarine bodies of water and eliminate discharges and disposal of sewage, sediments, aquatic debris, and other types of pollutants that are already impacting the estuary.	4	4	2	5	5	4	24
Restore and enhance coastal dunes impacted by extraction of sand and other causes.	4	5	4	5	5	4	**27**

STEP 9:
Preparing and Implementing an Action Plan

The objective of this step is to create the adaptation plan for the actions selected in Step 8. To do this, we must identify the participants involved in the adaptation plan, develop the concrete steps to take, and track implementation.

The actions to be included in the adaptation plan are:

ACTION 1: Restore and enhance coastal dunes impacted by extraction of sand and other causes.

Participating Groups:: SJBEP, DRNA; NOAA; FWS; TNC; UPR.

Time to completion: 18 months.

Monitoring or progress report frequency: Monthly.

Sand dunes are a part of the coastal zone and usually take the form of long rows parallel to the shore. They are the first line of protection against strong waves along the coast and an important area for water storage. In extreme cyclonic events such as hurricanes, they protect communities from coastal flooding, storm tides and surges, and winds. Over the years, dunes have been disappearing from the coasts around San Juan due to sand extraction and other causes. In addition, all-terrain vehicles and the use of cars to reach spaces near the beach have negatively impacted the dunes. The regeneration of these systems is necessary, as dunes are essential to coastal protection and as habitat for costal wildlife.

Each dune system is a unique ecosystem. However, as systems they are all fragile, and all are formed by similar factors: wind currents, wave action, and certain species of plants. It is important to be aware of the physical processes that allow and foster dune creation. Restoration should begin along the shoreline of Piñones and Isla Verde, as it is in these areas that we see the most severe coastal erosion along some stretches of the beach. To restore the dunes, the following steps are recommended:

1. *Install sand fences.*

Dune reconstruction should be undertaken in areas where the dune has become fragmented. It is important to keep in mind that a morphology similar to that which existed prior to the dune's fragmentation should be strived for. Dunes vary in shape and size, depending on the factors that led to their formation; thus, dune rehabilitation may vary depending on the space on the coast available and the project's complexity. Dunes should be reconstructed "naturally," using methods that aid re-formation. Ordinarily, sand fences are used, since they allow sand to accumulate quickly. Sand fences should be set at the foot of the dune (**Figure 31**), where sediment transport is greatest; this allows sand to accumulate even faster (Grafals-Soto, 2012).

The DRNA recommends two methods for restoring dunes on the Puerto Rican coastline: that proposed by Woodhouse (1978) and that proposed by Davis (Martínez et al., 1983). Another method that might be employed is setting up wooden pallets. This method has been used by the University of Puerto Rico's Caribbean Center for the Reduction of Aquatic Waste and its Dune Restoration Program, and has proven to be very effective in regenerating the coastal dunes in the town of Isabela. Finally, even discarded Christmas trees may be used as a sand trapping system, an alternative worth exploring.

2. *Plant plants native or fully adapted to the sandy coast.*

The reconstruction process should include planting plants that stabilize the dunes. Plants that grow on dunes can generally be classified as pioneer vegetation and scrubland vegetation (**Table 7**). Pioneer plants are hardy grasses that begin the process of dune formation in the part closest to the ocean (Martínez et al., 1983), and are the first plants to colonize the dune. Pioneer species typically adapt to shifting sand and resist both wind and salinity. The scrubland zone is behind the pioneer zone. The plants that grow in the scrubland zone are dominated by small shrubs, grasses, and woody plants (**Figure 32**). The scrubland zone is important in maintaining soil humidity. In addition to helping stabilize the soil, the vegetation that grows on dunes provides habitat for a wide variety of crustaceans, reptiles, and birds. The use of native plants is very important for the success of the project.

3. *Use of* sargassum *(Sargassum sp) as a tool for regenerating coastal dunes.*

In recent years, an anomalous accumulation of sargassum along coastlines in the Caribbean and the eastern seaboard of the United States has occurred. This accumulation has affected recreational activity on many beaches of high recreational value and by causing a drop in

Figure 31. Way in which sand fences should be placed in order to maximize sand capture.

Figure 32. Dune vegetation

Table 7: Native Plants Recommended for the Restoration of Coastal Dunes

Common Name	Scientific Name	Foredune	Back dune
Saltgrass/ Yerba de sal	*Spartina patens*	X	
Saltwater couch/ Matojo de playa	*Sporobolus virginicus*	X	
Beach morning glory/ Bejuco de playa	*Ipomoea pes-caprae*	X	
Coastal jack-bean/ Habichuela de playa	*Canavalia rosea*	X	
Seagrape/ Uva de playa	*Coccoloba uvifera*		X
Gray nicker/ Mato de playa	*Caesalpinia bonduc*		X

internal and external tourism has impacted area economies. Some scientists associate the arrival of sargassum to Puerto Rican beaches with climate change, due perhaps to shifts in ocean currents and gyres or perhaps to higher water temperatures. Sargassum along the coastline may, however, be turned into a resource for restoring dunes. Texas A&M University-Galveston, for example, recently developed a project to revitalize Galveston beaches through a sargassum-core-enhanced dune system. This project consists of compressing sargassum and baling it as a core for new dunes along the seacoast, as the bales catch blowing sand. In addition to physically trapping sand blown by wind, the decaying seaweed provides nutrients for the vegetation that eventually grows on the dune. Sargassum-core dunes can be created on all the sandy beaches in the estuary where seaweed accumulates in significant quantity.

Procedure for Using Sargassum to Regenerate Coastal Dunes*

1. Remove the sargassum from the beach.
2. Compact and bale the sargassum into bales approx. 2.5' x 2.5' x 2' to facilitate transport.
3. Place the bales on the windward side of the dune to be regenerated.
4. Plant vegetation on the dune.

*Procedure used by Texas A&M University-Galveston (TAMUG) and Sargassum Early Alert System (SEAS) on Galveston beaches, modified for SJBEP beaches.

Image above: Dune regenerated by TAMUG using sargassum. Accessed from http://seas-forecast.com/Pages/Gallery/Sargassum%20Dunes.html

ACTION 2: Implement a plan for frequent maintenance of stormwater and sewage collection systems.

Participating Groups: SJBEP, DRNA; PRASA; municipalities; PREQB

Time to completion: 1 year.

Monitoring or progress report frequency: Monthly.

Puerto Rico's water collection system consists of two sub-systems: the sewage (wastewater) system and a stormwater (rainwater) system. The sewage system collects wastewater from homes, industry, agriculture, and in commercial areas and transports it via a network of pipelines to a sewage treatment plant, where it is treated. The rainwater system is a network of pipelines that collects rainwater runoff from streets, etc., and discharges it into nearby bodies of water. The sewage system is under the authority of the Aqueducts and Sewer Authority (PRASA), while the rainwater system is under the responsibility of the municipalities. However, there are pipeline networks that collect both wastewater and rainwater runoff—the "combined" systems. These combined systems present an additional challenge to environmentalists and conservationists because there is no clear jurisdictional responsibility between the municipalities and the PRASA.

The sewage networks suffer from damage and lack of maintenance that have reduced their ability to transport wastewater. These systems should be under an aggressive program of preven¬tive maintenance. In addition, the public needs to be educated as to what is and is not allowed to be disposed of in sewage pipes and drainage openings (**Figure 33**). For example, awareness needs to be created to the fact that substances poured into rainwater drains will eventually wind up polluting beaches or streams. The objective is to keep the rainwater systems healthy, ready for heavy rainfalls and, on the other hand, droughts.

Preventive maintenance for the stormwater and wastewater system(s)

Preventive maintenance and visual inspection of drainage systems is essential for ensuring optimum functioning. Periodic cleaning and other maintenance will

Figure 33. Citizen volunteers from the SJBEP placing educational markers on rainwater drains.

keep the systems from overflowing or backflowing during extreme rainfalls. There should be rapid response when overflows occur in sensitive areas near bodies of water. (**Figure 34**, next page).

Rainwater Runoff Infiltration Systems

One measure to improve rainwater runoff disposal is the use of perforated drainage pipes that allow part of the runoff to infiltrate the soil. In this way, the volume of water reaching the stormwater collection system is reduced and the chance of overload is lessened. In addition, during events of extreme rainfall, a great deal of runoff enters the wastewater system, overloading treatment plants. Using perforated pipes could prevent urban flooding, as flow is regulated. The quality of water infiltrating the subsoil will be improved and wells and aquifers will be recharged. It is important that the subsoil drain well and the water table be relatively low. This would also be an effective measure for counteracting the impact of paved surfaces in the urban area.

ACTION 3: Begin an educational campaign aimed at restaurants on the proper management and disposal of oils and grease.

Participating Groups: SJBEP, DRNA; PRASA; restaurants; PREQB

Time to completion: 1 year.

Monitoring or progress report frequency: Monthly.

Data from the USEPA in its reports to Congress on combined sewer overflows (CSOs)—that is, in combined wastewater and stormwater systems—and sanitary sewer overflows (SSOs) identify restaurant grease as the main cause (47%) of obstruction to rainwater runoff collection systems. When it solidifies, the grease creates blockages that reduce the capacity of the pipeline network and causes overflows. It is estimated that a restaurant will produce between 800 and 17,000 pounds of grease per year. This production can be reduced significantly by following certain waste-management practices and by recycling yellow grease (oil used for cooking) to manufacture cosmetics, biofuel, and animal feed (**Figure 35**, page 52).

Some recommendations for restaurants are:

1. Avoid throwing food residue, oils, and grease down sink drains.

2. Dispose of oil in an appropriate, properly labeled receptacle.

3. Do not clean kitchen equipment (such as vent fans) in

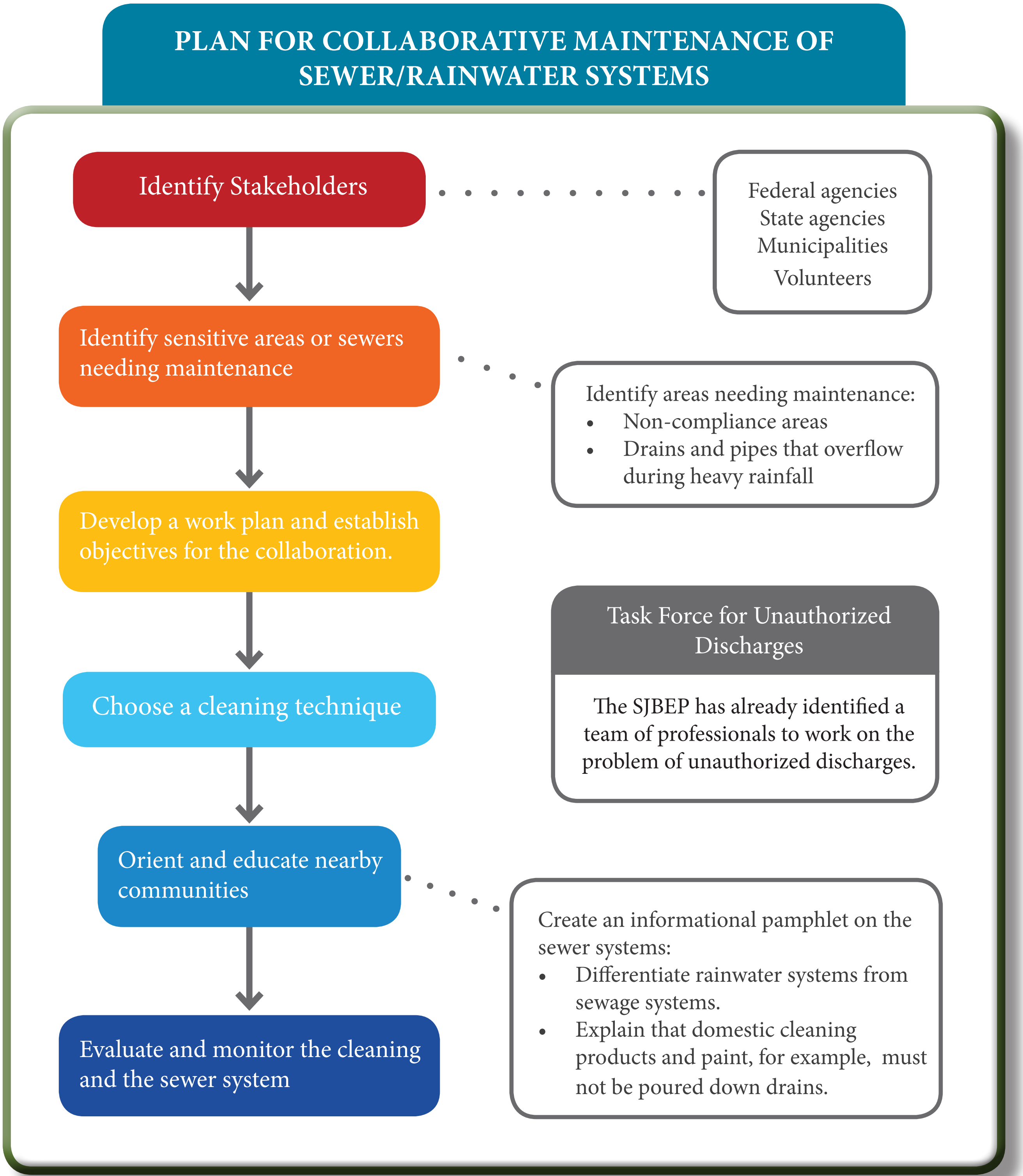

Figure 34. Roadmap for the creation of an effective collaboration plan for maintaining sewer/rainwater systems. (Adapted from *Combined Sewer Overflows Guidance for Long-Term Control*, USEPA, 1995.)

Figure 35. Educational sign on proper management of grease and oil in restaurants.

places where the water goes directly into a street drain. From there, the water goes directly onto beaches and others bodies of water, where there are people swimming and snorkeling.

4. Do not use large amounts of hot water in the sink or system connected to the grease trap. Some grease will dissolve and the greasy water will go directly into the sewer system.

5. Clean kitchen utensils with a disposable cloth and throw the used cloths into the trash before rinsing them.

6. Take part in oil and grease recycling programs.

7. Be sure that the grease trap is adequate for the volume of water used by the restaurant. Inspect and give frequent maintenance to the grease trap.

8. Clean up oil and grease spills with absorbent material, then throw the paper towels (for example) in the trash.

STEP 10:
Monitoring and Review of Action Plan Implementation

The objective of this step is to monitor, review, and update the risks, the vulnerability assessment, and the implementation of the action plan. This step allows the SJBEP to ensure the actions' effectiveness during implementation and therefore allows it to reevaluate and update the risks as new information comes to light. It must be kept in mind that climate changes cannot be precisely predicted or foreseen, and that responses will not be linear. Thus, new information will emerge day by day, information that should be taken into consideration in carrying out, updating, and amending the adaptation plan. The results of Step 10 will be published in future editions of the adaptation plan once the three actions outlined above are implemented and monitored.

APPENDIX 1:

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Ackerman, R. A. 1997. The nest environment and the embryonic development of sea turtles. In: Lutz, P. L. and J. A. Musick. The Biology of Sea Turtles. New York CRC Press. 83–106.

Bruun, P. 1962. Sea level rise as a cause of shore erosion. Journal of Waterways and Harbours Division ASCE 88: 117-130.DRNA, 2010.

Fish, M. R., I. M. Cote, J.A. Gill, A.P. Jones, S. Renshoff, and A. Watkinson. 2005. Predicting the impact of sea level rise on Caribbean sea turtles nesting habitat. Conservation Biology 19: 482-491.

Grafals-Soto, R. 2012. Effects of sand fences on coastal dune vegetation distribution. Geomorphology 145 – 146: 45 – 55.

Hawkins, Ed., and R. Sutton. 2009. The Potential to Narrow Uncertainty in Projections of Regional Precipitation Change. Deep Sea Research Part I: Oceanographic Research Papers 80, 37-46.

Hernández-Pacheco, R., E. A. Hernández-Delgado, and A. M. Sabat. 2011. Demographics of bleaching in the Caribbean reef-building coral *Montastraea annularis*. Ecosphere 2: 1-13.

IPCC. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Knutson, T. R., J. L. McBride, J. Chan, K. Emanuel, G. Holland, C. Landsea, I. Held, J.P. Kossin, A. K. Srivastava, and M. Sugi. 2010. Tropical cyclones and climate change. Nature Geoscience 3, 157 – 163.

Kunkel, K. E., P. D. Bromirski, H. E. Brooks, T. Cavazos, A. V. Douglas, D. R. Easterling, K. A. Emanuel, P. Groisman, G. J. Holland, T. R. Knutson, J. P. Kossin, P. D. Komar, D. H. Levinson, and R. L. Smith, 2008: Observed changes in weather and climate extremes. In: Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands[Karl, T.R., G.A. Meehl, C.D. Miller, S.J. Hassol, A.M. Waple, and W.L. Murray (eds.)]. Synthesis and Assessment Product 3.3. U.S. Climate Change Science Program, Washington, DC, 35-80.

Martínez R. F., L. Encarnación, and L. M. Cruz. 1983. Dune Restoration in Puerto Rico: A Manual for Environmental Managers. Departamento de Recursos Naturales y Ambientales. San Juan, PR.

McKee, K. L., D. R. Cahoon, and I.C. Feller. 2007. Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. Global Ecology and Biogeography 16: 545-556.

Mendez-Lázaro, P. 2010. Análisis de tendencias hidroclimáticas recientes y transformaciones del paisaje en la isla de Puerto Rico. Doctoral dissertation. Universidad de Salamanca, Salamanca, España.

Méndez-Lázaro P., O. Martínez-Sánchez, R. Méndez-Tejeda, E. Rodríguez, E. Morales, and N. Schmitt-Cortijo. 2015. Extreme Heat Events in San Juan Puerto Rico: Trends and Variability of Unusual Hot Weather and its Possible Effects on Ecology and Society. Journal of Climatology & Weather Forecasting 3.2 (http://dx.doi.org/10.4172/2332-2594.1000135).

Miller, J., R. Waara, E. Muller, and C. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality on reefs in U.S. Virgin Islands. Coral Reefs 25:418.

Miller, J., E. Muller, C. Rogers, R. Waara, A. Atkinson, K. R. T. Whelan, M. Patterson, and B. Witcher. 2009. Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the U.S. Virgin Islands. Coral Reefs 28: 925-937.

Nyberg, J., B. Malmgren, A. Winter, M. R. Jury, H. Kilbourne, and T. Quinn. 2007. Low Atlantic hurricane activity in the 1970s and 1980s compared to the past 270 years. Nature 447: 698-701. PRCCC, 2013.

PRCCC. 2013. Estado del Clima de Puerto Rico 2010 – 2013 Evaluación de vulnerabilidades socio-ecológicas en un clima cambiante. Programa de Manejo de la Zona Costanera, Departamento de Recursos Naturales y Ambientales, Oficina de Océanos y Recursos Costeros (NOAA-OCRM). San Juan, PR.

Rivera-Herrera, L. J., 1996. List of the Flora and Fauna of the San Juan Bay Estuary System, SJBR Program Technical Publication # 01-96. 80 pp.

Woodhouse, W. S., Jr., 1978. Dune building and stabilization with vegetation. USACE CERG, Special Report No.3.

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