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Coral Reef and Coastal Ecosystems Decision Support Workshop

April 27-29, 2010






Caribbean Coral Reef Institute
La Parguera, Puerto Rico


Office of Research and Development
National Health and Environmental Effects Research Laboratory

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Executive Summary

The U.S. Environmental Protection Agency (EPA) and Caribbean Coral Reef Institute (CCRI) hosted a Coral Reef and Coastal Ecosystems Decision Support Workshop on April 27-28, 2010, at the Caribbean Coral Reef Institute in La Parguera, Puerto Rico. Forty-three participants, including representatives from federal and territorial government agencies, non-governmental organizations and academic institutions, and Guánica Bay watershed citizens participated in the workshop. The purpose of the workshop was to facilitate development of a decision analysis framework with stakeholder and decision-maker input to help address problems related to ecologically damaging human activities (e.g., agriculture, urbanization, sediment and nutrient loads, stormwater run-off, and wetland loss) in the Guánica Bay Watershed in southwest Puerto Rico.

During the workshop, participants reviewed the characteristics and threats to the Guánica Bay watershed, coral reefs and coastal ecosystems and overviewed ongoing NOAA and USDA activities in the watershed. EPA introduced an organizational framework (DPSIR), which can be used to link ecological and socioeconomic factors and to scope the important causal elements of environmental decision-making. The group incorporated knowledge and issues relevant to the Guánica Bay watershed and southwestern Puerto Rico into the framework. Using the Guánica Bay Management Plan as a foundation, EPA applied a structured decision analysis process to the decision-making processes in the watershed.

This report serves two purposes: 1) to document the workshop and 2) to provide a process and tools for implementing some of the approaches used at the workshop. The report provides detailed step-by-step examples, accompanied with graphics, guidance, templates, and discussion of potential software.

Chapter 1. Introduction

1.1 The U.S. Coral Reef Task Force and the Guánica Bay Watershed Initiative

The United States Coral Reef Task Force (USCRTF) was established in 1998 by Presidential Executive Order to lead U.S. efforts to preserve and protect coral reef ecosystems. The USCRTF includes leaders of 12 Federal agencies and seven U.S. States, Territories, and Commonwealths (Florida, Hawaii, Puerto Rico, U.S. Virgin Islands, American Samoa, Guam, and the Commonwealth of the Northern Marianas) and three Freely Associated States (Federated States of Micronesia, Republic of the Marshall Islands, and the Republic of Palau).

In 2000 the USCRTF adopted the National Action Plan to Conserve Coral Reefs, the first U.S. plan to comprehensively address the most pressing threats to coral reefs. The National Action Plan is the Nation's roadmap to more effectively understand coral reef ecosystems and reduce the adverse impact of human activities. In 2002 the USCRTF collaborated to produce a complementary document, *A National Coral Reef Action Strategy,* to address priorities and strategies in the short term.

Recognizing that the threat of land-based sources of pollution (LBSP) to coral reef ecosystems occurs in all U.S. coral reef jurisdictions, and both authority and responsibility to address LBSP involve a multitude of governmental and jurisdictional levels, the USCRTF initiated a Watershed Partnership Initiative in 2009. The initiative is intended to facilitate and enhance coordination, partnerships, and contribution of Agency resources and expertise to implement geographically specific and integrated activities to reduce pollutant loads to coral reef ecosystems, while also promoting consistent and strengthened application and enforcement of laws and authorities intended to address LBSP. The USCRTF Watershed Partnership Initiative includes two distinct components:

a. Individual federal and state/territory agency contributions through direct application of resources, authorities, technical assistance, and/or program expertise; and

b. A competitive funding opportunity that awards Federal funds to local organizations and individuals to implement projects in support of clean water. This fund is administered for the USCRTF through the National Fish and Wildlife Foundation (NFWF).

The Puerto Rico Department of Natural and Environmental Resources (DNER) and the USCRTF chose Guánica Bay Watershed as the first Watershed Initiative. Partners in the Guánica Bay Watershed Initiative include the National Oceanic and Atmospheric Administration (NOAA), US Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS), US Fish and Wildlife Service (FWS), Puerto Rico DNER, Puerto Rico Department of Agriculture (PRDA), Puerto Rico Lands Authority (PRLA), Center for Watershed Protection (CWP), US Environmental Protection Agency (EPA), US Geological Survey (USGS), University of Puerto Rico (UPR), Puerto Rico Electric Power Authority (PREPA), and Puerto Rico Aqueduct and Sewer Authority (PRASA).

The Guánica Bay Watershed

The Guánica Bay Watershed is located in the southwestern corner of Puerto Rico (**Fig. 1-1**), approximately 32 kilometers west of Ponce and 160 kilometers southwest of San Juan (CWP 2008). It includes portions of Guánica, Yauco, Lajas and Cabo Rojo municipalities. Rainfall in the watershed ranges from less than 20 inches/year in the arid southwest to over 100 inches/year in the mountains, and includes Spanish Colonial cultural resources. More detailed information about Puerto Rico is included in Appendix A.

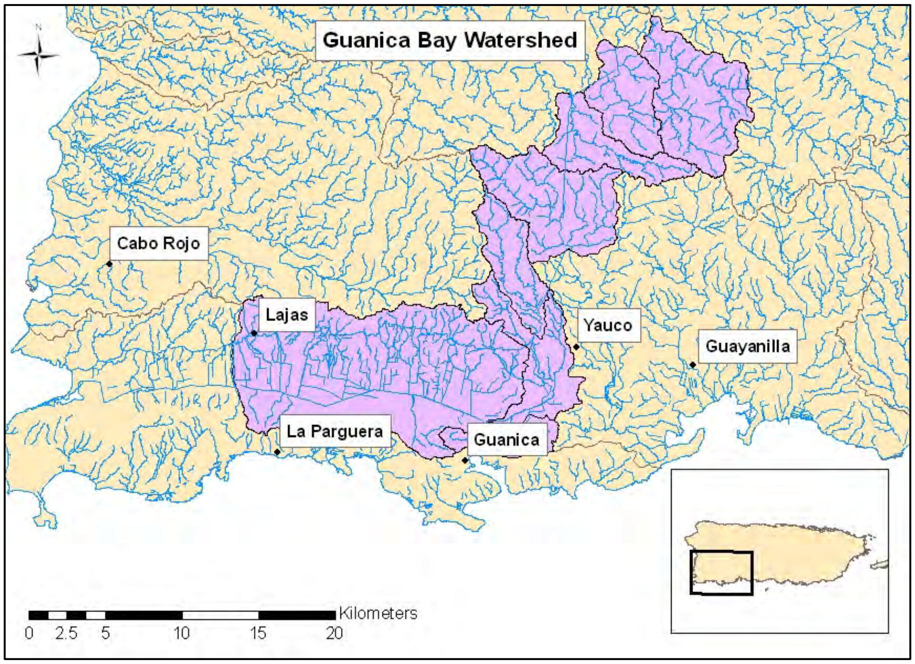

Figure 1-1. Guánica Bay Watershed. The Guánica Bay drainage area (purple) includes portions of eight 12-digit HUC watersheds.

Guánica Bay receives fresh water primarily from a single location, the mouth of the Rio Loco at the northern end of the bay. Human alterations have significantly altered the volume and flow of water in the Guánica Bay watershed. The water originates in several different watersheds and travels several different paths to reach the bay. In the 1950's, as part of the Southwest Puerto Rico Project (or the Southwest Project, SWP) five reservoirs and two hydroelectric plants (Yauco 1 and 2) were built in the ridges north of Guánica Bay to increase and regulate potable water from the high elevation watersheds of the central cordillera (mountain region) for use by the local populations in Yauco and Guánica.

At about the same time, as part of the Lajas Valley Irrigation Project, canals and channels were constructed to divert water from just below the southernmost reservoir (Lago Loco) along the foothills to the west primarily to provide water for agriculture in the broad Lajas Valley. A long drainage channel along the southern edge of the valley returns the water eastward to rejoin the Rio Loco near its mouth.

Water entering Guánica Bay therefore receives flow from the five smaller basins and associated reservoirs: Lago Yahuecas, Lago Guayo, Lago Prieto, Lago Lucchetti, and Lago Loco (**Fig. 1-2**). The altered watershed is approximately 391 square kilometers in size.

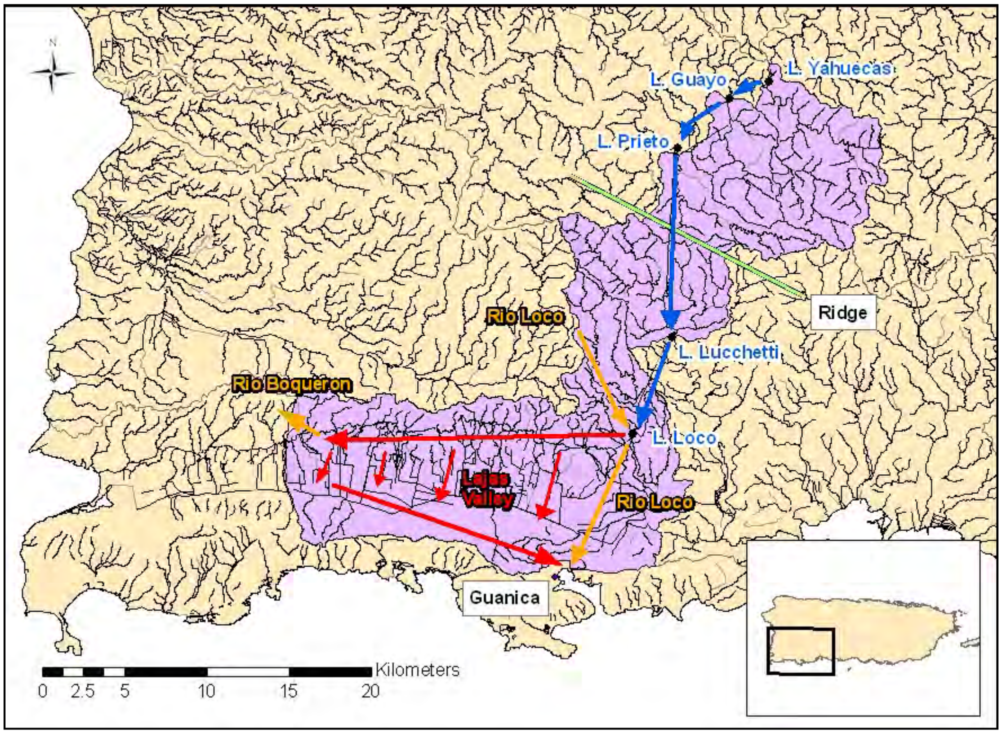

Figure 1-2. Map of the flow of water between watersheds that contribute water to Guánica Bay

The watershed includes an array of ecosystems including forests, mangroves, coral reefs, and a bioluminescent bay. Historically there was also a large natural freshwater wetland and lagoon system, which was drained in 1955 as part of an agricultural development project in the Lajas Valley. Shallow, open water, occupying most of the lagoon, provided foraging habitat for resident and migrant waterfowl, and the surrounding emergent vegetation was used for nesting by resident aquatic birds. The gradual decline in water levels associated with the dry season extended foraging opportunities for wading species. The lagoon also served as a sink for sediments and nutrients. There is a proposed plan to restore Guánica Lagoon to reclaim its value as a wildlife refuge and ecological resource (CWP 2008). Restoration of the Lagoon would reduce sediment, nitrogen, and total phosphorus from moving into Guánica Bay and the coastal coral reef system.

More detailed information about the Guánica Bay watershed is included in Appendix B.

The population in the Guánica watershed is of relatively low density—there is only one small city (Yauco) and several small towns and communities. Unemployment is high in Guánica (13.8%) and Yauco (12.6%), and approximately 60% of the population lives below the poverty level.

Agriculture and tourism are two of the key economic sectors in the Guánica Bay watershed. Current agriculture in the watershed is primarily coffee on the northern slopes and various fruit and vegetable crops and pastureland in the Lajas Valley. Additional information on economics is included in Appendix C.

The upper watershed (Yauco) is heavily farmed for coffee, however, the coffee yield has dropped in the watershed from 21,527,000 pounds in 1998 to 14,476,000 pounds in 2002 (CWP 2008). This was approximately 7% of the annual coffee grown in Puerto Rico and has a value of $2M.

Lajas Valley was established as an agricultural reserve in 1999, by enabling legislation, Law 277. Agricultural production in Lajas Valley is economically important. On the lands owned by the Puerto Rico Land Authority (2818 acres), farm income totaled $4,300,158 annually (2009-2010). Crops include: coffee, citrus, plantains, bananas, tomatoes, peppers, papaya, pumpkins, cantaloupes, and other vegetables. Area farmers also produce beef, pork, sheep, goats, and eggs. Because this region has an extended dry season, agriculture in the Lajas Valley is only possible because of the Lajas Valley irrigation system.

Tourism, an important component of Puerto Rican economy, supplies approximately $1.8 billion annually. Between 2000 and 2005, an average of 3,407,483 visitors per year (excluding same-day visitors) visited Puerto Rico. Three quarters of the visitors were from the Americas. Coral reefs provide substantial benefits to communities throughout Puerto Rico. EPA and NOAA will be conducting an economic valuation study of Puerto Rico's coral reef tourism and recreation to better understand the economics associated with this sector. The study results will be provided for all of Puerto Rico and for five regions in Puerto Rico (Northeast, Southeast, Southwest, Northwest, and the islands of Culebra and Vieques).

Growth in the Guánica Bay watershed (urban and agricultural) has provided social and economic benefits for residents. However, this same growth has led to reduced forest cover, draining of the historic Guánica Lagoon and increased sediment and nutrient runoff. Coastal communities, such as the city of Guánica, partially rely on fishing and tourism, both of which have been adversely affected by diminishing coastal water quality, e.g., decline of fish habitats such as coral reefs, seagrasses and mangroves, as well as pathogens and contaminants in the coastal waters (Whitall et al. 2013). The Center for Watershed Protection developed a Watershed Management Plan (WMP) that proposed management actions to reduce sediment runoff and effects in the coastal zone (CWP 2008).

1.2 Workshop Goals

EPA invited decision makers, scientists and other coral reef stakeholders in the Guánica Bay Watershed to a workshop held at the University of Puerto Rico's Caribbean Coral Reef Institute in La Parguera, Puerto Rico, on April 27-28, 2010. The workshop agenda is shown in Appendix D, workshop participants in Appendix E, and a glossary in Appendix F.

Through a facilitated process, the workshop participants began to:

- Look at the watershed as a system
- Share a collaborative vision for sustainable coral reefs
- Initiate a systematic, deliberative process to analyze coastal and watershed decisions that impact coral reefs and other ecosystems that provide services to humans
- Advance an integrative framework to incorporate the ecological, social, economic and legal consequences of alternative decisions

There was also an optional working meeting on April 29, 2010. The purpose of the meeting on April 29 was to (1) refine and detail the organizational framework and decision analysis process; (2) consolidate findings from the workshop into workshop and research products that will support the Guánica managers in their decision-making; and (3) discuss future potential interactions.

1.3 The Structured Decision Process

The USCRTF chose the Guánica Bay Watershed as a pilot watershed for their interagency efforts to protect coastal and stream water quality, improve wildlife habitat and enhance near-shore coastal and coral reef health through land-based management. Effective protection of coral reefs begins with the recognition and appreciation of services they provide. Land-use and water management decisions in the watershed are improved with full understanding of resulting economic and social losses to downstream resources such as coral reefs. One of the greatest challenges of resource management is melding scientific information and approaches with management needs and objectives. Part of this challenge is simply a consequence of different cultures; scientists and managers perceive aspects of any issue differently (**Table 1-1**). Nonetheless, management without relevant facts and understanding of ecological concepts may result in unexpected adverse outcomes; likewise research on issues over which managers have no authority may not be very useful to the managers.

Table 1-1. Contrasting features of science and management cultures (adapted from Bernstein et al. 1993)

Aspect	Science	Management
Valued Action	Research	Decisions, plans
Timeframe	That needed to gather evidence	Immediate, short-term
Goals	Increase understanding	Manage problems, set policy
Basis for Decisions	Scientific evidence	Science, values, opinions, economics
Expectations	Understanding never complete	Expect clear answers from science that form the basis of decisions
Granularity	Focus on details, contradictions	Focus on broad outline
World View	Primacy of biological, physical, chemical mechanisms; factors (including human activities) heavily parameterized	Primacy of political, social, interpersonal, economic considerations; factors often dealt with qualitatively

One way to approach this challenge is to apply a *structured-deliberative process*, which is simply the give and take between scientists and managers to reach an appropriate course of action. Analytic products—theories, results and scientific insights—inform the deliberative process to determine a course of action, and the deliberative process concurrently frames scientific analysis (Judd et al. 2005). The iterative process is intended to assist communication among decision-makers and scientists and to reach a 'good' decision – "one that is consistent with what we know (information), what we want (value and preferences), and what we can do (options)" (North and Renn 2005; Dietz 1994). It is emphasized that scientific information is only one factor that influences a decision (**Fig. 1-3**).

Given the recognized risks of over-reliance on scientific information for environmental management (Gregory et al. 2006), the need for a structured decision process to effectively include facts and values for better environmental decision-making is increasingly apparent (Gregory and Keeney 2002). The general process is well documented (Failing et al. 2007; Gregory et al. 2012; Carriger and Benson 2012), and is a key component of EPA's Decision Support Framework for better inclusion of ecosystem services and stakeholder values into the decision-making process (EPA 2009).

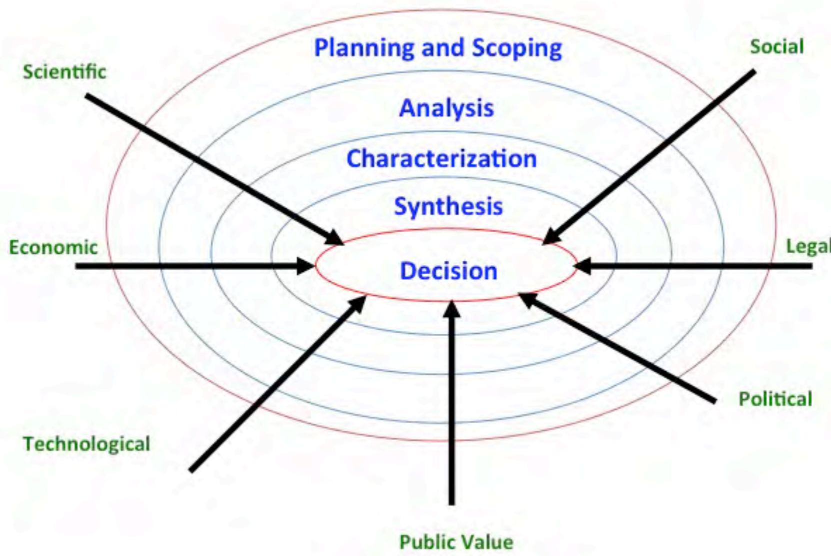

Figure 1-3. Multiple factors influence steps in any decision-making process (EPA 2014a)

The Structured Decision Process entails five steps 1) Understand the Decision Context; 2) Define Objectives; 3) Develop Decision Alternatives; 4) Evaluate Alternatives; and 5) Take Action. According to Gregory et al. (2011), the first three steps are more qualitative and seek to establish scope, goals, and value preferences, while the latter steps are more quantitative and serve to assess and evaluate proposed actions developed in Steps 1-3. It should be noted that while the process description is linear, its application is typically iterative with re-visiting of previous steps as analysis of information and on-going deliberation improves understanding of the decision context and subsequent management options. Each step is discussed in more detail below.

Step 1 - Understand the decision context

The first step in the structured-deliberative process is to establish the context for the management problem. Environmental decisions will commonly have multiple stakeholder perspectives and require a variety of data and information from environmental, economic, and social sciences. Gathering and organizing information relevant to the decision is defining the *decision landscape* (Rehr et al. 2012).

The first step in describing the decision landscape is to frame the *decision context* (i.e., the problem, issue, or reason for making a decision) that defines the scope of the information that will be needed (Gregory et al. 2012). The decision context includes identifying all the stakeholders (e.g., who is involved in a decision and their role in the decision process) as well as legal issues (e.g., applicable laws and who is responsible for enforcing them) and historical issues and current conditions.

Stakeholders generally fall into two broad categories: direct users and beneficiaries of the ecosystem (e.g., commercial and recreational fishers), and information gatherers (e.g., scientists in government agencies and academia). Communication among these groups is vital but not always direct or sufficient. A Social Network Analysis (SNA) at this step provides a visual insight into who is, and more importantly, who is not sharing in the information flow.

A systems-based conceptual model of the issue(s) to be resolved and the likely effects of different decisions on the things that people care about can prove very useful for decision-makers. The Drivers-Pressures-State-Impact-Response (DPSIR) conceptual model (**Fig. 1-4**) can be developed to demonstrate relationships among the many issues in a decision context and provide a sense of causes and effects and the likely tradeoffs (Bradley et al. 2013; EPA 1999).

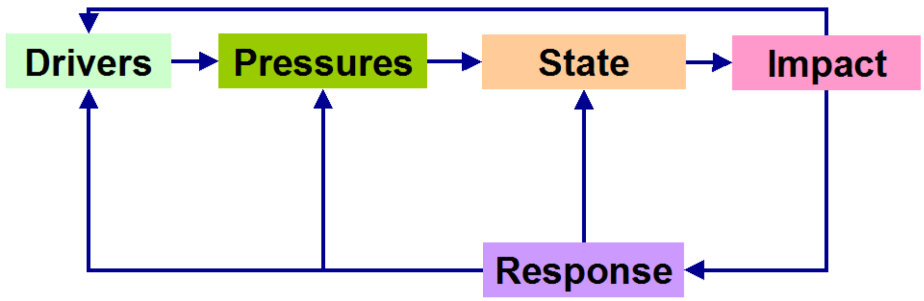

Figure 1-4. The DPSIR framework

DPSIR is an inherently human-centric framework, and terminology can often confound discussion. In DPSIR, the driving forces are the socio-economic sectors that support human needs. This definition allows us to directly map the driving forces with the North American Industry Classification Standards (NAICS) that economists use to derive socio-economic indicators, including the gross domestic product. However, ecologists and other environmental scientists use the term “driver” more generally – defining a driver as anything that drives a change in ecological condition. This would include things like global climate change. This looser use of terminology presents a problem when trying to develop the conceptual model, since climate is in truth a part of the natural environmental state. The changes to climate can be anthropogenic (from human use of fossil fuels) or part of a natural cycle. The EPA DPSIR definitions provide more precision and resolve this conundrum. The definitions allow us to tease out the impact of human activities from natural environmental processes.

Step 2 - Define objectives

Once the decision landscape is well formulated and bounded, and communication pathways are clarified, the context and structure for inclusion of stakeholder values is established. Values can be ecological, economic, social, or human health related.

Objectives reflect the values of stakeholders. Objectives are described with a direction of preference (maximize or minimize) and an item of value (availability of quality habitat or costs) (Mollaghasemi and Pet-Edwards 1997, Dunning et al. 2000, McDaniels 2000, Keeney 2007).

Formal decision analysis includes tools to properly elicit values and structure objectives from stakeholders and decision-makers in a way that is practical and useful for evaluating decisions and identifying new alternatives (Merrick et al. 2005).

Once elicited, the objectives are organized into an objectives hierarchy, which arranges objectives from broad, or inclusive values to lower-level, specific accomplishments or actions. Evaluation measures (i.e., attributes that can be used to evaluate performance toward higher-level objectives) are at the bottom of the objectives hierarchy (Keeney 1992). When possible, objectives can be prioritized in anticipation of tradeoffs to be made (not all objectives can be fulfilled) (Gregory and Keeney 1994).

Step 3 - Develop decision alternatives

In the third step, alternatives for achieving the objectives are identified. Decision alternatives should be considered only after objectives are understood. By fully considering the various options, decision-makers can be more certain they will achieve the objectives (Payne et al. 1999). Eliciting stakeholder input on decision alternatives is extremely important because stakeholders have innovative ideas and a strong local sense of what is threatened, what is creating the threat, what responses are feasible in their community and who or what might be affected by different decisions.

Step 4 - Evaluate alternatives and select management option

The next step is to assess the options and assemble or provide scientific information to address critical unknowns. Most decision situations can be characterized as a set of alternative options, each with a set of consequences and varying degrees of uncertainty. Decision alternatives can be rated for complexity (which affects the amount of time or cost to implement), effectiveness for the proposed objective, and potential consequences to other objectives. Sensitivity and uncertainty analysis will be a crucial element of all studies, as it assists in understanding the confidence that can be placed in predictions and helps to identify critical needs for further research and data collection. The level of confidence that decision-makers require in order to make a decision also needs to be taken into account. Sometimes, if not often, new information will generate new concerns, objectives, decision options or evaluation criteria.

Although not generated in the workshop, a consequence table is extremely helpful for evaluating options and typically contains a matrix of potential effects of alternatives on performance measures for objectives in each cell (Gregory et al. 2012). The consequence table provides a feedback loop to earlier stages in the decision making process, including generating new alternatives, identifying missing or insufficient objectives and performance measures, eliminating dominated alternatives, identifying information sources for the impact of alternatives on objectives, trade-off analysis, and appraising the impact of objectives on alternatives from the best available information.

Once a consequence table is populated, the next step is to explore tradeoffs that stakeholders are willing to make among the objectives (e.g., how much of one objective are they willing to sacrifice to have more of another) (Keeney 1992). A variety of methods are available for considering tradeoffs (e.g., direct ranking and swing weighting).

Step 5 - Take action

After deciding on a management that best meets objectives in Step 4, decision-makers must begin implementation. This step often involves monitoring and adaptive management within a structured decision-making process.

Chapter 2. Condition, Use, Stakeholder Perceptions, and Management of Coral Reef Resources

Three presentations were given during the first workshop session, each designed to help frame the decision context. These included an overview of coral reef and coastal resources in southwestern Puerto Rico, an overview of USDA-NRCS plans to reduce soil erosion in the watershed, and a summary of the alternatives proposed in the WMP to protect coral reefs from further degradation (CWP 2008). These presentations provided a common understanding of the Guánica Bay Watershed Management Plan for the participants.

2.1 Status of Southwest Puerto Rico's Coral Reef and Coastal Resources

Summary of a Presentation given by Jorge (Reni) Garcia-Sais, Department of Marine Sciences, UPRM

This presentation was intended to provide the workshop participants with a summary of the extent, distribution, composition and condition of Puerto Rico's coral reef and coastal ecosystems.

Puerto Rico has fringing coral reefs with a total area of 3,370 km^2 off the east, south and west coasts (Wilkinson 2004, Burke and Maidens 2004). Puerto Rico's coral reef ecosystem is a complex mosaic of interrelated habitats, including mangrove forests, seagrass beds and coral reefs (Garcia-Sais 2008). Reefs in Puerto Rico were historically dominated by the reef-building coral taxa, *Montastraea annularis* (complex), *Agaricia agaricites*, *Montastraea cavernosa, Porites astreoides* and *Colpophyllia natans*. Dense thickets of *Acropora palmata* and *Acropora cervicornis* provided high relief in fore and back reef habitats (Morelock et al. 2001).

On Puerto Rico's southern coast, coral reefs fringe many small islands (such as those off La Parguera and Guánica), and are found as extensive coral formations associated with the shoreline at the mouths of coastal bays (such as Guánica Bay) (Garcia-Sais and Sabater 2004) (**Fig. 2-1**).

The Puerto Rico Coral Reef Monitoring Program (PRCRMP), which is sponsored by the National Oceanic and Atmospheric Administration (NOAA) and administered by the Puerto Rico Department of Natural and Environmental Resources (DNER), was implemented in 1999-2002 to provide a baseline characterization of Puerto Rico's coral reefs and to monitor water quality. Monitoring was conducted in 27 areas within nine reserves. DNER identified the natural reserves of Mayagüez Bay, Desecheo Island, Mona Island, Rincón, Guánica, Caja de Muerto Island, Ponce Bay, La Parguera, Cordillera de Fajardo, and the islands of Culebra and Vieques as high-priority monitoring sites. Baseline characterizations for these reef systems were prepared by García-Sais et al. (2001a, 2001b, 2001c, 2001d, 2004, 2005, 2006). The baseline characterization and monitoring for the Culebra Marine Reserve was prepared by Hernández-Delgado (2003).

Figure 2-1. Coral reefs at Guánica (source: CWP 2010, Morelock et al. 2001)

The monitoring program follows the CARICOMP protocols (CARICOMP 2001). At each reef, quantitative measurements of the percent substrate cover by sessile-benthic categories and visual surveys of species richness and abundance of fishes and motile megabenthic invertebrates were performed along five permanent transects per station. Four stations are located on the south coast, including sites off Guánica and La Parguera (**Fig. 2-2**).

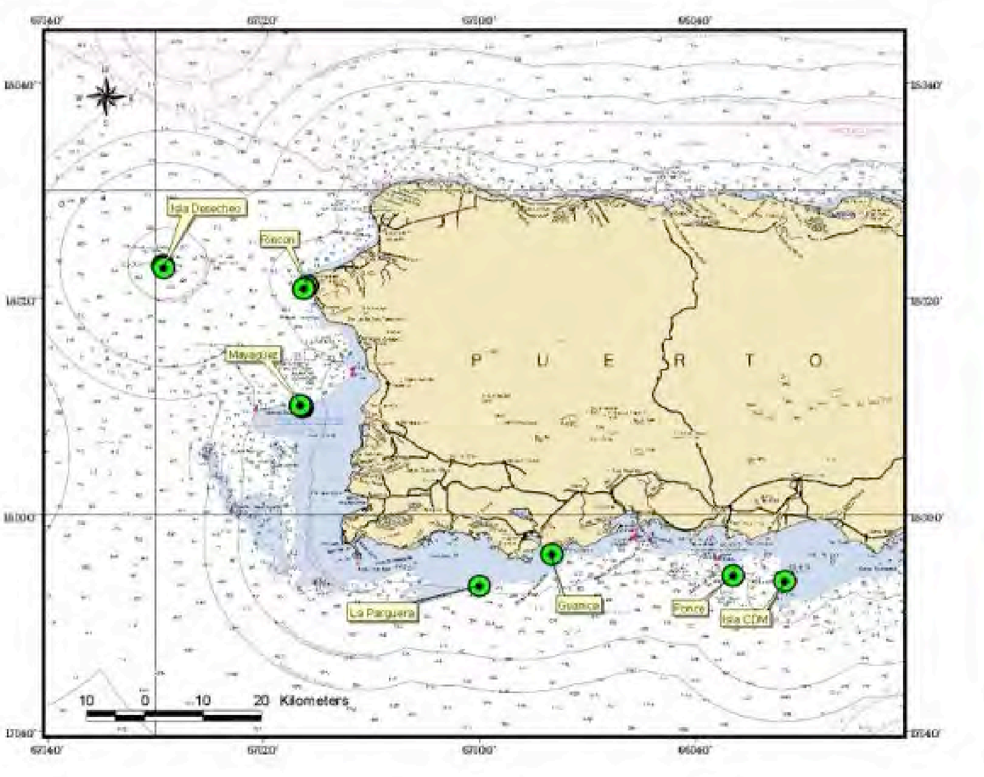

Figure 2-2. Puerto Rico Coral Reef Monitoring Program – site locations

In the fall of 2005, record-breaking sea surface temperatures (SST) resulted in 14.3 degree heating weeks. Corals start to feel stressed when the sea surface temperature is more than 1°C above the average we expect to see in the hottest month. NOAA maps cumulative stress, or Degree Heating Weeks (DHWs), by adding up the HotSpots over a 3-month period. DHWs pinpoint areas where corals are at risk for bleaching. When DHW reaches 4°C-weeks (7.2°F-weeks), significant coral bleaching is likely, especially in more sensitive species. When DHW is 8°C-weeks (14.4°F-weeks) or higher, widespread bleaching and mortality from thermal stress may occur.

Comparison of satellite data from the previous 20 years confirmed that thermal stress from the 2005 Caribbean event was greater than the previous 20 years combined (**Fig. 2-3**).

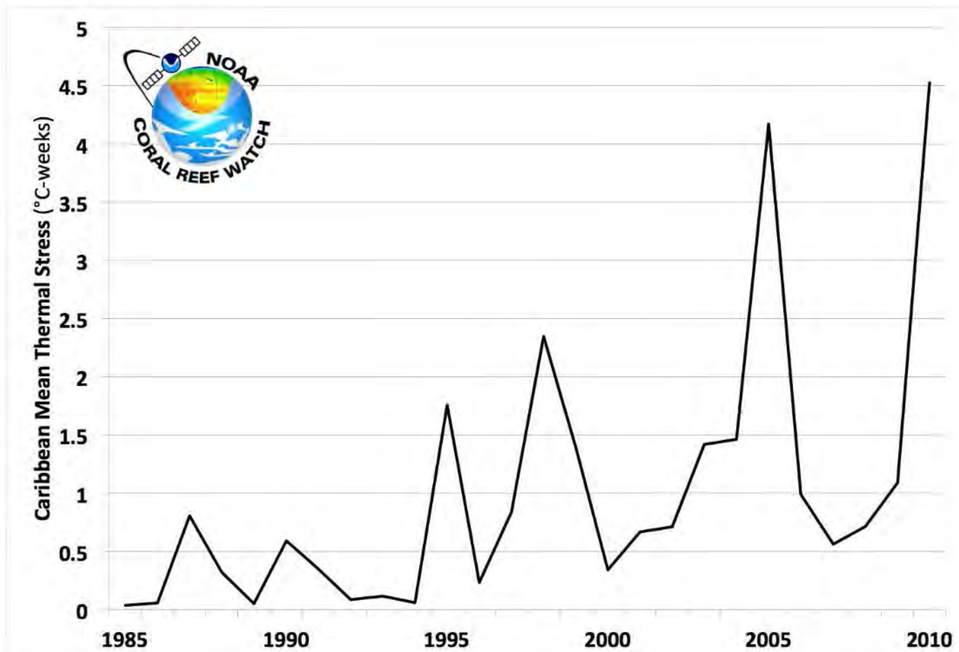

Figure 2-3. Thermal stress in the Caribbean (source: NOAA Coral Reef Watch, Mark Eakin)

A major bleaching event in the fall of 2005 was associated with high sea surface temperature (SST) and was followed in 2006 by post-bleaching coral mass mortality. This caused drastic shifts in the community structure of Puerto Rican coral reefs. Boulder Star Coral, *Montastraea annularis,* was the most severely affected species, presenting large-scale mortalities throughout Puerto Rico. Reef systems dominated by *M. annularis* suffered significant degradation (**Figs. 2-4 and 2-5**). Affected corals were subsequently hit by outbreaks of white plague and yellow band disease, causing even more colony and tissue loss. During the 2009 monitoring survey, live coral cover presented a pattern of mild improvement in most reefs surveyed, particularly associated with what appears to be an indication of partial recuperation of *Montastraea annularis* colonies previously affected by bleaching.

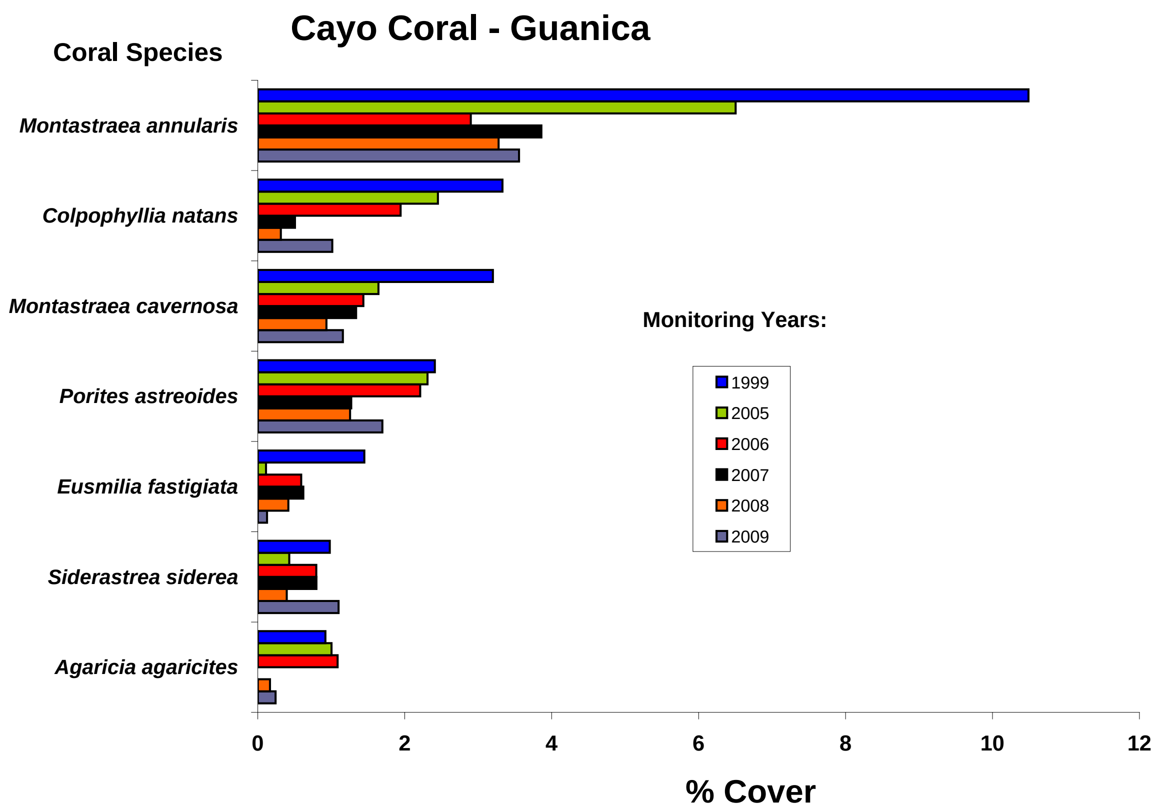

Figure 2-4. Percent coral cover (by species) at Cayo Coral Reef off of Guánica (García-Sais et al. 2014)

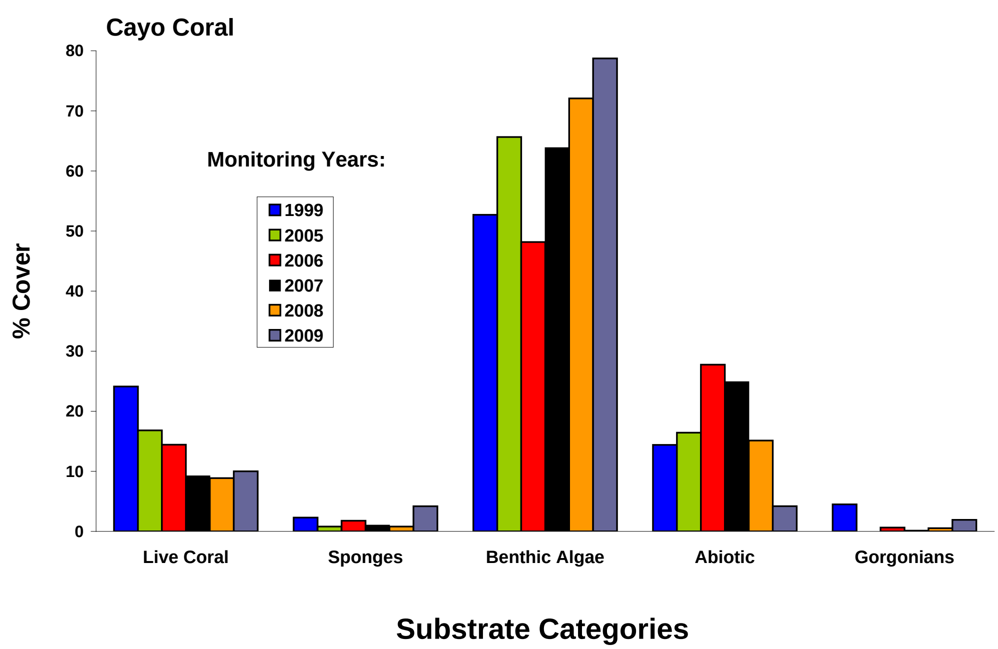

Figure 2-5. Percent cover for 5 substrate categories at Cayo Coral Reef off of Guánica (García-Sais et al. 2014)

2.2 Threats to Southwest Puerto Rico's Coral Reef and Coastal Resources

Summary of a presentation given by Paul Sturm, Center for Watershed Protection

This presentation was intended to provide the workshop participants with an overview of the type, duration and intensity of threats to Southwest Puerto Rico's coral reef and coastal ecosystems from the agricultural watershed, and to describe the Guánica Bay Watershed Management Plan, development process, participants and stakeholders, and planned actions.

NOAA's Coral Reef Conservation Program funded the Center for Watershed Protection (CWP) to create a model sub-watershed plan for a portion of the Guánica watershed. After meeting with Federal government staff from NOAA, USGS, DNER, USDA/NRCS, academicians from the University of Puerto Rico (UPR) and local farmers and residents, to better understand the historic and current land use, farming practices, water usage, waste water treatment, local political constraints, and condition of the Rio Loco and its contributing drainage area, it was determined that focusing on only one sub-watershed may be a mistake as there were important challenges facing multiple areas of the watershed. As a result, rapid assessment techniques were chosen to assess the watershed including stream assessments evaluating general measures of stream stability and other visual indicators (Kitchell and Schueler 2004) and visiting representative upland areas to evaluate potential pollution sources and determining restoration and conservation opportunities throughout the watershed (Wright et al. 2004).

After conducting the field study, CWP, DNER and NOAA worked together to identify priority management recommendations and implementation strategies for the Guánica Watershed based on a review of existing studies, input from local experts, observations from on-the-ground assessments, GIS analysis of exposed soils and cropland, and customization of the Watershed Treatment Model (WTM) to construct a rough nutrient and sediment budget for the watershed and to estimate water quality benefits of identified implementation measures (Caraco 2001).

The priority management recommendations and implementation strategies were documented in the Guánica Bay Watershed Management Plan (CWP 2008). The field study and existing literature helped identify potential pollutants that were impacting the Guánica Bay and the offshore coral reefs, as well as the sources of those pollutants. These include increased loading of nitrogen, sediment, bacteria, PAHs, PCBs and pesticides (**Table 2-1**).

Table 2-1. Priority pollutants in the Guánica Bay/Rio Loco Watershed (source: CWP 2010)

Pollutant	Impact	Sources
Nitrogen	Eutrophication, algae growth, enrichment beyond tolerance of coral reefs	Wastewater, fertilizers, stormwater runoff, atmospheric deposition
Sediment	Deposition on reefs, effects on sediment intolerant reef organisms, sediment particles leading to water temperature warming, pollutants attached to sediment particles	Soil erosion, channel erosion, poor erosion and sediment control practices, African dust
Bacteria	Health related illnesses due to water contact, swimming, beach closures, source of pathogens that effect coral reefs	Untreated wastewater, sewage overflows, stormwater runoff, pet waste, animal waste, wildlife
PAHs	Toxicity to coral reefs	Stormwater runoff of automobile related contaminants, boat engine discharge particularly 2-stroke engines
DDT, PCBs	Toxicity to coral reefs	Legacy contaminants, erosion of legacy sediments

2.2.1 The Problems

CWP found that five land-based activities were the source of most of the pollutants: 1) agriculture on steep slopes, 2) historic irrigation infrastructure in stream channels, 3) cleared riparian areas, 4) increased impervious surfaces, and 5) sewage treatment. A brief discussion of each was provided.

Agriculture on steep slopes

Puerto Rico is largely composed of mountainous and hilly terrain, with nearly one-fourth of the island covered by steep slopes. The mountains are the easternmost extension of a tightly folded and faulted ridge that extends from the Central American mainland across the northern Caribbean to the Lesser Antilles. High amounts of agriculture on steep slopes can increase the amount of soil erosion leading to increased sediment in streams, lakes and estuaries. Farms also export nutrients to water bodies from inorganic fertilizers and non-stable organic residues.

Factors contributing to potential soil loss include the steepness and length of slope, surface cover, rainfall erosivity, soil erodibility, and management practices (Hillel 1998). These factors are all present in the Guánica Bay Watershed. Coffee and other crops are being grown on high elevation steep slopes with very little evidence of conservation practices. Sun-grown coffee without any cover crop predominates, leaving soils more exposed to the elements, particularly drenching rains typical during the rainy season. Hartemink (2006) estimated that sun-grown coffee results in 3.5 times more erosion than shade-grown coffee over the first several years after establishment.

Historic irrigation infrastructure in stream channels

The Rio Loco contains head dams, concrete footers, and other structures that were previously used for irrigation purposes. This relict infrastructure continues to act as strainers and constrictions in the channel causing debris to become lodged and changes in erosive forces to destabilize banks, which increases channel erosion, bed scour and sediment transport (**Fig. 2-6**).

Figure 2-6. Debris that had been captured by former railroad structures (photo provided by Paul Sturm)

Cleared riparian areas

Throughout the Guánica Bay Watershed, riparian zones have been completely eliminated as humans have cleared land for agriculture or commercial and residential development. Removing riparian vegetation increases the erodibility of stream banks and can also speed the rate of channel migration. Severe erosion is associated with areas that lack mature riparian trees, particularly those areas that contain non-native species that seem to exacerbate erosion (CWP 2008).

Increased impervious surfaces

Impervious surfaces such as roads, sidewalks, driveways and parking lots eliminate rainwater infiltration and increase stormwater runoff. While only approximately 2.3% of the Guánica Bay watershed is currently impervious (**Fig. 2-7**), the urban areas of Yauco and Guánica have significant amounts of impervious surfaces that convey untreated stormwater to the Rio Loco and Guánica Bay respectively. Storm water picks up pollutants and carries them into storm sewer systems during storm events. Common pollutants include oil and grease from roadways and parking lots, pesticides and fertilizers from lawn treatment and maintenance, sediment from construction sites, and carelessly discarded trash, such as cigarette butts, paper wrappers, and plastic bottles.

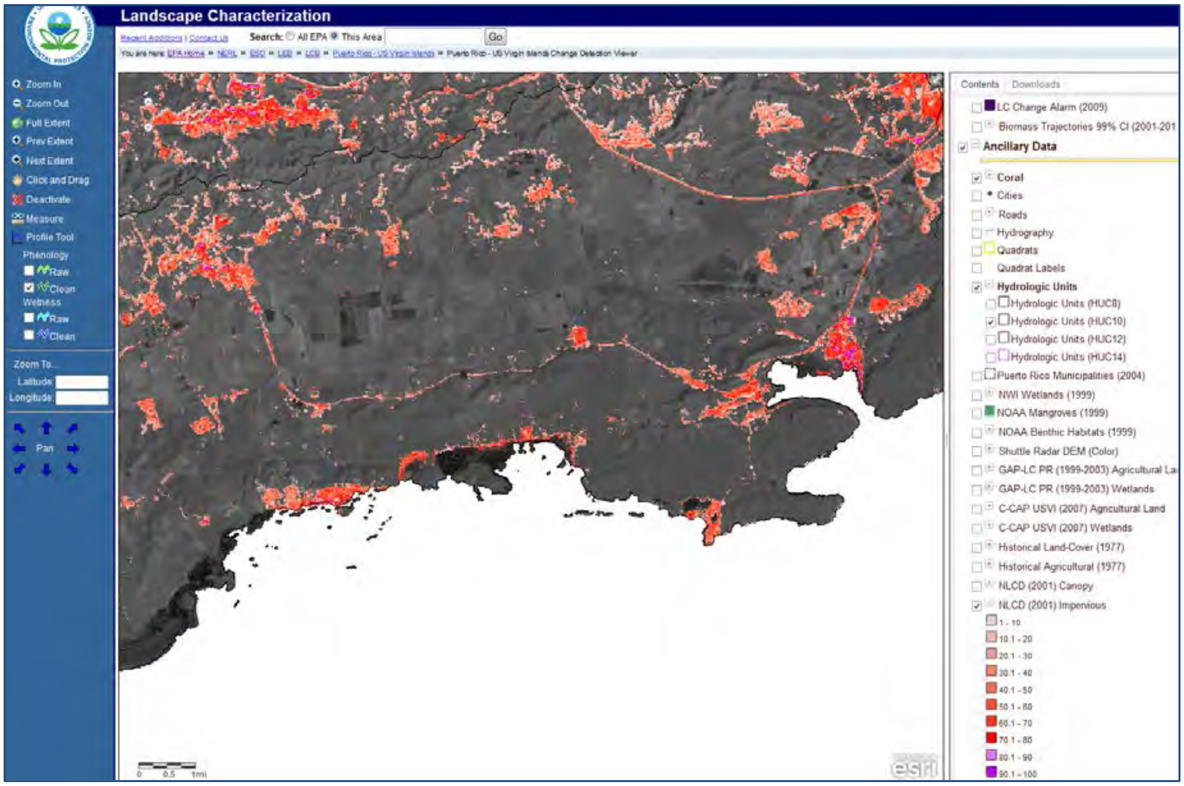

Figure 2-7. Impervious surfaces in the Guánica Bay watershed (shown in red) (source: EPA 2014b)

NOAA's Assessment of Chemical Contaminants in the Marine Sediments of Southwestern Puerto Rico, National Status and Trends Program for Marine Environmental Quality (Pait et al. 2007) found relatively high concentrations of polycyclic aromatic hydrocarbons (PAHs) in the sediment samples in Guánica Bay. A fingerprinting analysis linked the PAHs primarily to automobile related sources. During rain events, the PAHs are carried in stormwater runoff. These pollutants have very little chance for attenuation or remediation due to the flashy nature of the Rio Loco and the loss of Guánica Lagoon. EPA has classified seven PAH compounds as probable human carcinogens: benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene.

Sewage

Sewage contains a variety of harmful pollutants, including disease-causing organisms, metals and nutrients (EPA 2014c). Humans exposed to sewage-polluted water can develop waterborne infections including hepatitis, gastroenteritis, as well as skin, wound, respiratory and ear infections. Humans develop waterborne diseases after ingesting contaminated water, inhaling water vapors, eating contaminated fish and shellfish, and swimming. The most common symptoms are diarrhea and nausea (EPA 2011).

Scientific evidence also supports significant impact of sewage pollution on water quality and health of seagrasses and corals. The most common response to sewage loading include an increase in benthic algae and filter feeding invertebrates such as bryozoans, sponges, and tunicates, with a corresponding decrease in the diversity and abundance of hermatypic corals (Pastorak and Bilyard 1985). Lapointe (1997) suggests that a critical nitrogen threshold for coral reefs may be 14 parts per billion (ppb). Primary and secondary treated sewage is between 40,000 and 30,000 ppb.

Pristine ocean waters are typically around 1 ppb. Recently, scientists found that a gut bacterium found in human feces called *Serratia marcescens* causes white pox disease that affects Elkhorn coral (Sutherland et al. 2011).

Puerto Rico's Water Quality Standards classify Guanica Bay's designated use to be SB: "Coastal waters and estuarine waters intended for use in primary and secondary contact recreation, and for propagation and preservation of desirable species, including threatened or endangered species". The Water Quality Standards permit a limit of 5,000 ppb daily maximum allowable daily concentration for total nitrogen (PR EQB 2010).

Two wastewater treatment plants (WWTP) are located in tidal areas in the Guánica Bay Watershed. Guánica WWTP has been recently upgraded with one additional module, increasing its capacity to 2 million gallons per day for secondary-advanced treatment. The Caña Gorda Beach WWTP handles about 3000 gallons per day but has a treatment regime dictated by seasonal use of the public beach and associated facilities. Also in the watershed, but not in the tidal areas, are two additional WWTPs – Yauco and Lajas. Yauco has an NPDES permit to provide secondary treatment for an average daily flow of 4.5 million gallons per day (MGD) of wastewater, and Lajas has an NPDES to provide advanced secondary treatment with nutrient removal to a monthly average flow of 1.2 MGD, and to remove 85% of Biochemical Oxygen Demand (BOD) and total suspended solids (TSS).

However, many homes and businesses in the Guánica Bay Watershed are not connected to central sewer systems; instead they utilize septic systems and cesspools or discharge directly into the Bay. These sewage treatment methods or lack of treatment provide a nearly direct input of nutrients into coastal waters due to discharging to groundwater that is likely hydrologically connected to adjacent tidal water. Additionally, coastal resorts and beaches are often served by onsite sewage treatment and disposal systems (OSTDS). These systems are akin to secondary treatment and therefore provide very little reduction of nutrients.

2.2.2 Responding to the Problems

The Guánica Bay Watershed Management Plan (CWP 2008) lays out a series of management actions proposed to address these problems. Several key actions became the focus of the workshop discussions and exercises:

Restoration of the historic Guánica Lagoon (top priority project)

There is a proposed plan to restore historic Guánica Lagoon in Barrio Arenas of Guánica. DNER and EPA originally commissioned a study to evaluate the feasibility of restoring the Lagoon to reclaim its value as a wildlife refuge and ecological resource. Gregory Morris Engineering (GME) was contracted by DNER to conduct a hydrologic and hydraulic study of the lagoon. The resulting reports: "*Hydrologic and Hydraulic Analysis: Guánica Lagoon Restoration Impacts on Regulatory Flood Levels*" and "*Guánica Lagoon Hydrology & Restoration Alternatives*" were both prepared in 1999 (GME 1999a and 1999b). These reports have been updated, an extensive farm inventory has been performed, and a salinity and ground water survey has been completed. The objective is to look at the feasibility of partially or completely restoring the lagoon to maximize economic and ecological benefits of the area while minimizing any impact on important agricultural lands in the Lajas Valley. The lagoon served as a sink for sediments and nutrients–restoration of the Lagoon would reduce an estimated 8,760 tons of sediment, 108 tons of total nitrogen, and over 8 tons of total phosphorus annually from moving closer to Guánica Bay and the coastal coral reef system.

Urban Best Management Practices (BMPs) (e.g., sewage, erosion and stormwater)

The second highest priority project in the WMP is a demonstration project to construct a series of treatment wetland cells at the 850,000 GPD Guánica wastewater treatment plant to reduce nutrient concentrations from secondary effluent before being discharged into Guánica Bay (**Fig. 2-8**). This is important because secondary treatment only provides for minimal nutrient reduction and tropical coastal systems, particularly coral reefs, are more sensitive to nutrient enrichment than other coastal systems because of the extremely low natural [N] in these locations.

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Figure 2-8. Proposed constructed treatment wetlands (photo provided by Paul Sturm)

NOAA and CWP are planning to convene a roundtable of experts and practitioners to develop regional amendments to hydro seed mixtures and erosion control practices, stabilize up to 19 acres of highly erodible bare soils in the Guánica Watershed, provide on-site demonstrations and erosion control design and implementation training, and monitor the impact of the erosion control techniques.

Several other projects are proposed, including pet waste cleanup and education and ordinance in coastal cities such as Guánica to reduce transport of nutrients and pathogens in stormwater runoff, rainwater collection systems in Guánica and Yauco, exploring the possibility of slower releases for a longer duration from Rio Loco, and dredging of reservoirs that are filled beyond their capacity.

Agricultural Best Management Practices (BMPs)

Agricultural BMPs are practical, cost-effective actions that farmers can take to reduce the amount of pesticides, fertilizers, animal waste, and other pollutants entering waterbodies, and to conserve water supply. BMPs are designed to benefit water quality and water conservation while maintaining or even enhancing agricultural production. Several BMPs were proposed in the WMP.

Through their Coastal and Partners for Fish and Wildlife Programs, the Caribbean Ecological Services Field Office of the FWS, has begun working in close cooperation with USDA/NRCS to promote sun-to-shade coffee and riparian reforestation initiatives in the extended upper watershed of the Río Loco in Yauco as part of the Guánica Bay Watershed Restoration Plan. The FWS is providing plant material and technical assistance, in conjunction with NRCS and Envirosurvey, to contact farmers and orient them on the initiative, evaluate the farm for treatments, assist the farmer with the layout for planting shade trees, and certifying the practice once tree seedlings are planted (**Fig. 2-9**). NRCS provides technical assistance and incentives to the farmers for planting the trees and other practices.

Figure 2-9. FWS and farmers surveying a farm (A), the Envirosurvey nursery (B), and plants delivered to the farmer (C) (photos provided by USF&WS)

Upland erosion in the coffee growing regions was identified as a land-based source of pollution where steep slopes, high tropical rainfall patterns, and highly erodible lands exist. Converting from sun-grown coffee to shade-grown coffee keeps the sediment on the farms and out of waterbodies. Early successes in the Guánica Bay to convert to shade-grown are ongoing but several obstacles still exist to ensure shade-grown coffee growers are economically successful. The CWP planned to hold a Shade-Grown Coffee Roundtable to: 1) assist farmers in Puerto Rico growing shade-grown coffee to improve marketing and receive a higher premium and return for shade-grown products; 2) bring together a group of experts and farmers to convene a discussion about how to the achieve the above; and 3) identify domestic/Puerto Rico coffee markets as well as international and Caribbean markets.

NRCS is also planning demonstration projects on several farms in the relatively unstable area of the Rio Loco between Yauco and the La Laguna community to remove old irrigation infrastructure and plant native species of trees to promote bank stability. Conservation buffers, which are permanently vegetated areas or strips of land designed to intercept pollutants and manage other environmental concerns, are being promoted (**Fig. 2-10**). Strategically placed buffer strips in the agricultural landscape can effectively mitigate the movement and export of sediment, nutrients, and pesticides. It is anticipated that these demonstration projects will showcase the benefits of these best management practices and lead to a more comprehensive program to improve stream stability and buffers in the watershed.

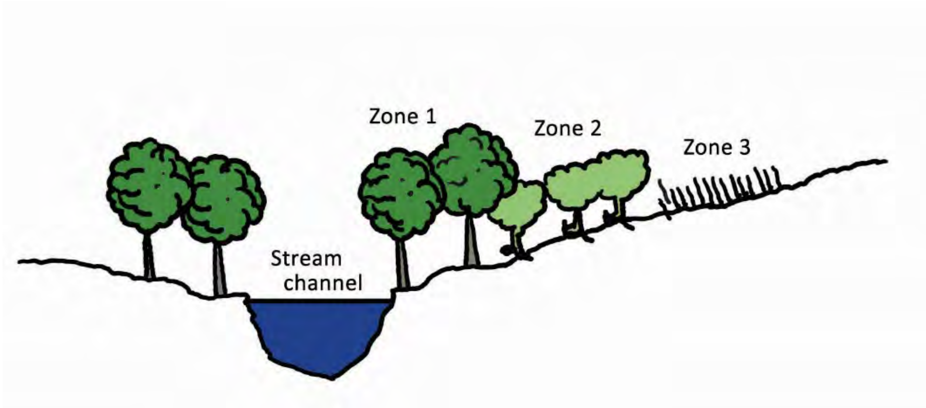

Figure 2-10. Illustration showing a buffer strip design for an agricultural landscape. Zone 1 shows native trees, Zone 2 shows native woody vegetation (shrubs), and Zone 3 would be the agricultural zone.

Education and Outreach

Finally, the watershed management plan (CWP 2008) proposed development of programs that would introduce children and their parents to the coral reefs, fisheries, and the importance of both to ecological health and the economy. The programs would include conservation-based activities that enable participants to learn as a group and to learn from experience. Experiential learning experiences have been shown to have a strong positive impact on changing environmental conservation attitudes, beliefs and behaviors.

2.3 USDA's Detailed Plans for the Guánica Watershed

Summary of a presentation given by José Castro, USDA NRCS

This presentation was intended to provide the workshop participants with an overview of USDA's plans for the Guánica Bay watershed.

The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) works with private landowners to help them conserve, maintain and improve their natural resources. NRCS emphasizes voluntary, science-based conservation, technical assistance, partnerships, incentive-based programs, and cooperative problem solving at the community level.

NRCS and its conservation partners have started a project to reduce land-based sources of pollutants in the Guánica Bay Watershed through soil conservation practices on agricultural land and water (**Table 2-2**). NRCS will provide technical and financial assistance to eligible land stewards on eligible lands to improve soil conditions and water qualities impaired by nonpoint source pollutants, as well as increase the efficiency of water management for agricultural purposes. These practices will help improve the fertile valley lands, restore infrastructure and agricultural irrigation, and protect adjacent coral reefs.

Table 2-2. Agricultural practices that potentially affect water quality (source: UNEP 1998).

Agricultural Activity	Potential Impact on Surface Waters
Tillage/ploughing	Sediment/turbidity: sediments carry nutrients and pesticides adsorbed to sediment particles; siltation and loss of habitat, spawning ground, etc.
Fertilizing	Nonpoint source pollution, especially nutrients, leads to eutrophication, excess algae growth leading to deoxygenation of water and fish kills
Manure spreading	Nonpoint source pollution containing pathogens, metals and nutrients leads to eutrophication and potential contamination.
Pesticides	Nonpoint source pollution leads to contamination of surface water and biota; dysfunction of ecological system in surface waters by loss of top predators due to growth inhibition and reproductive failure; public health impact from eating contaminated fish.
Irrigation	Runoff of fertilizers and pesticides to surface waters leads to ecological damage, bioaccumulation in edible fish species, etc.
Clear-cutting	Erosion of land leads to high levels of turbidity, siltation of bottom habitat, etc. Hydrologic regime is disrupted and changed.

The ***Upper Río Loco*** watershed has very steep slopes and humid subtropical forest vegetation. Conservation goals are to reduce erosion, improve water quality and quantity, improve forest habitat for wildlife, and apply conservation practices like tree and shrub planting, nutrient and pest management and riparian forest buffers. NRCS and the USFWS Caribbean Field Office are partnering to provide technical assistance to area stakeholders to convert sun coffee plantations to shade to improve wildlife habitat.

The ***Lower Río Loco*** watershed has flat slopes and dry subtropical forest vegetation. Conservation objectives are to reduce erosion and sediment deposition from the upper watershed, improve water quality and quantity for irrigation, manage flooding and stabilize riverbanks. Conservation practices include: water management, sediment basins, nutrient and pest management, tillage systems using residues and cover crops, and runoff control. NRCS, the PR Department of Agriculture and the PR Land Authority are partnering to assist stakeholders.

The conservation objectives of the Guánica Watershed Project will be addressed though the execution of 2008 Farm Bill conservation programs in partnership with federal, state and local agencies and the support of local NGOs. Over $2 million in assistance will be devoted to implementation of projects on private lands through Conservation Technical Assistance Program (CTA), the Environmental Quality Incentive Program (EQIP), and the Wetlands Reserve Program (WRP).

The **Conservation Technical Assistance Program (CTA)** is a voluntary conservation network that fosters partnership between NRCS, conservation districts, state conservation agencies, and private landowners. This assistance may be in the form of resource assessment, practice design, resource monitoring, or follow-up of installed practices. Although the CTA program does not include financial or cost-share assistance, clients may develop conservation plans, which can serve as a springboard for those interested in participating in USDA financial assistance programs. CTA planning can also serve as a door to financial assistance and easement conservation programs provided by other Federal, State, and local programs.

The **Environmental Quality Incentive Program (EQIP)** provides financial assistance to implement conservation practices. Owners of land in agricultural production or persons who are engaged in livestock or agricultural production on eligible land may participate in the EQIP program. Program practices and activities are carried out according to an EQIP program plan of operations developed in conjunction with the owner/producer that identifies the appropriate conservation practice or measures needed to address the resource concerns. Contracts are offered with a minimum term that ends one year after the implementation of the last scheduled practices and a maximum term of ten years.

The **Wetlands Reserve Program (WRP)** is a voluntary program that provides technical and financial assistance to private landowners and Tribes to restore, protect, and enhance wetlands in exchange for retiring eligible land from agriculture. The program offers three enrollment options:

1. *Permanent Easement* is a conservation easement in perpetuity. USDA pays 100 percent of the easement value and up to 100 percent of the restoration costs.
2. *30-Year Easement* is an easement that expires after 30 years. USDA pays up to 75 percent of the easement value and up to 75 percent of the restoration costs.
3. *Restoration Cost-Share Agreement* is an agreement to restore or enhance the wetland functions and values without placing an easement on the enrolled acres. USDA pays up to 75 percent of the restoration costs.

Stage 1: In 2010, NRCS allocated $1 million in federal and state funds for the project's first stage sediment control and restoration of irrigation systems on Santa Rita and Maria Antonia farms in Guánica Valley. Practices to be installed during this first stage include three 3-acre water reservoirs, two 3-acre sediment basins, 5,500 linear feet of open channels, 6,000 linear feet of pipeline, 4,500 feet of grassed waterways, and pump houses with irrigation system upgrades to serve approximately 900 acres.

Stage 2: In 2011, NRCS plans to allocate $1 million for the second stage to connect the Puerto Rico Electric Power Authority (PREPA) irrigation channel with a 6,000 foot, 18" pipeline to the first stage, and at the same time restore irrigation systems and runoff control on Fraternidad farms in Guánica. Conservation practices to be installed in this second stage include 6,000 linear feet of water conveyance, pump houses, two water reservoirs, one sediment basin, and irrigation water system upgrades to serve approximately 350 acres.

Both stages 1 and 2 include stabilization projects along the riverbanks of Rio Loco. Three initial riverbank segments (Las Lajas sector, the former irrigation channel crossing, and the old bridge pilasters of the Sugar Cane train) will be reconstructed using bioengineering.

Stage 3: Planning will be initiated in Fiscal Year 2012 to restore the existing runoff control channel system and restore agricultural irrigation and sediment control systems in the Caño section of Guánica. As part of this project, NRCS helped local landowners and community leaders form the new Southwestern Soil and Water Conservation District (SWSCD). The Southwest District will administer construction of the NRCS Guánica Bay Watershed projects.

Chapter 3. Framing Knowledge about Coral Reef and Coastal Ecosystems Using a Systems Framework (DPSIR)

The second workshop session began with a presentation on systems thinking and the DPSIR framework. This presentation set the stage for three breakout groups to discuss and characterize specific decision scenarios that had been outlined in the management plan (CWP 2008). These were:

1. <u>Change Agricultural Practices</u>
   Removal of historic irrigation system
   Stream bank riparian plantings near farms
   Cover crops at high elevation farms
   Switch from sun to shade-grown coffee [through subsidies]
2. <u>Restore Guánica Lagoon</u>
   Re-flooding of the lagoon
   Restoration of wetland vegetation
   Monitoring of discharge into the lagoon
3. <u>Low Impact Development</u>
   Rainwater collection systems
   Stormwater runoff treatment centers
   Hydro seeding of bare soil associated with roads and homes
   Enhanced wetlands for sewage treatment
   Pet waste cleanup ordinances in coastal cities

3.1 Systems Thinking and Example DPSIR

Systems thinking focuses on understanding how a system's constituent parts interrelate and how the system works over time and within the context of larger systems. Systems thinking is extremely effective at resolving difficult problems. Examples of types of problems where systems thinking can result in improved decision-making include:

- Complex problems that involve helping many actors see the “big picture” and not just their part of it;
- Recurring problems or those that have been made worse by past attempts to fix them;
- Issues where an action affects (or is affected by) the environment surrounding the issue, either the natural environment or the competitive environment; and
- Problems whose solutions are not obvious (Aronson 1996).

Use of systems thinking when approaching a problem may result in strikingly different conclusions than those generated by traditional forms of analysis, especially when what is being studied is dynamically complex or has a great deal of feedback.

EPA’s Coral Reefs Ecosystem Services Research Program (ESRP) adopted the European Environmental Agency’s DPSIR (Driving Forces, Pressure, State, Impact, and Response) framework to show the broad array of human interactions with coral reefs, and for examining consequences (e.g., changes in benefits, costs and sustainable delivery of ecosystem services) across multiple socioeconomic sectors (EEA 1999). DPSIR has been used by the United Nations to organize information about the state of the environment in relation to human activities (UNEP 2007).

The utility of a DPSIR framework lies in its transparency to stakeholders and its ability to organize components and relationships among components are clearly obvious. It also brings a capacity to isolate particular linkages and interactions while retaining conceptual relevance to the larger system. The framework does not capture every situation perfectly but is a reasonable means to depict the many social, economic and ecological interactions of any resource decision.

The framework assumes cause-effect relationships between interacting components of social, economic, and environmental systems (Pierce 1998; Smeets and Weterings 1999), which are:

- **D**riving Forces: The factors that motivate human activities. *Driving Forces* can be divided into economic and social categories. Ultimately, Social and Economic *Driving Forces* arise within a society as the means to fulfill basic ***human needs***, which have been consistently identified as the necessary conditions and materials for good life, good health, good social relations, security, and freedom. Hence, *Economic Driving Forces* fulfill core human needs for food and raw materials, water, culture, security, health, shelter, and infrastructure; and *Social Driving Forces* fulfill human needs for social relations, equity, governance, value fulfillment (e.g., environmentalism) and cultural identity. The spatial distribution and intensity of *Driving Forces* varies–they can originate and act globally, regionally or locally.
- **P**ressures: Human activities, derived from the functioning of Social and Economic *Driving Forces* that induce changes in the environment. *Pressures* are not stressors. Stressors are the naturally occurring components of state that are changed by pressures (e.g., land development [the pressure] - increases sediment [the stressor] in the coastal zone, which then may stress the ecological components of the reef).
- **S**tate: Natural systems (e.g., the quantity and quality of physical, chemical, and biological components). Chemical, physical and biological processes interact to affect different ecosystem components (e.g. chemicals, biological species) that can be measured by their attributes (metrics of quantity or quality). ***Abiotic State*** includes the non-living chemical and physical factors in the environment, which affect the survival, growth, and distribution of living organisms in the Biological State. Abiotic phenomena underlie all of biology. The *Abiotic State* reflects the magnitude, frequency, and concentration of abiotic components of the environment including:
    - Physical environment (e.g., climate, air and sea temperature, precipitation, storms and hurricanes, drought, hydrology, ocean circulation patterns, fire)
    - Chemical environment (e.g., nutrients, pH, atmospheric CO2 levels, salinity, contaminants)

  Biotic State includes the biological components of the ecosystem and their interactions, including humans. In general, this includes sessile plants or animals that provide the living habitat and base of the food web that supports higher trophic levels. Biological condition may be measured by individual- or community-level attributes, including:
    - Living habitat (e.g., deserts, wetlands, forests, grasslands, coral reefs, agricultural lands)
    - Inhabitants (e.g., birds, mammals, reptiles, amphibians, invertebrates)
    - Invasive/non-native species (e.g., plants, animals, insects)
    - Microorganisms and pathogens (e.g., decomposers, mycorrhizae, bacteria, fungi, viruses)

- **I**mpact: delivery of ecosystem goods and services as a consequence of changes in ecological state. Ecosystem services, in particular, are the benefits that ecosystems can provide. Other factors, such as human health, habitat, and behavior also contribute to human well-being. *Human well-being* is an abstract concept that captures a mixture of people's life circumstances and quantifies the degree of fulfillment of basic human needs for food, water, health, security, culture, and shelter.
- **R**esponse: A key benefit in using the DPSIR framework is that it explicitly includes an Action or *Response* component that can be taken at any level of the causal network. In the DPSIR framework, *Responses* are actions taken by groups or individuals in society and government to prevent, compensate, ameliorate or adapt to changes in the state of the environment.

Generation of a comprehensive framework to link ecological and socioeconomic factors, even an introductory version, is significant because it has never been attempted for coral reefs. For decades, scientists have conducted research to assess and understand the ecological phenomena of coral reefs around the world. While the body of information is extensive, it is unevenly distributed across disciplines, times and places. Consequently, the information has not been effectively used to identify gaps and prioritize research; nor has it been easily synthesized into concepts and tools for conservation that resonate with stakeholders and influence management. This situation is not unique to coral reefs, a recent commentary (Curran 2009) suggests that there are currently no single programs capable of delivering overall support (including social and economic perspectives) to environmental decision-making, and emphasizes the need for further research on viable decision-support frameworks. Application of the DPSIR framework will better ensure that we do not overlook critical relationships and that we recognize the full consequence of a decision to related parts of the larger system (O'Connor and McDermott 1997).

During the Guánica workshop, Dr. William Fisher, EPA, walked through an example DPSIR, demonstrating how it might be used to display knowledge about coral reef and coastal ecosystems and linkages between human-ecosystem interactions. The facilitator used CmapTools software (Cañas et al. 2004) to construct a concept map of a coral reef and some associated human influences. Concept maps are graphical tools for organizing and representing knowledge, which include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts.

In this example, Dr. Fisher began with one Driving Force–the tourism and recreation economic sector. Coral reef-based tourism and recreation used to be an important industry in the Guánica Bay Watershed. The tourism and recreation industry includes facilities and services for various cultural, entertainment, and recreational interests of residents and tourists, such as swimming, diving and snorkeling; cruise ships; recreational fishing and boating; and the infrastructure needed to support the industry, including hotels, restaurants, and transportation. In the concept map, these were introduced as Driver sub-sectors, and recreational fishing was chosen as an example for demonstration purposes (**Fig. 3-1**). Participants added harvesting, by-catch and waste; anchor, gear and boat groundings; and oil, metals and sewage discharge as Pressures generated by recreational fishing, and identified changes in State from these pressures included effects on the harvested species, namely invertebrates, fish and sponges (**Fig. 3-2**).

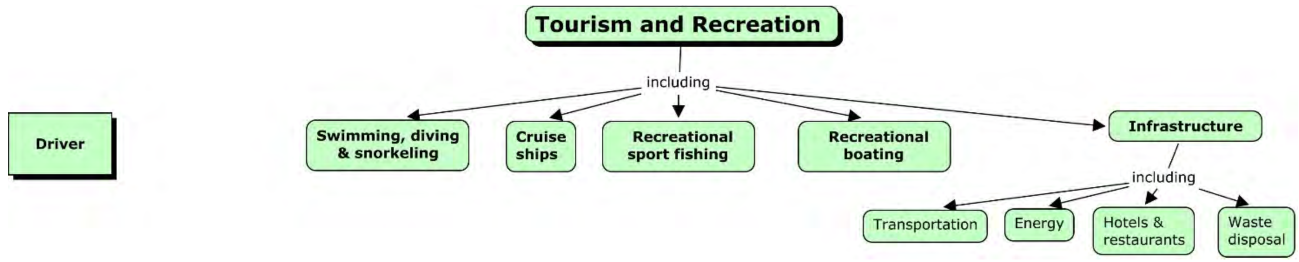

Figure 3-1. Driving Force–tourism and recreation economic sector

Next, Dr. Fisher asked which pressures resulted from the economic sub-sectors. In this example he focused on recreational fishing and recreational boating. The pressures included harvesting, by-catch and waste; anchor, gear and boat groundings; and oil, metals and sewage discharge (**Fig. 3-2**).

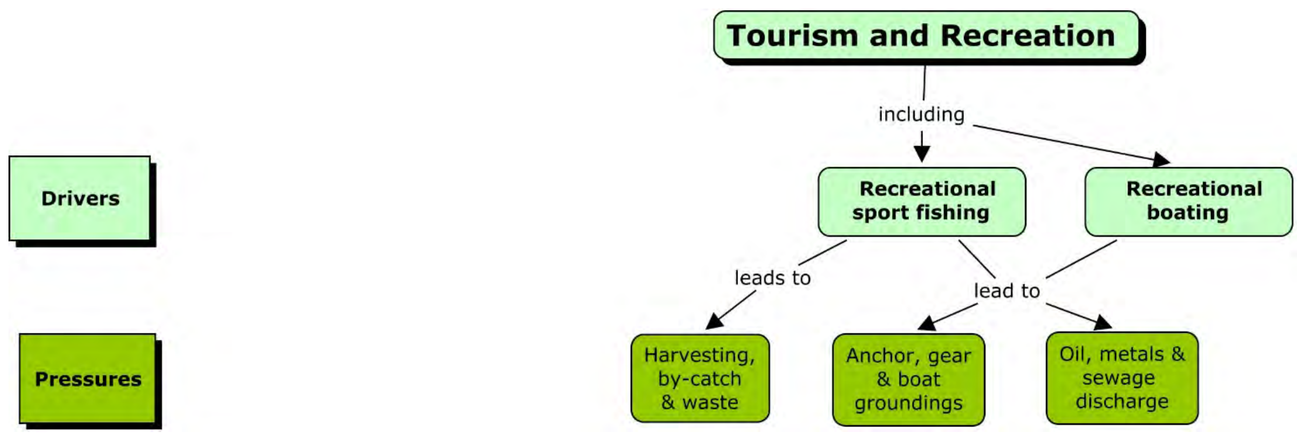

Figure 3-2. Pressures associated with recreational fishing and boating

Focusing down again, Dr. Fisher asked what organisms were being harvested, and identified invertebrates, fish and sponges (**Fig. 3-3**).

Further construction of the map illustrated how more complex relationships could be captured. Recreational fishing and boating were additionally linked to oil, metals and sewage discharge pressures (**Fig. 3-4**). To account for physical and chemical changes (rather than biological and ecological) a separate State category was introduced. Changes in environmental state were shown to have an effect on ecological state, including invertebrates, fish, sponges, stony corals, octocorals, seagrasses, mangroves and macro-algae, in the DPSIR map (**Fig. 3-4**).

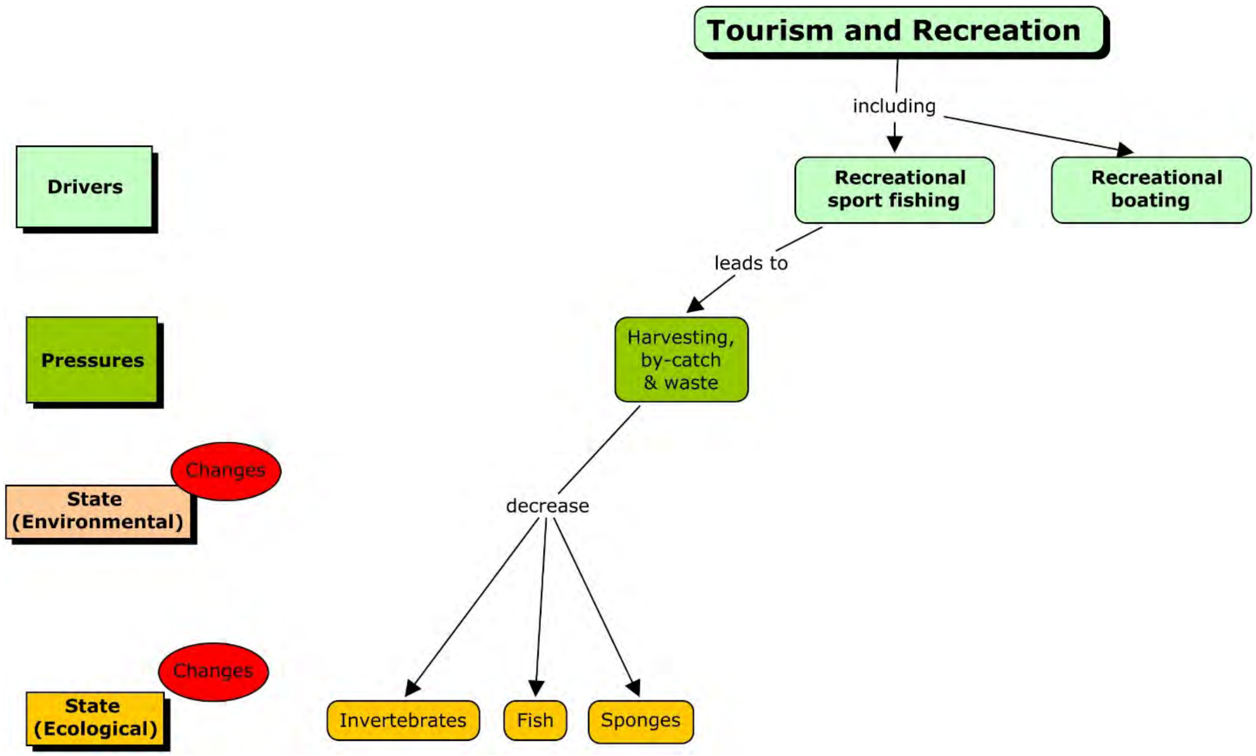

Figure 3-3. An initial coral reef DPSIR conceptual map showing one example Driving Force (recreational fishing) creating a Pressure (harvesting, by-catch and waste) that affects the State of harvested organisms (invertebrates, fish and sponges)

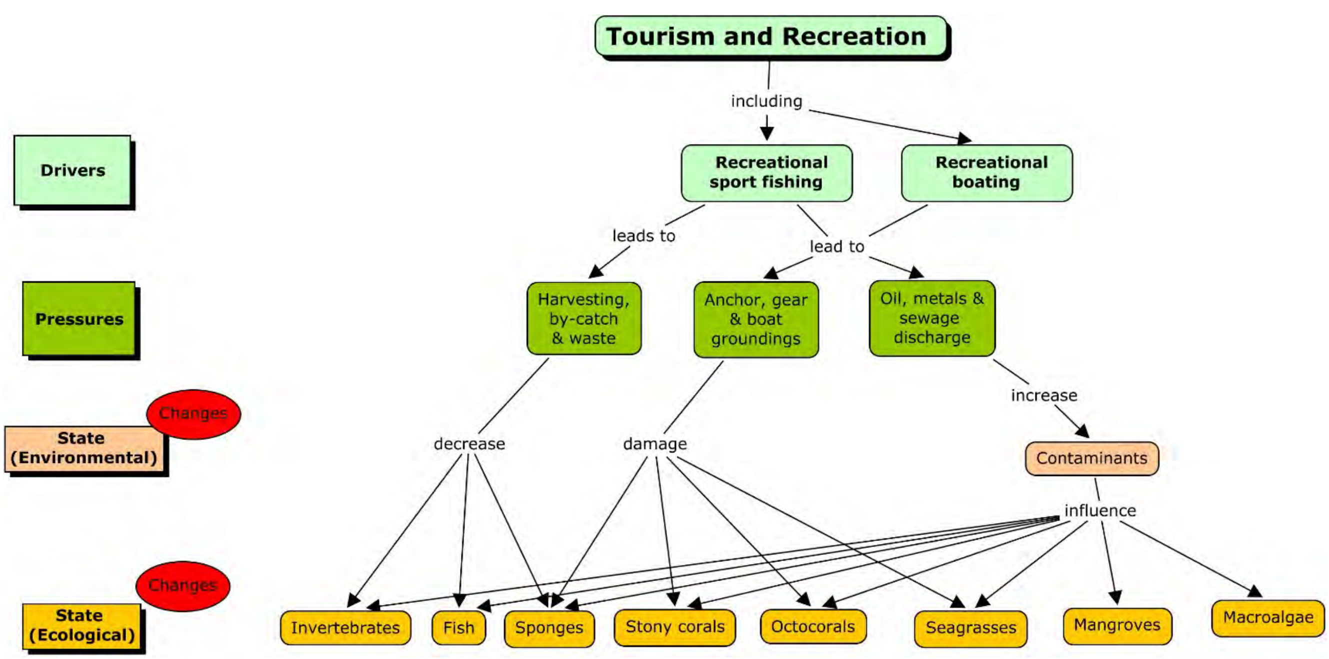

Figure 3-4. Changes in environmental and ecological State associated with recreational fishing and boating

Participants then identified a wide range of ecosystem services that would be impacted by an altered ecological state, and these were added to the model in the Impact category (**Fig. 3-5**). The list included services that directly benefit humans (food, erosion control, pharmaceuticals, tourism and recreation), as well as supporting services–the processes and functions that underlie many ecosystem services (e.g., biodiversity, primary production, and nutrient cycling).

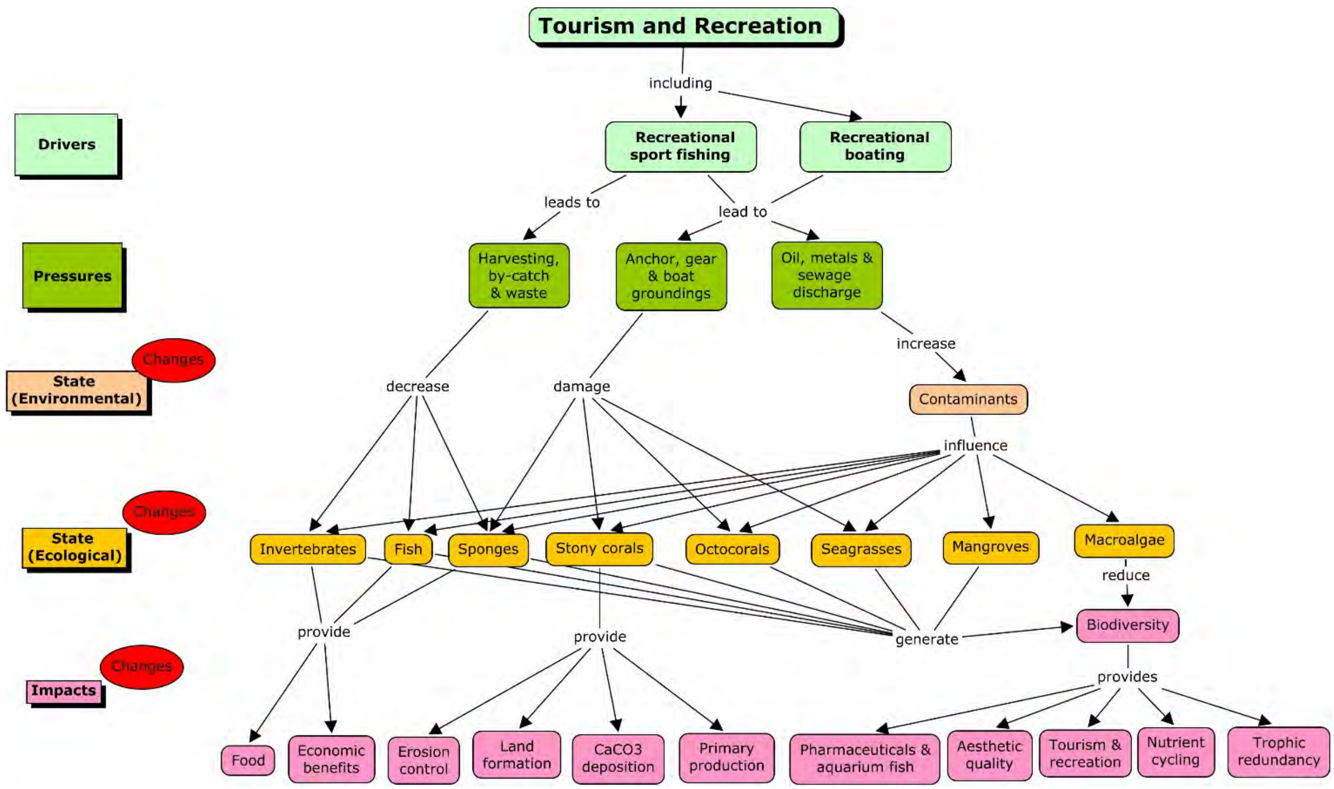

Figure 3-5. Ecosystem services affected by recreational fishing and boating

Most of the services provided by coral reefs are affected by Driver sub-sectors other than tourism and recreation, such as swimming, diving and snorkeling; cruise ships; and infrastructure, so these were added back into the conceptual map with appropriate links to Pressures. Additional Pressures generated by these Drivers were introduced, including beach re-nourishment, sunscreen, trampling, dredging, greenhouse gas emissions, point and non-point source discharges, hydrology, and shoreline alterations (**Fig. 3-6**).

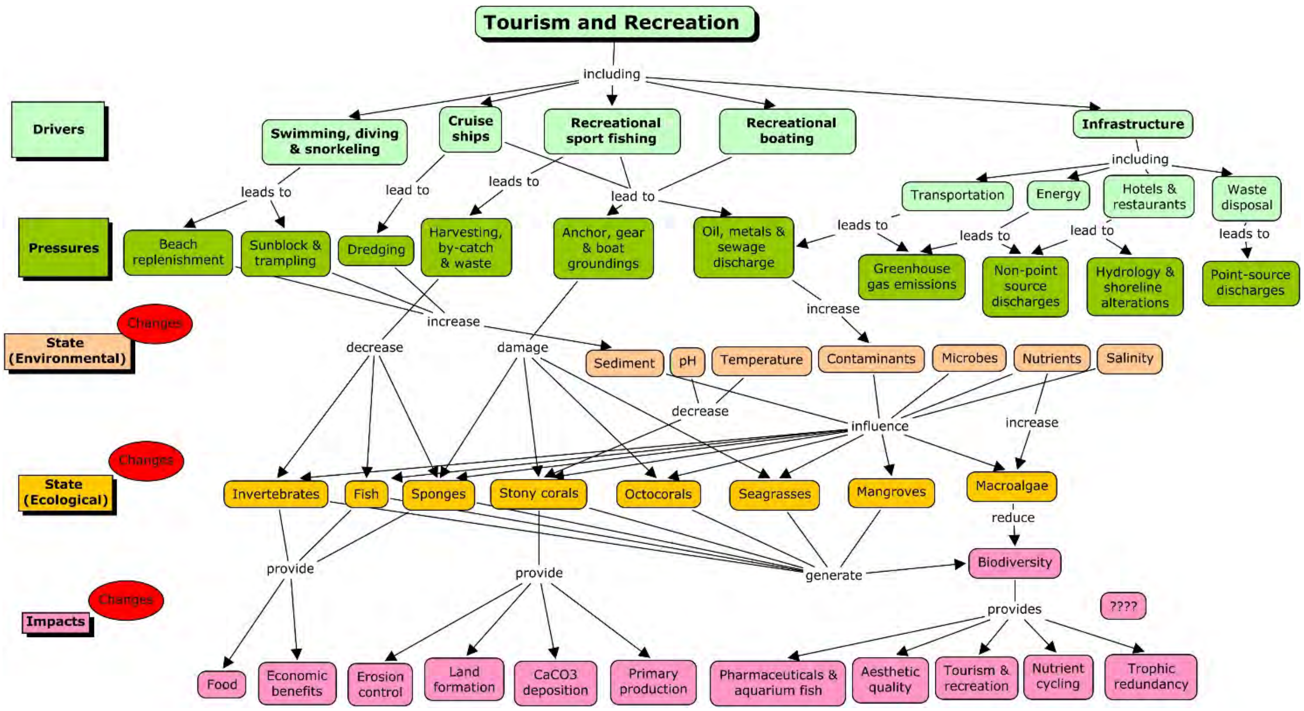

Figure 3-6. Additional tourism and recreation subsectors generate additional Pressures and changes in environmental and ecological State. Services provided by coral reefs (Impact) remain unchanged

In developing the DSPIR framework, an important next step was to incorporate potential responses that could mitigate adverse changes in Impact. The participants suggested several management and policy options including recreational fishing regulations and enforcement, market incentives, tourism policies, damage assessment and mitigation, coastal zone management and marine protected areas (**Fig. 3-7**). Many other policies that were related to tourism and recreation infrastructure were identified, such as land use zoning, building permits, point and nonpoint pollution control, Clean Water Act enforcement, agricultural best management practices and CO_2 emission regulations. These policies regulate or define responses.

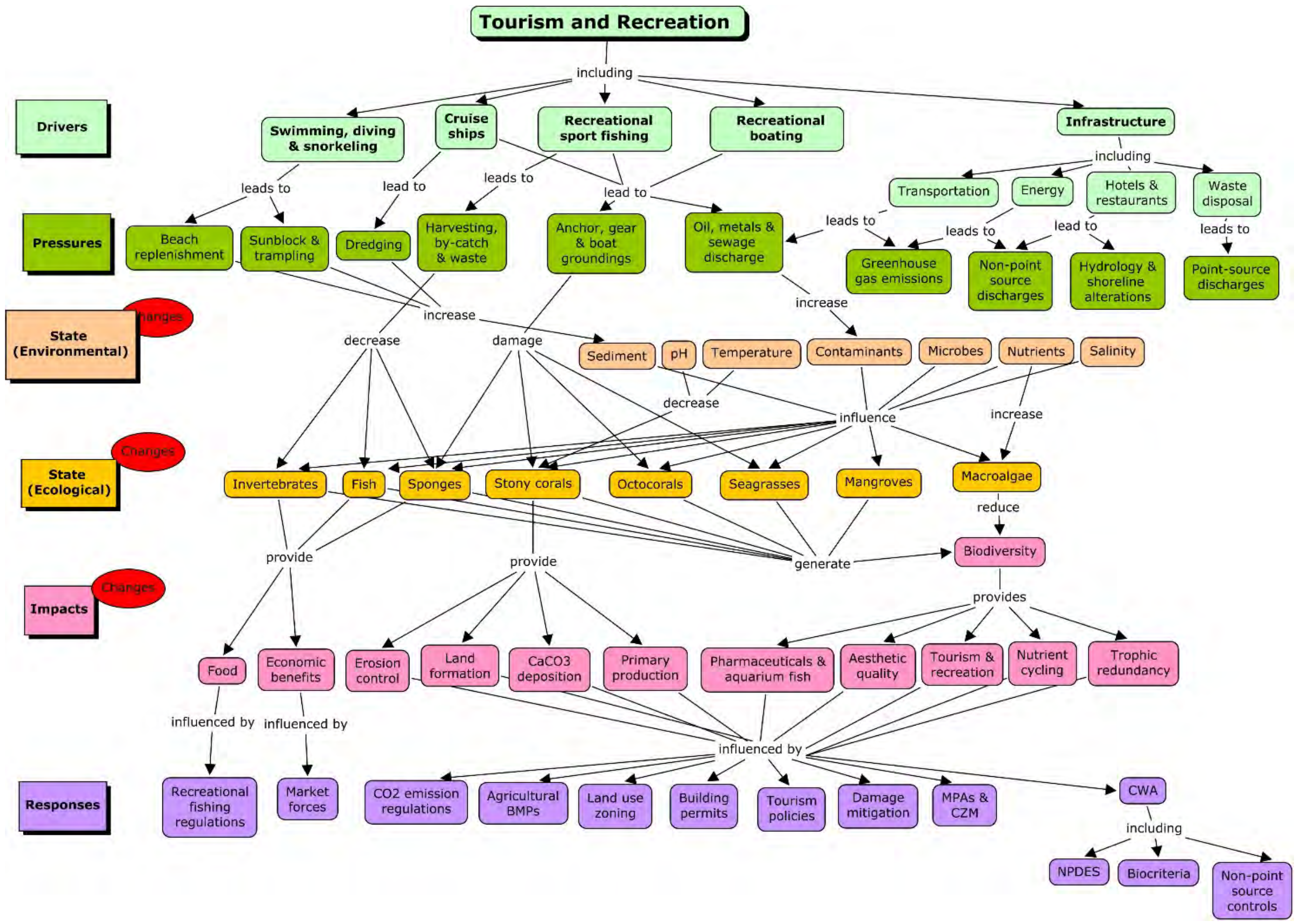

Figure 3-7. Responses that could be implemented to mitigate the impact of the tourism and recreation sector

The last step in the example of building a DPSIR was to demonstrate how different potential responses could be applied in different parts of the framework. Most of the suggested Responses were related to curbing a Pressure (**Fig. 3-8**) but Responses could be applied to any section of the DPSIR framework. For example, changes in market forces (such as tax incentives and subsidies) would act at the level of Impact and land use zoning would act at the Driver level. The importance of this last step was to illustrate that responses can be leveraged at several levels and that no single response may be sufficient to alter adverse impact.

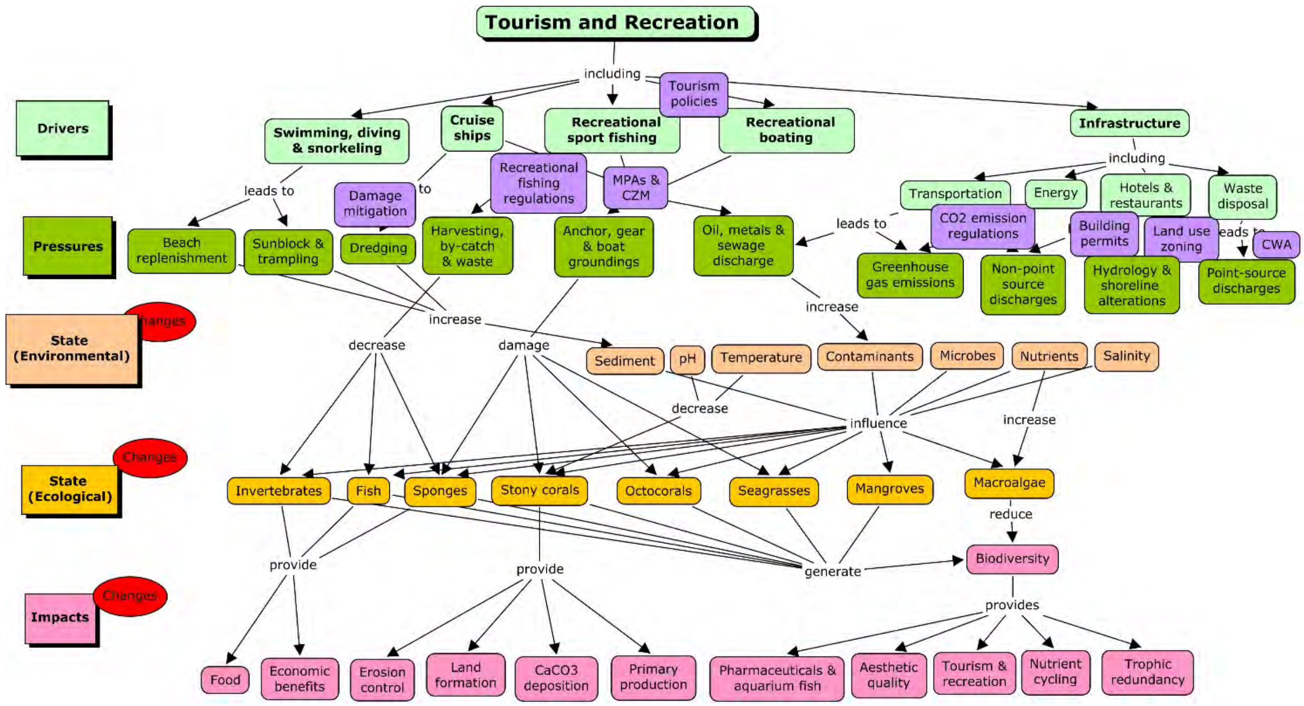

Figure 3-8. Responses aligned with Drivers and Pressures

3.2 DPSIR Breakout Groups

Following the DPSIR presentation, workshop participants broke into small groups to develop three DPSIRs around topics based upon management actions proposed in the Guánica Bay Watershed Management Plan (CWP 2008). The goals of the DPSIR breakout groups were to 1) use the DPSIR framework to characterize information related to a management response (agricultural practices, lagoon restoration, low impact development) and the effects on persistence of reefs and the delivery of ecosystem services; 2) identify the current state-of-knowledge on human-environmental relationships affecting coral reef and coastal ecosystems management in southwest Puerto Rico; and 3) summarize this knowledge in a framework that links the various components of the human-environmental system in southwest Puerto Rico.

Each breakout group had a facilitator and a note-taker who captured the discussion into DPSIR using the CmapTools software. The management actions were grouped into three categories:

- Change Agricultural Practices
    - Remove historic irrigation system
    - Re-vegetate riparian zones near farms
    - Plant cover crops on farms with steep slopes
    - Switch from sun to shade-grown coffee [through subsidies]

- Restore Guánica Lagoon
  - Re-flood the Lagoon
  - Restore wetland vegetation
  - Monitor water discharge into Guánica Lagoon
- Low Impact Development
  - Construct rainwater collection systems
  - Construct stormwater runoff treatment centers
  - Hydro seeding of bare soil associated with roads and homes
  - Construct wetlands for sewage treatment
  - Enact pet waste cleanup ordinances in coastal communities

The facilitators guided the participants through the process of building the DPSIR, beginning with the management action (Response) and tracking vertically through Pressure, State, Impact, and Drivers. Note-takers began with a template that showed the DPSIR running from top to bottom, and the Responses running along the top (**Fig. 3-9**). The template was projected on a screen and the DPSIR was completed in real-time during the breakout discussions.

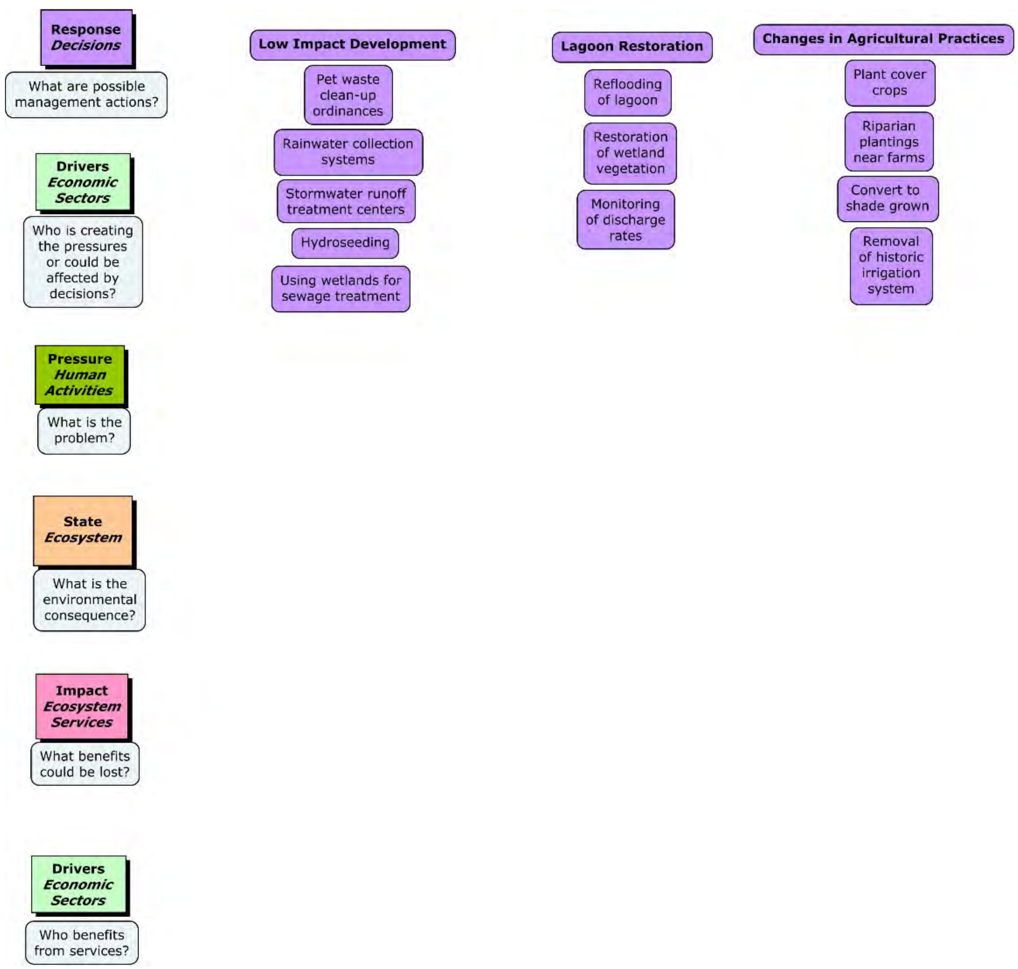

Figure 3-9. Template used by Cmap note-takers to develop the DPSIRs

The facilitators asked a series of questions:

- Why is this management action proposed? What Pressures or human activities is it intended to reduce?
- What effect do these Pressures or human activities have on the State of the ecosystem, abiotic and biotic (environmental and ecological)?
- What are the Impact on benefits to humans provided by the ecosystem? Why should we care about the State of coral reefs?
- What social or economic sectors (Drivers) benefit from ecosystem services? What other sectors could be affected by any decisions (Drivers)?

As the participants responded to the questions, a basic DPSIR concept map was completed. The facilitator then guided the participants to further complete the DPSIR map by brainstorming additional decision points where something else could change a Driver, Pressure, State or Impact and then identifying the corresponding decisions (Reponses), pointing them to the decision point in the framework. Most Reponses point to Pressures or Drivers, but some pointed to State or Impact. The note-taker continued to add more DPSIR boxes as participants continued to brainstorm.

Throughout the process, the facilitator captured discussions on a flip chart. For each decision, the facilitator elicited information about the decision (Who makes the decision? Who is impacted? What tools and information are needed? How do you value benefits and costs?). Finally, the facilitator asked the participants to prioritize the decisions and to identify what would determine the priority of decisions (e.g., money, politics, scientific knowledge, confidence in result). The facilitators also emphasized that decisions at one level may have repercussions at another level (i.e., a decision to limit Pressures will have a consequence for Drivers).

3.2.1 Agricultural Practices

A set of Agricultural Best Management Practices (BMPs) were proposed in the Guánica Bay Watershed Management Plan (CWP 2008), some of which were being implemented throughout the watershed (Chapter 2). The breakout group began to develop an Agricultural Practices DPSIR around those management actions (cover crops, riparian plantings, shade-grown coffee, and removal of historic irrigation systems). Dr. Fisher (EPA) facilitated the Agricultural Practices DPSIR breakout group and Dr. Amanda Rehr (Carnegie Mellon) was the Cmap note-taker.

The group began with the DPSIR template for the Agricultural Practices Management Actions that were proposed in the Guánica Bay Watershed Management Plan. These included converting sun-grown coffee to shade-grown coffee, removing historic irrigation infrastructure, planting cover crops and planting riparian areas near farms (**Fig. 3-10**).

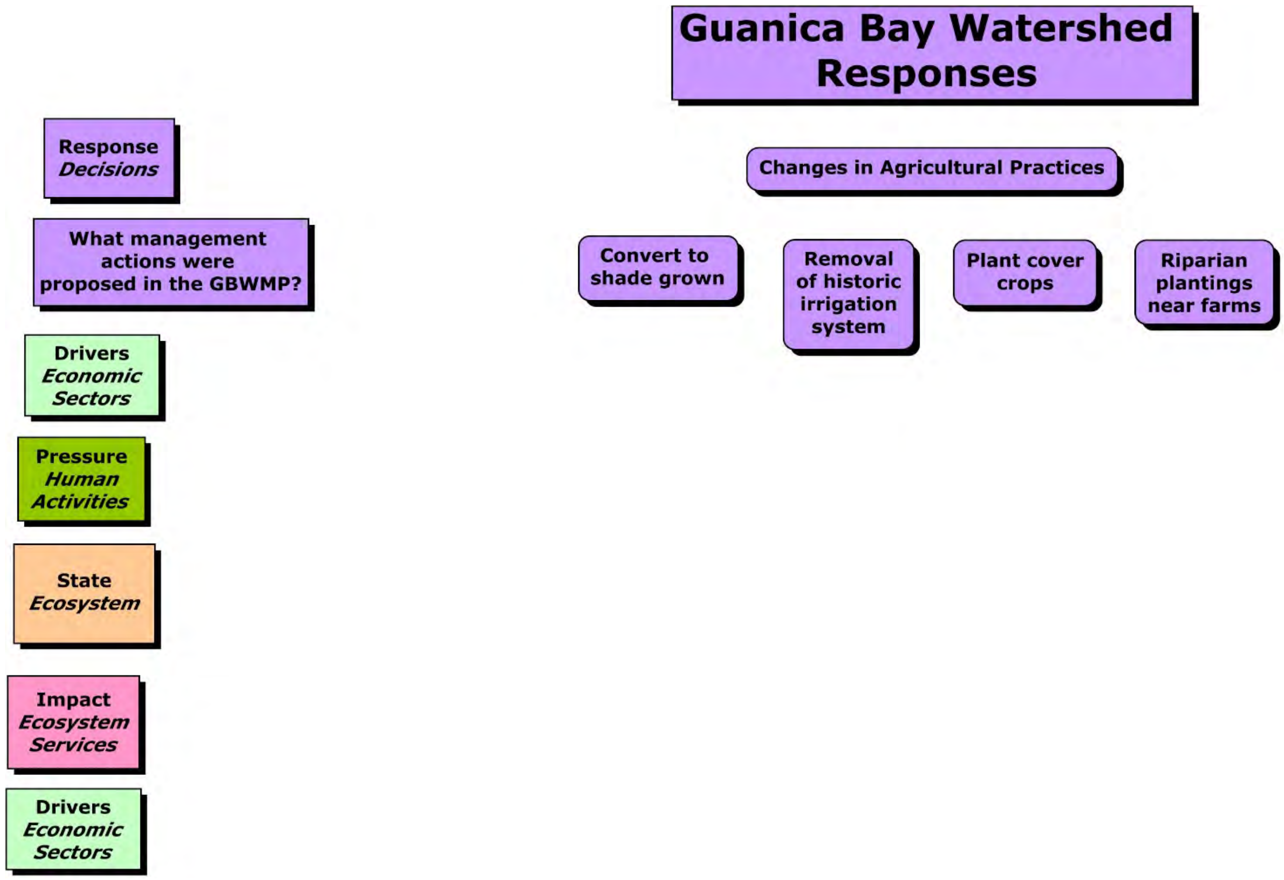

Figure 3-10. DPSIR template for the Agricultural Practices breakout group

The facilitator asked a series of questions to facilitate the development of the DPSIR Cmap. The first questions focused on the Pressures.

- Why is this management action proposed?
- What Pressures or human activities is it intended to reduce?

The group identified a suite of stressors, including: scouring, sediment transport, erosion, fertilizer, nitrogen loadings, phosphorus, and legacy contaminants (**Fig. 3-11**).

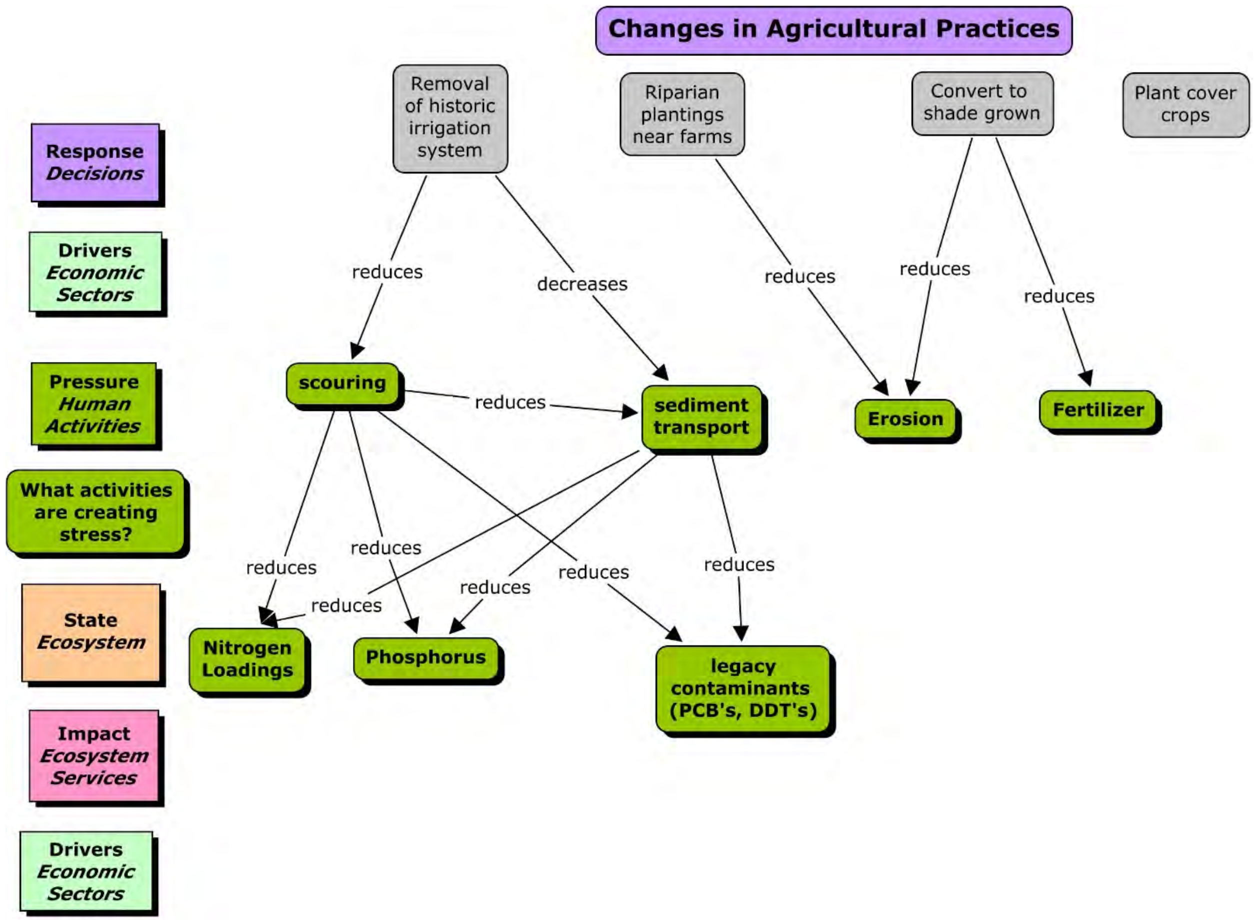

Figure 3-11. Pressures associated with Agricultural Practices (developed during the DPSIR breakout session)

As the discussion turned to changes in State from the identified Pressures, the concept map became much more complex (**Fig. 3-12**). Suggestions for changes in environmental (physical/chemical) State included effects on water quality, air quality, soil quantity and quality, natural hydrology, stream bank stability, habitat for birds and wildlife, groundwater recharge and evapotranspiration rates among others. Potential changes in ecological State included effects on biodiversity and species richness, population abundance and reproduction, algal growth, coral reef condition, other aquatic species condition (freshwater and marine), native and invasive species and agricultural production.

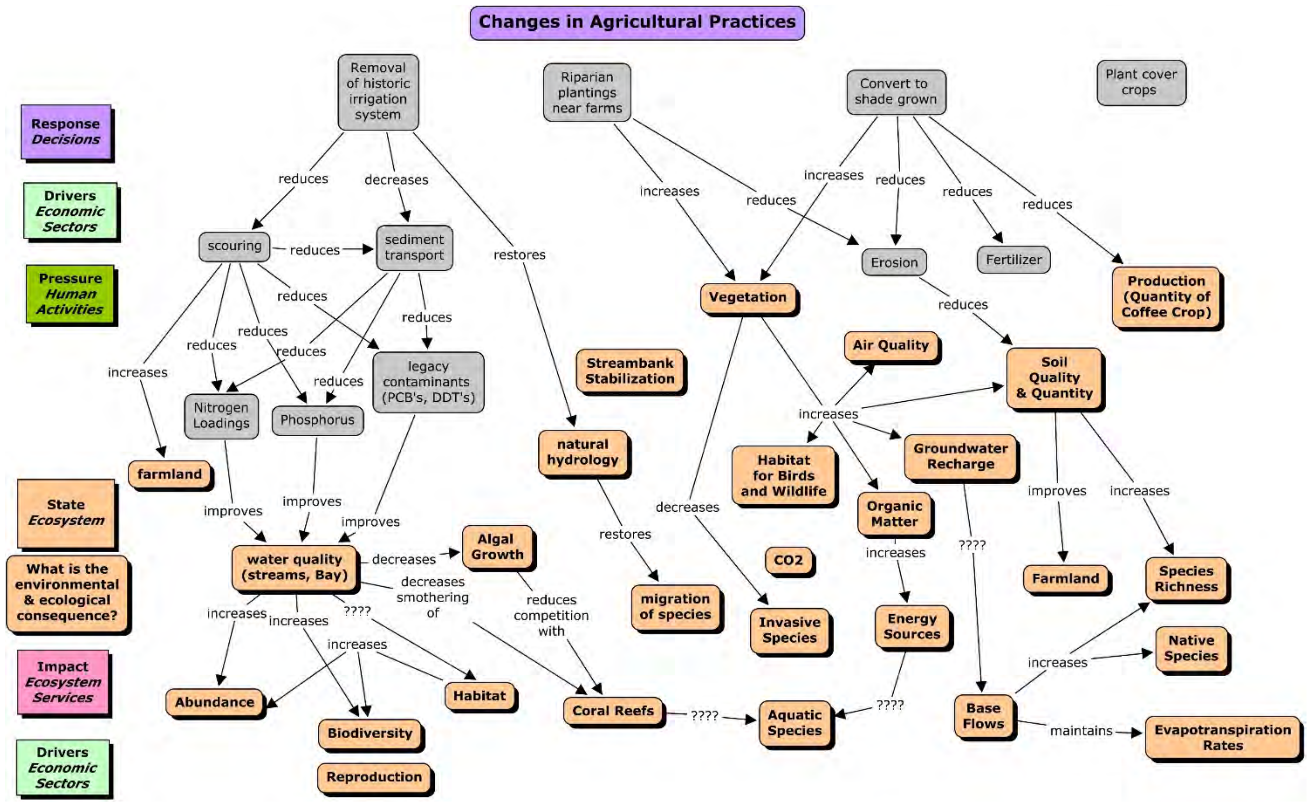

Figure 3-12. Changes in Ecosystem State resulting from Agriculture (developed during the workshop breakout group session)

Several topics were raised to address the question of Impact, or changes in services provided by the affected ecosystems. These included agriculture and fisheries (food provision); provision of drinking water and future pharmaceuticals; shoreline protection, flood protection and coastal property values; and tourism, recreation and the aesthetic value of the environment. Some ecosystem services were aggregated into broader concepts during the discussion, such as human wellbeing (cultural identity and mental health [peace of mind] created by aesthetic values of nature and sense of stewardship from ecological integrity) and economics (increased production efficiency created by higher productivity and lower costs in a shorter period of time).

A consequence of the discussion was not only a more complex map (**Fig. 3-13**) but also a better understanding of how ecosystems benefit humans socially, economically and spiritually. Unfortunately, there was insufficient time in the breakout session to discuss Drivers and additional Response topics, but additional information from later discussions (**Table 3-1**) were included in the final Agricultural Practices conceptual map (**Fig. 3-14**).

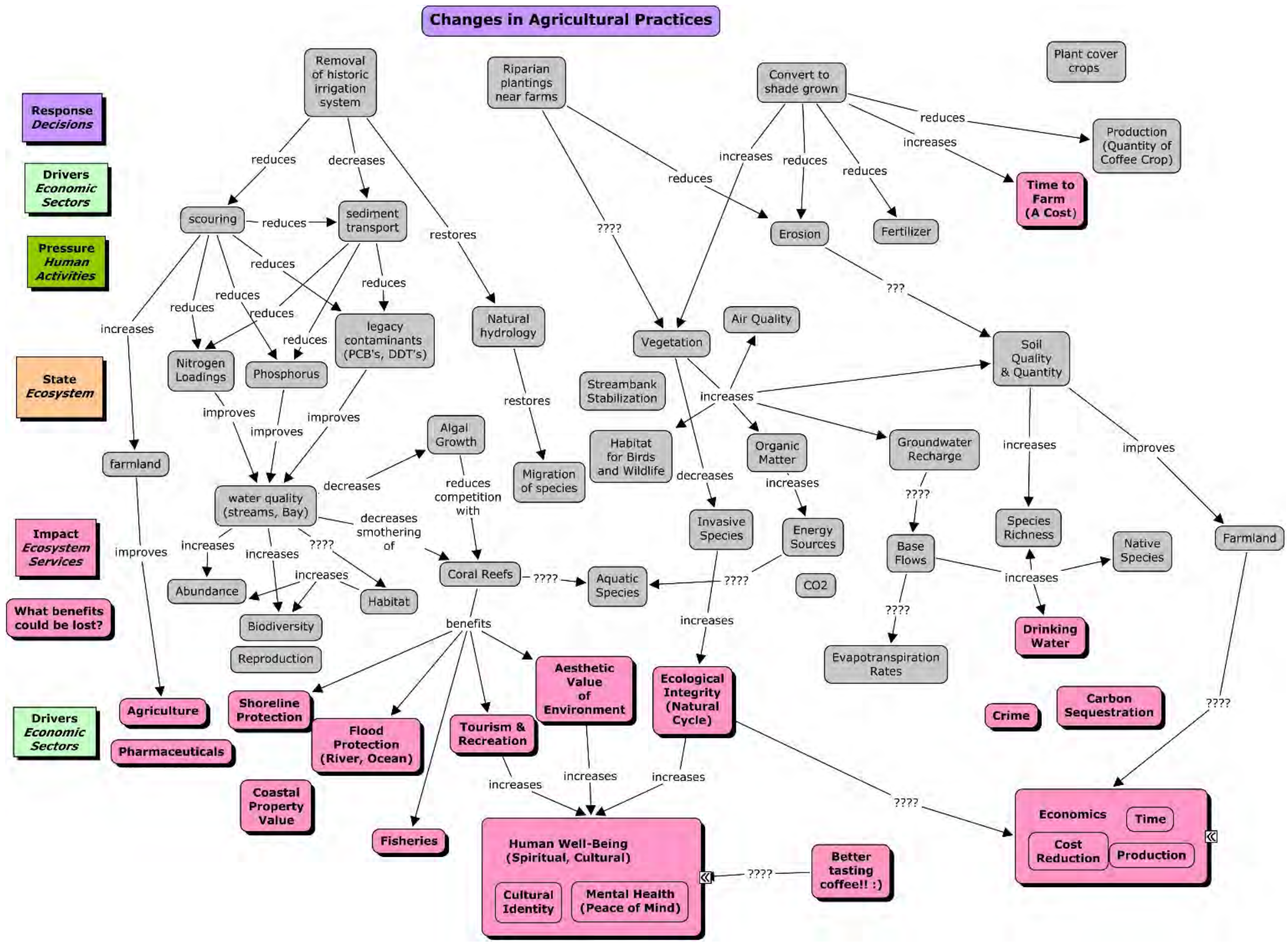

Figure 3-13. Ecosystem services (Impact) associated with changes in Ecosystem State (identified during the Agricultural Practices breakout group session)

The group did not have time to discuss the Drivers, or to brainstorm additional Responses.
By the end of the breakout group session, the group had produced a basic DPSIR for Agricultural Practices in the Guánica Bay Watershed.

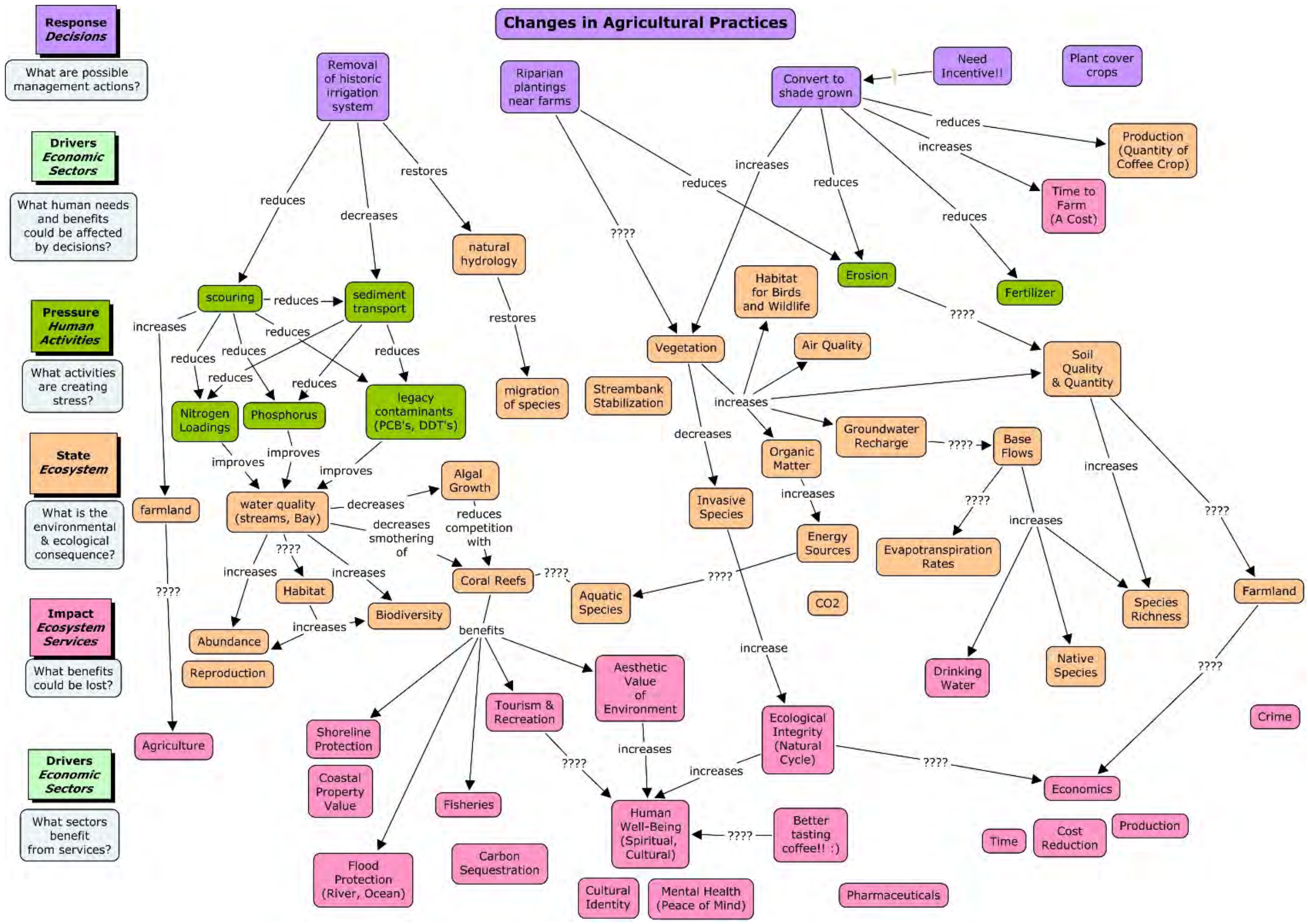

Figure 3-14. Final Agricultural Practices DPSIR (developed during the breakout group session)

Additional discussions not reflected in the DPSIR were captured on a flipchart (**Table 3-1**), and were incorporated into the final consolidated DPSIR for the Guánica Bay Watershed (**Figs. 3-28a and b,** see pages 55 and 56).

Table 3-1. Topics captured on the flipchart but not included in the basic Agricultural Practices DPSIR

Coral Reef State	Terrestrial State	Shoreline Protection	Other Ecosystem Services	Shade-Grown Coffee
Migration of species	Habitat for birds/wildlife	Property values	Spiritual	Less disease
Deep hydrology	Soil quality	Flood protection	Cultural	Less pesticides
Reproduction	Invasive species		Aesthetic	Less nutrients
Biodiversity			Improve air quality	Base flows
Algal growth				Groundwater discharge
Coral abundance				Better coffee
Coral mortality				Increased vegetation
CO_2N_2 fixation				Species richness/native species
				Drinking water
				Stewardship
				Less coffee/higher value

3.2.2 Lagoon Restoration

The restoration of the historic Guánica Lagoon is identified as the top priority management action in the Guánica Bay Watershed Management Plan. Ms. Kelly Black (Neptune and Company, Inc.) facilitated the Agricultural Practices DPSIR breakout group, and Ms. Leah Oliver (EPA) was the Cmap note-taker.

Restoration of the lagoon includes three major actions: reconnecting the historical Rio Loco watershed and floodplain with the Guánica Lagoon; restoring the wetland vegetation in the lagoon; and establishing long-term monitoring of the water discharge rates from Lago Loco to ensure sustainable flow rates for the Guánica Lagoon and the and Rio Loco. The group began with the DPSIR template for the Lagoon Restoration Management Actions that were proposed in the Guánica Bay Watershed Management Plan (**Fig. 3-15**).

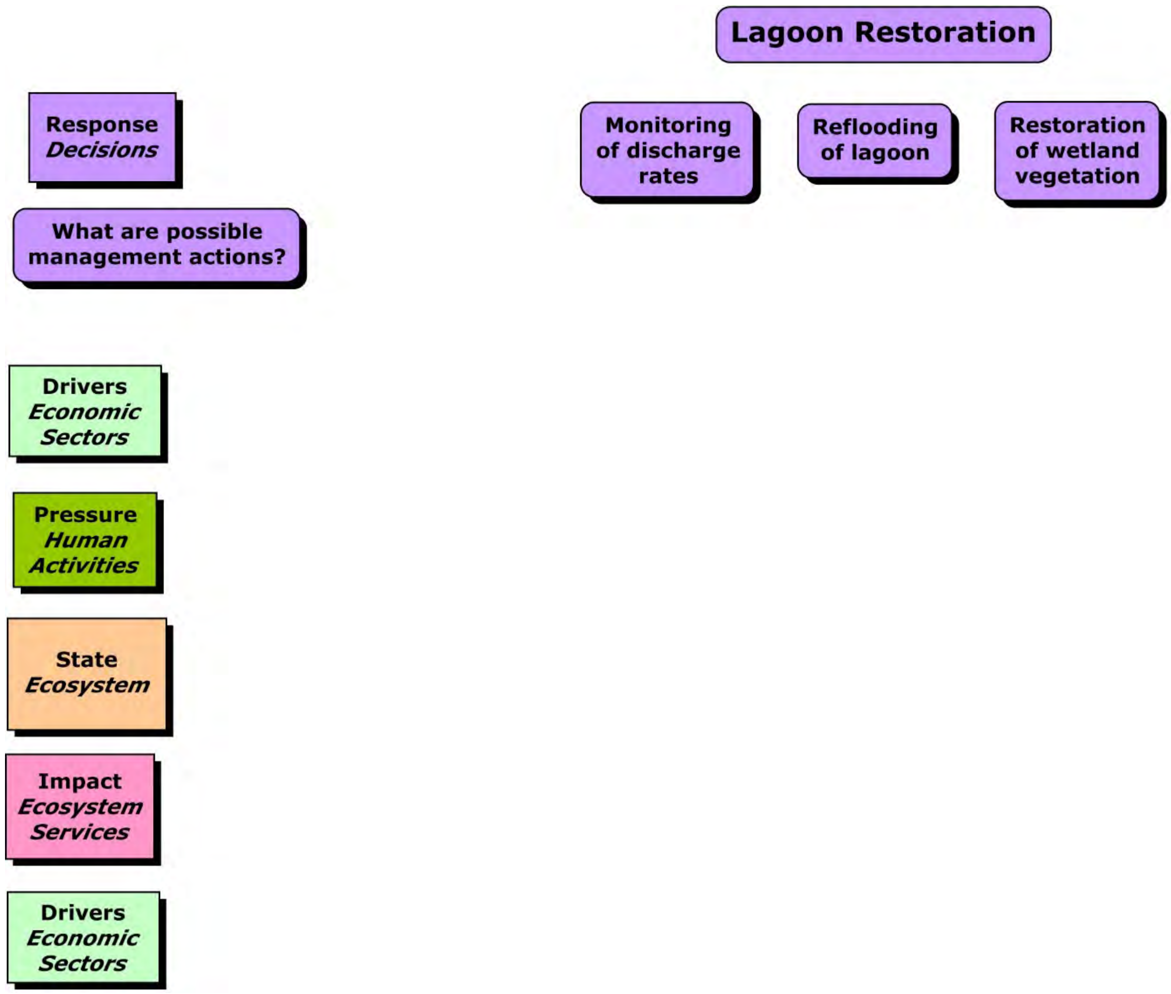

Figure 3-15. DPSIR template for the Lagoon Restoration breakout group

The facilitator asked a series of questions to facilitate the development of the DPSIR Cmap. The first two questions focused on the Pressures.

- Why is this management action proposed?
- What Pressures or human activities is it intended to reduce?

The group identified two main categories of pressures (non-point source pollution and development/construction) (**Fig. 3-16**).

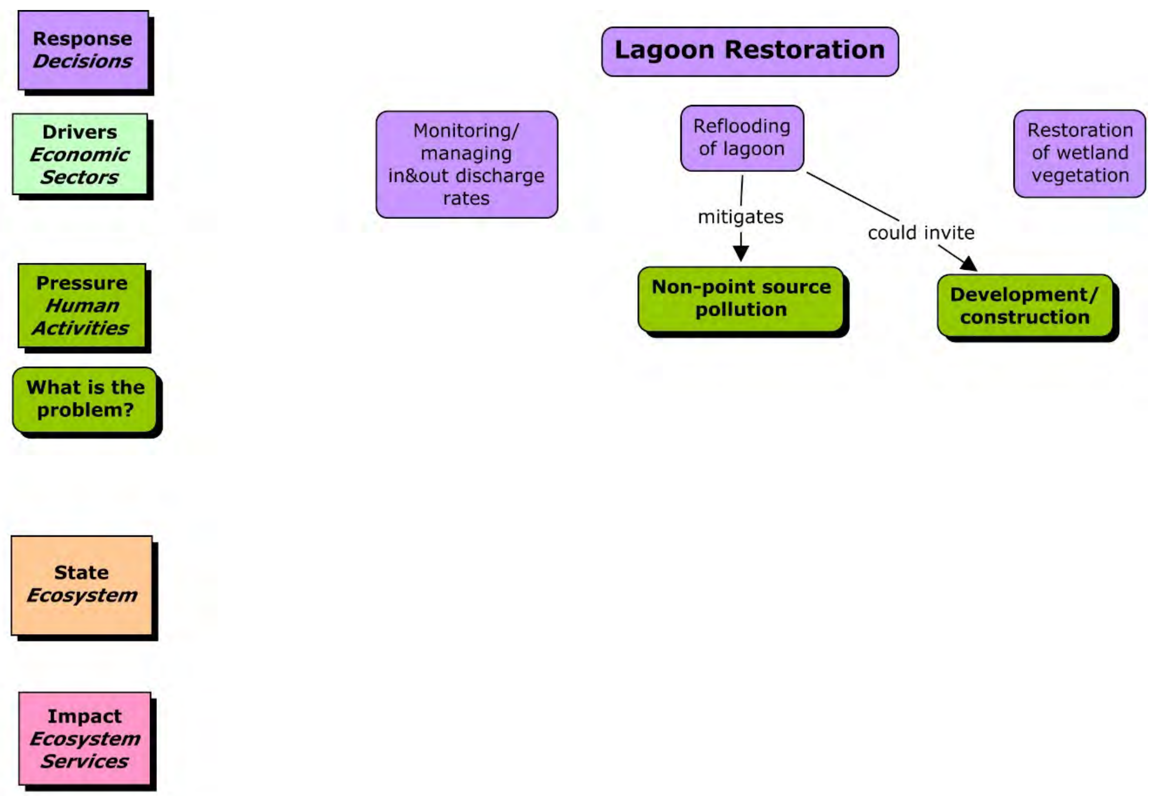

Figure 3-16. Pressures associated with the loss of the Guánica Lagoon (developed during the DPSIR breakout session)

The next question focused on the Abiotic and Biotic State.

- What affect do these Pressures or human activities have on the State of the ecosystem, Abiotic and Biotic?

The group identified some changes in environmental State, such as clean water, sediment, water quality, and spatial distribution of water (**Fig. 3-17**), and several changes in ecological State, including effects on biota (birds, mangroves, oysters, coral reefs, sea grass, fish, food crops and wetland vegetation). One participant identified a change in mosquito populations related to reflooding of the Lagoon. This is important because the community of Fuig has grown closer to the Lagoon footprint since it was drained, and mosquito-borne dengue fever is a human health threat in Puerto Rico.

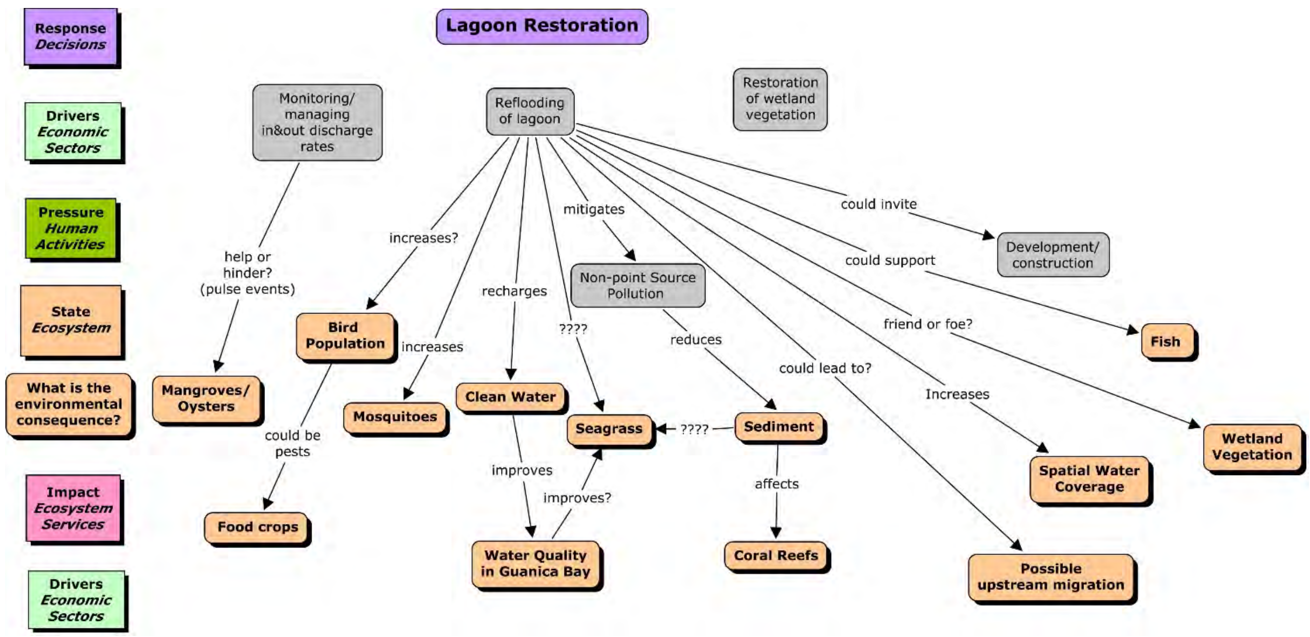

Figure 3-17. Changes in Ecosystem State resulting from Pressures generated by restoration of the Guánica Lagoon (developed during the workshop breakout group session)

The facilitator next asked about the Impact or ecosystem services provided by the ecosystem.

- What are the Impact on benefits to humans provided by the ecosystem?
- Why should we care about the State of reefs?

The group identified Impact as changes in food, jobs and income (from changes in food crops and fish production); changes in biodiversity and marine fisheries (from changes in water quality), and changes in tourism (from changes in bird populations). The group also identified some of the Drivers (economic sectors) that would be affected, including agriculture, land ownership (real estate) and potential housing development (**Fig. 3-18**). One suggestion was that the aquaculture sector would benefit from a restored lagoon.

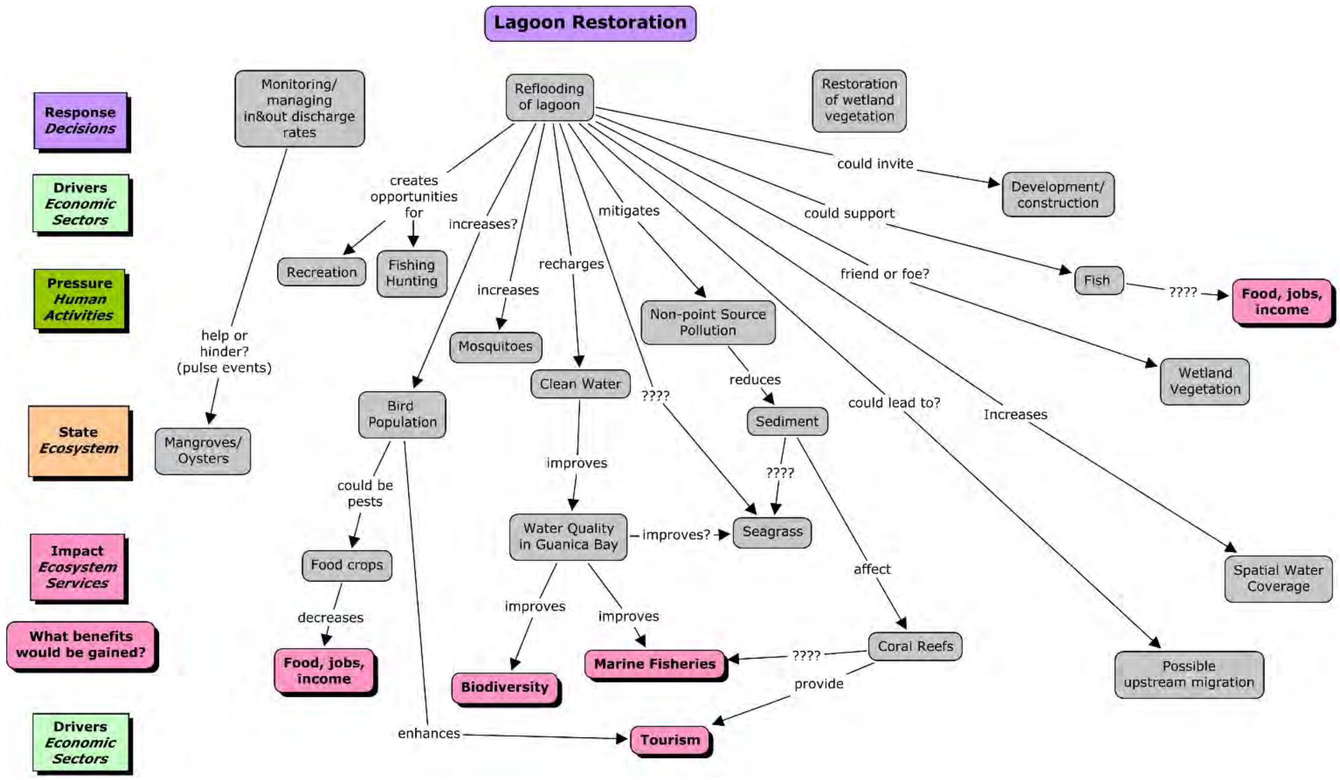

Figure 3-18. Ecosystem services associated with Ecosystem State (developed during the Lagoon Restoration breakout group session)

The group then discussed the Drivers, or socio-economic sectors, and how the Drivers either benefit from the ecosystem services or are affected by any decisions.

- What social or economic sectors (Drivers) benefit from ecosystem services?
- What sectors could be affected by any decisions (Drivers)?

Socio-economic sectors that could be affected include agriculture, aquaculture, housing, land ownership, and tourism and recreation (**Fig. 3-19**).

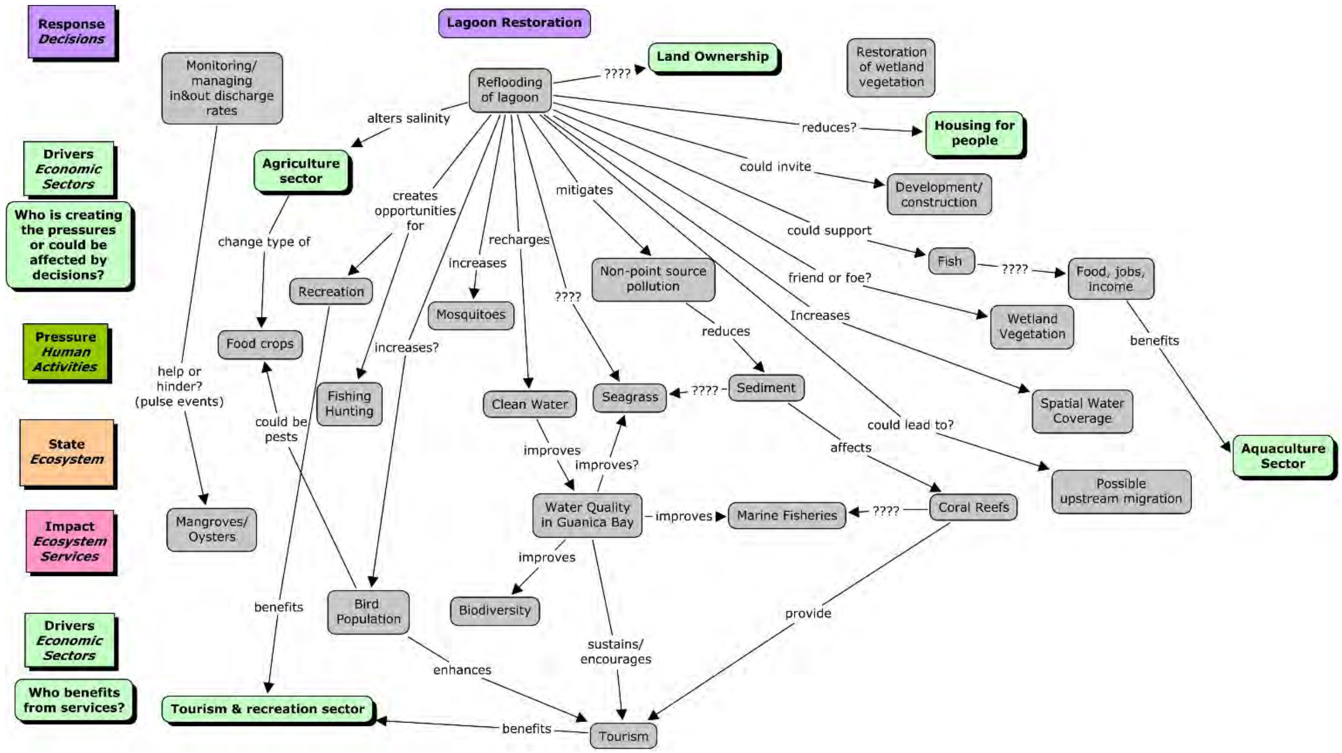

Figure 3-19. Socio-economic sectors (Drivers) that benefit from ecosystem services or are impacted by management actions relating to restoration of the historic Guánica Lagoon (developed during the breakout group session)

By the end of the breakout group session, the group had produced a basic DPSIR for the restoration of the historic Guánica Lagoon (**Fig. 3-20**).

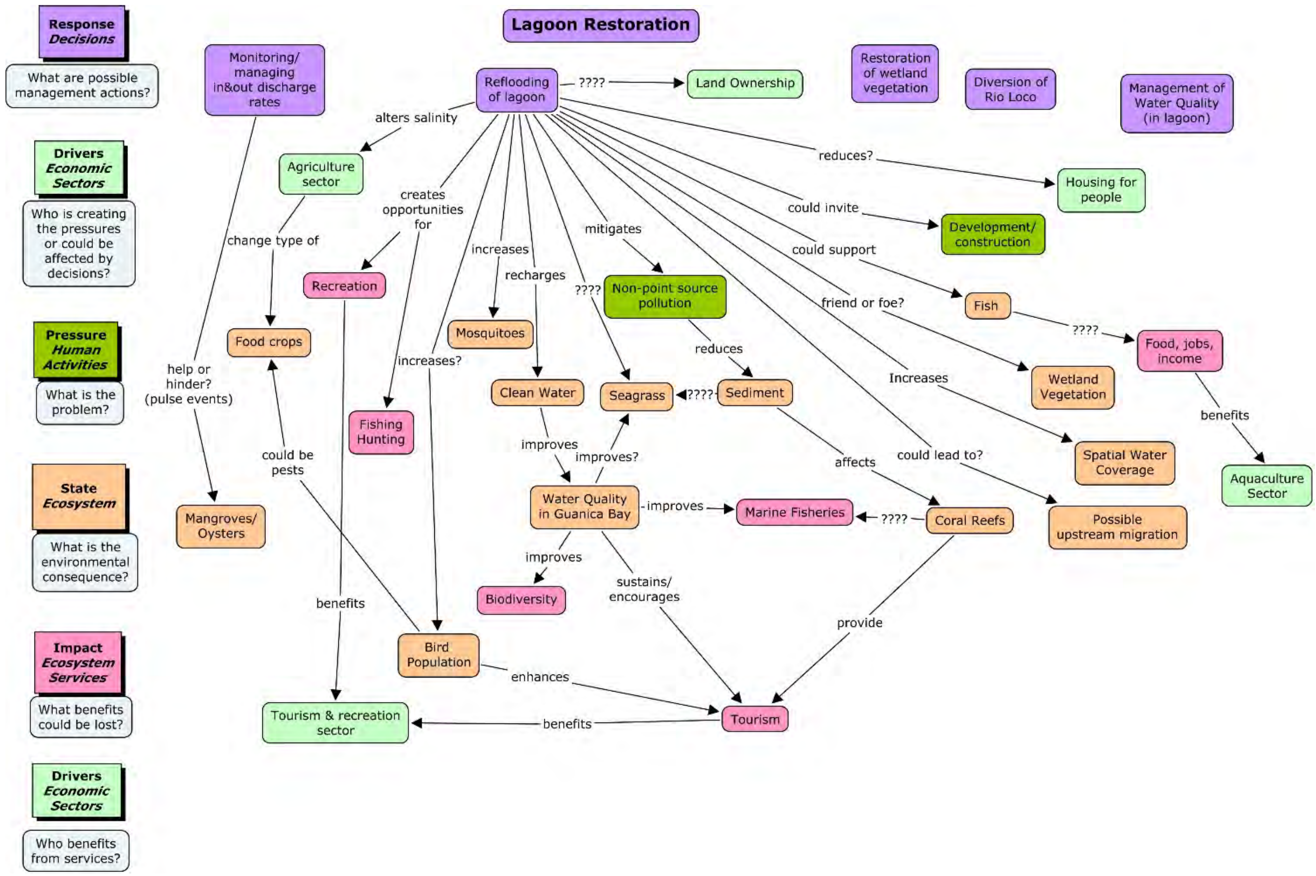

Figure 3-20. Final Guánica Lagoon restoration DPSIR (developed during the breakout group session)

The breakout group discussion focused mainly on how the lagoon restoration would impact the coral reef ecosystem (corals, fishes and seagrasses). However, there was also some discussion about the costs and benefits of a restored wetland. These were not reflected in the DPSIR concept map constructed during the workshop but were captured on a flipchart (**Table 3-2**) for incorporation into the final consolidated DPSIR for the Guánica Bay Watershed (**Figs. 3-28a and b,** see pages 55 and 56).

Table 3-2. Topics captured on the flipchart but not necessarily included in the basic Lagoon Restoration DPSIR

Wetland (Lagoon) Ecology	Wetland (Lagoon) Ecosystem Services	Other Management Actions (Responses)	Local Community Issues
Pulse events (tropical storms & water releases)	Recreational Fishing	Lagoon as an ecological reserve	Housing
Wetland plants (Cattail)	Recreation – Bird watching	Management plan for the lagoon	Mosquitoes
Retention time	Recreational boating	Manage wetland vegetation	Flooding (FEMA)
Birds	Hunting	Permits	
Non-native species (caimans, tilapia)		Research (WQ, pulse event)	
Invertebrates (shrimp, crabs)			
Diversion of Rio Loco			

3.2.3 Low Impact Development

Low Impact Development (LID) is an approach for land development that attempts to work with nature to manage stormwater runoff as close to its source as possible (EPA 2012). LID principles include preserving and recreating natural landscape features and minimizing impervious surfaces. LID can maintain or restore a watershed's hydrologic and ecological functions and has been adapted to a range of land uses from high-density ultra-urban settings to low-density development.

The Guánica Bay Watershed Management Plan (CWP 2008) recommended several approaches to more effectively manage wastewater. A high priority action was a demonstration project to construct a series of treatment wetlands at the Guánica wastewater treatment plant (WWTP) to reduce nutrients from secondary effluent before being discharged into Guánica Bay. Other related actions included rainwater collection systems, stormwater runoff treatment centers, hydro-seeding of erodible land, and enactment and enforcement of pet waste ordinances.

Ms. Deb Caraco (CWP) facilitated the Low Impact Development DPSIR breakout group and Dr. Tom Stockton (Neptune and Company, Inc.) was the note-taker.

The group began with the DPSIR template for the LID Management Actions that were proposed in the Guánica Bay Watershed Management Plan (**Fig. 3-21**).

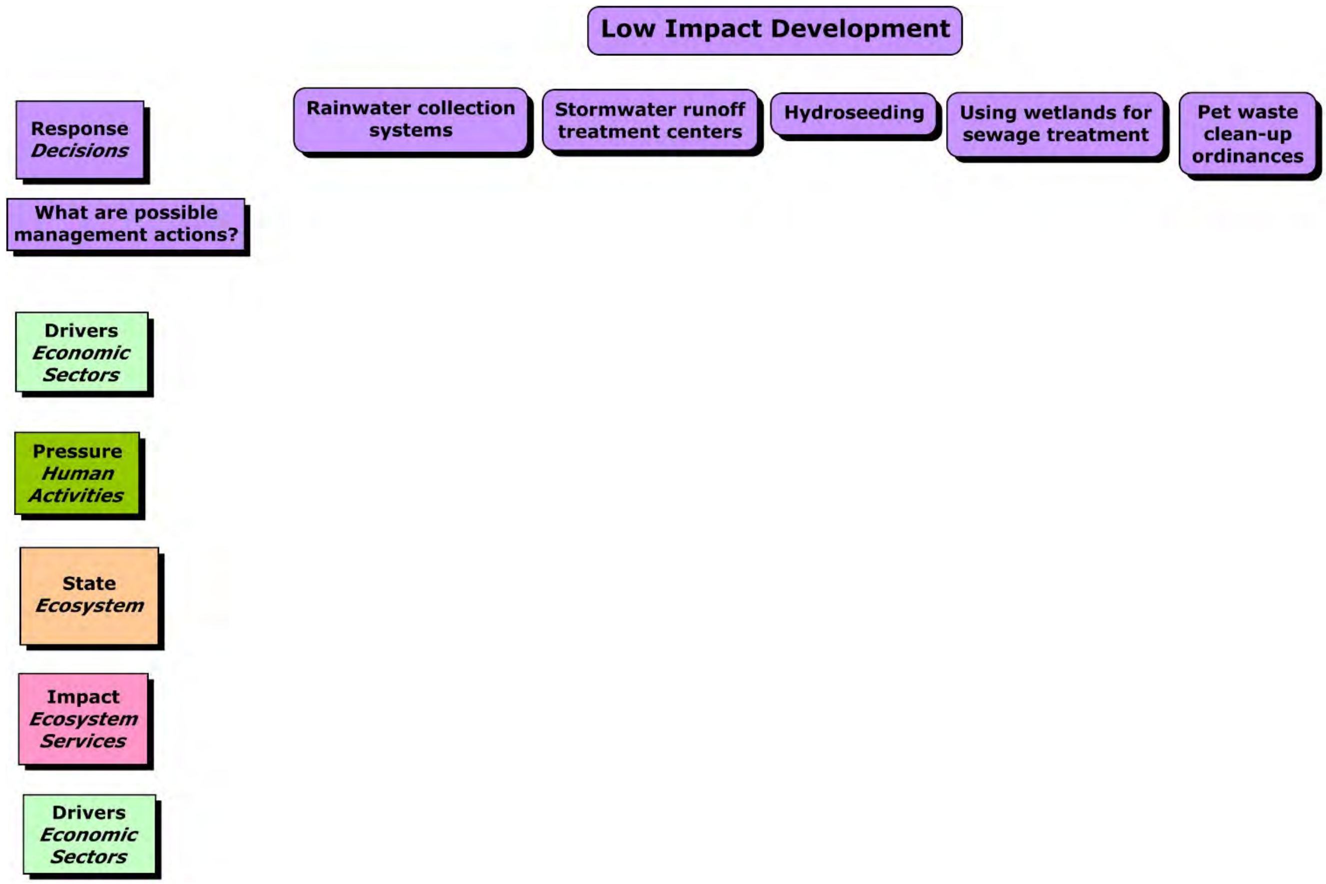

Figure 3-21. DPSIR template for the LID breakout group

The facilitator asked a series of questions to facilitate the development of the DPSIR Cmap. The first questions focused on the Pressures.

- Why is this management action proposed?
- What Pressures or human activities is it intended to reduce?

The group identified several Pressures related to rainwater collection systems and stormwater runoff treatment centers, including changes in irrigation needs and practices, bank erosion, land erosion and flooding (**Fig. 3-22**).

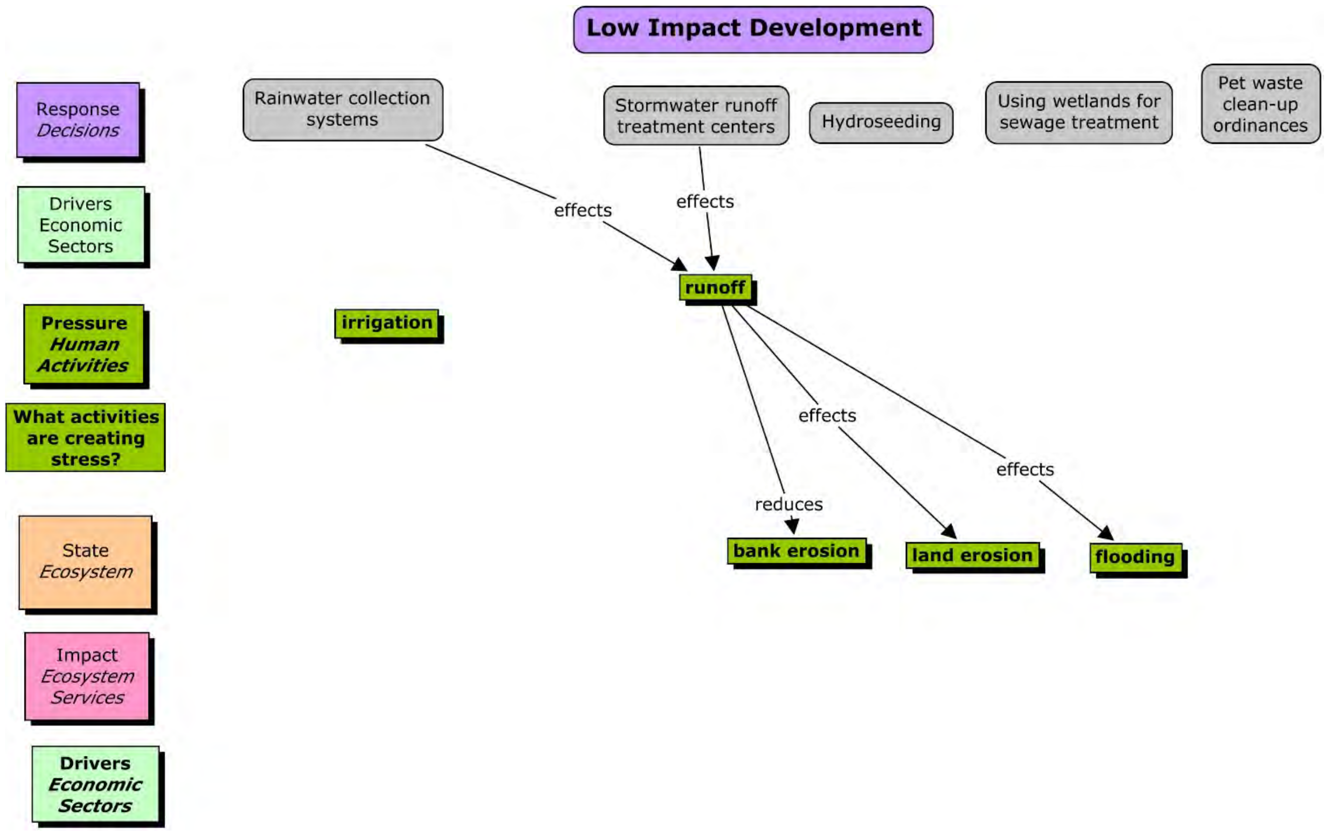

Figure 3-22. Pressures that can be mitigated with LID (developed during the DPSIR breakout session)

The next question focused on the Abiotic and Biotic State.

- What affect do these Pressures or human activities have on the State of the ecosystem, Abiotic and Biotic?

From these Pressures the group recognized several changes in environmental State, including changes to sediment runoff and filling of reservoirs, contaminants and nutrients, water turbidity, groundwater volume and recharge, and sedimentation in the Bay and reef zone. These changes were expected to lead to changes in Ecosystem State, such as effects on phytoplankton, mangroves, coral reefs and reef fish (**Fig. 3-23**).

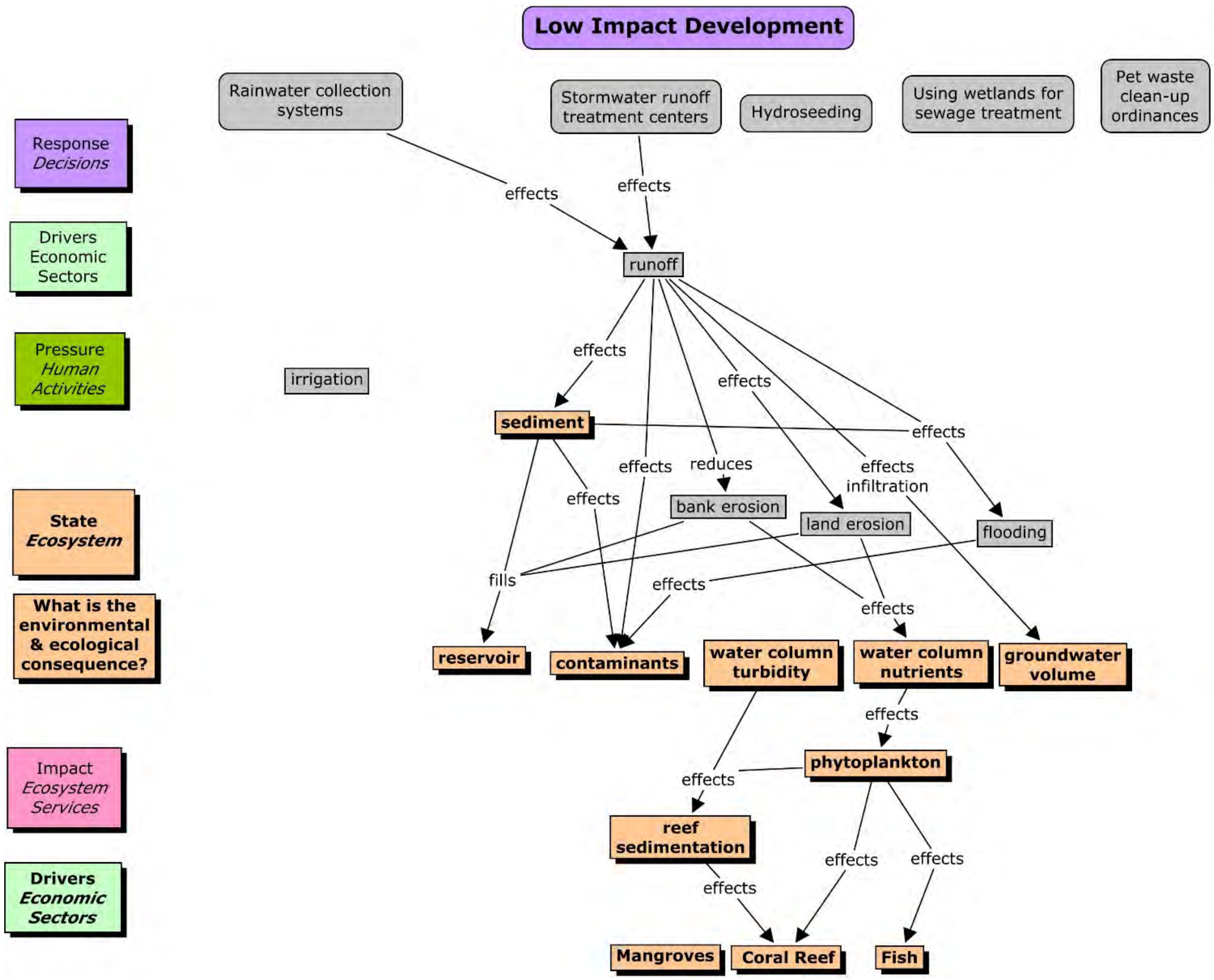

Figure 3-23. Changes in environmental and Ecosystem State possible from LID (developed during the workshop breakout group session)

The facilitator next asked about the Impact, or ecosystem services provided by the ecosystem.

- What are the Impact on benefits to humans provided by the ecosystem?
- Why should we care about the State of reefs?

The ecosystem services (Impact) that could be affected from rainwater collection programs and stormwater treatment centers were flood control, shoreline protection, water supply and recreation (**Fig. 3-24**).

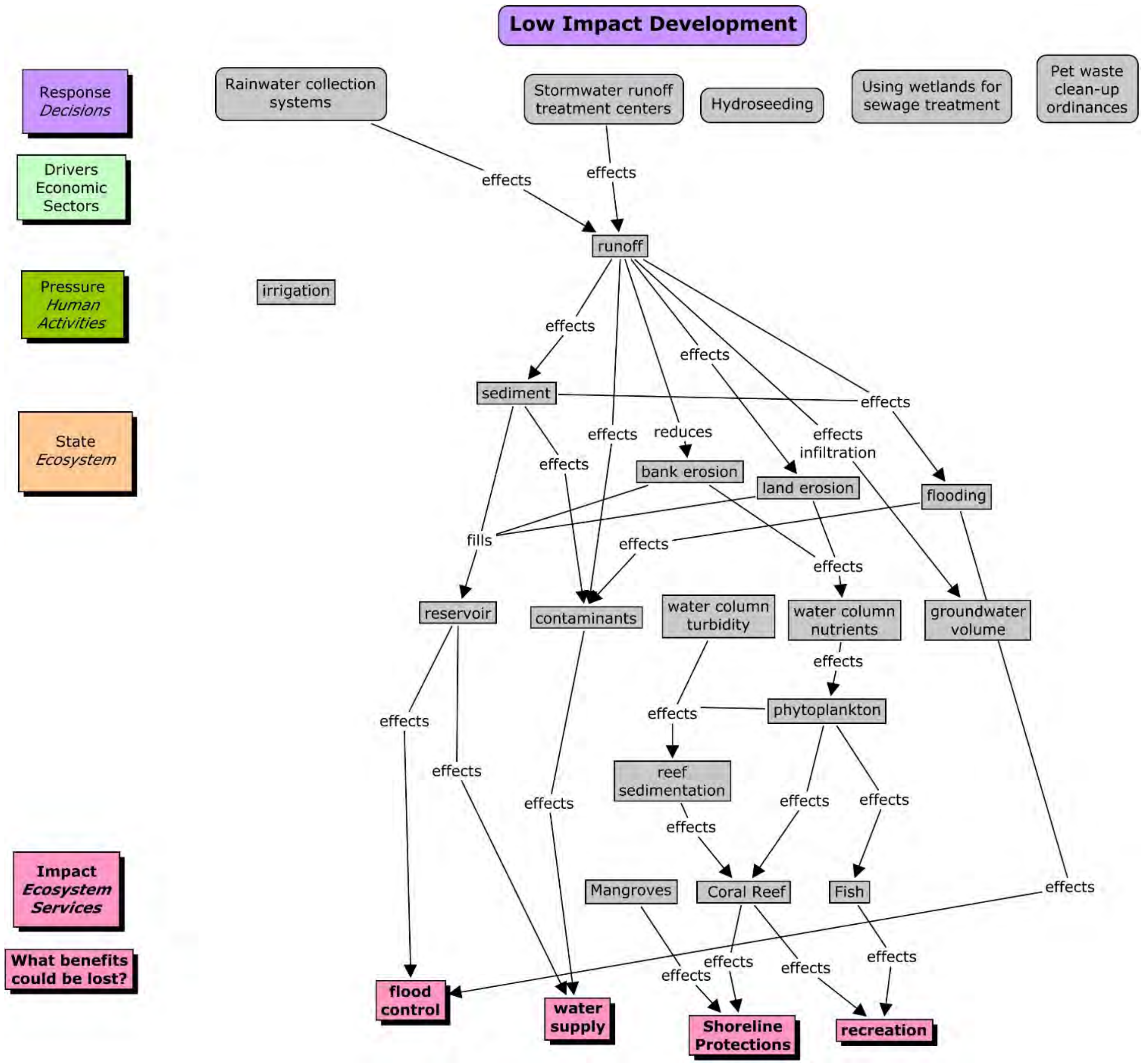

Figure 3-24. Ecosystem services associated with Ecosystem State (developed during the LID breakout group session)

The group then discussed the Drivers, or socio-economic sectors, and how the Drivers either benefit from the ecosystem services or are affected by any decisions.

- What social or economic sectors (Drivers) benefit from ecosystem services?
- What sectors could be affected by any decisions (Drivers)?

The group identified the following Drivers: land development, agriculture, human safety, tourism and water supply (**Fig. 3-25**).

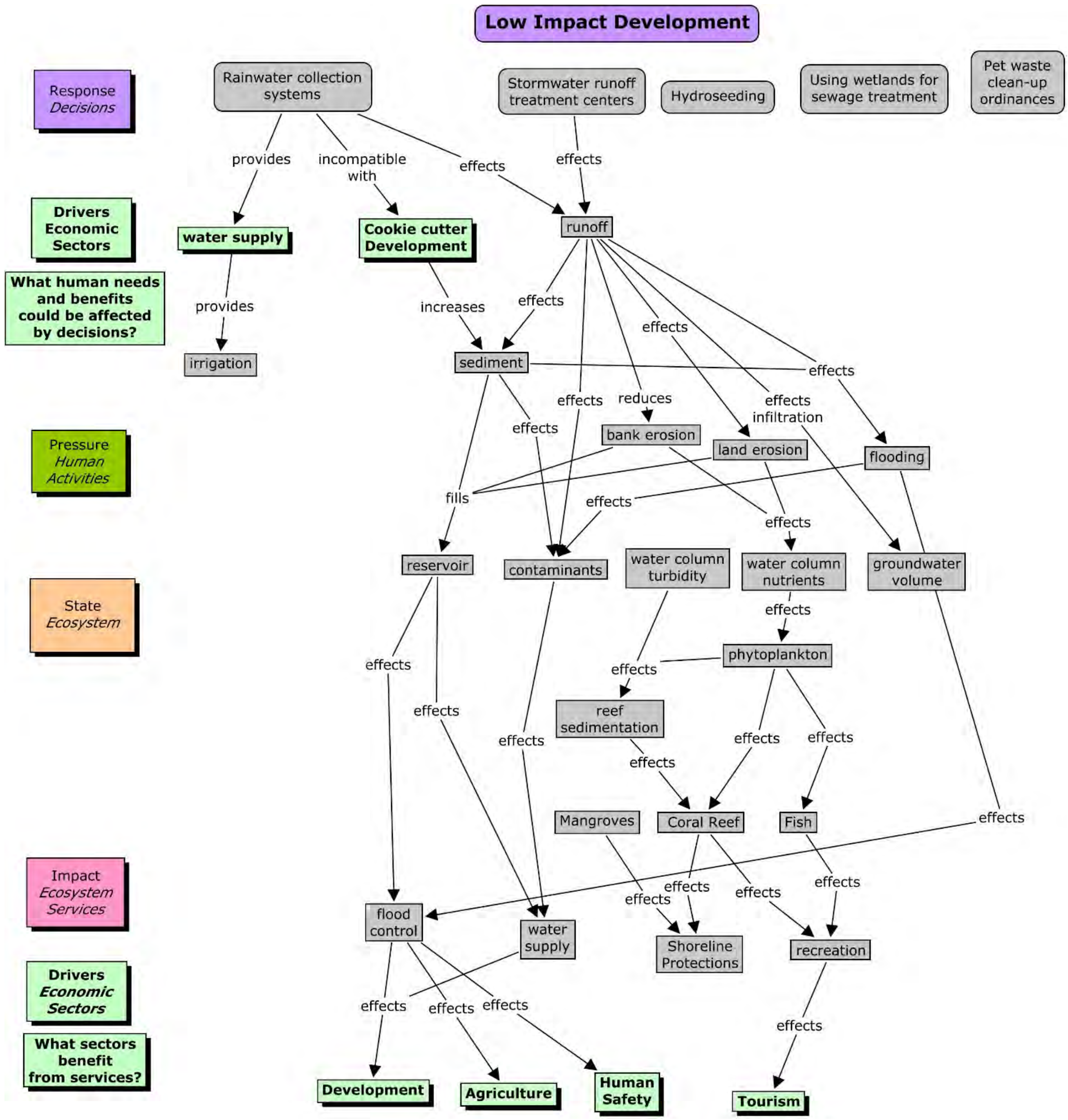

Figure 3-25. Socio-economic sectors (Drivers) that benefit from ecosystem services or are impacted by LID (developed during the breakout group session)

The facilitator guided the group to complete the DPSIR concept map by brainstorming additional decision points where something else could change a Driver, Pressure, State or Impact. These responses were then placed into the map at the appropriate decision point (**Fig. 3-26**).

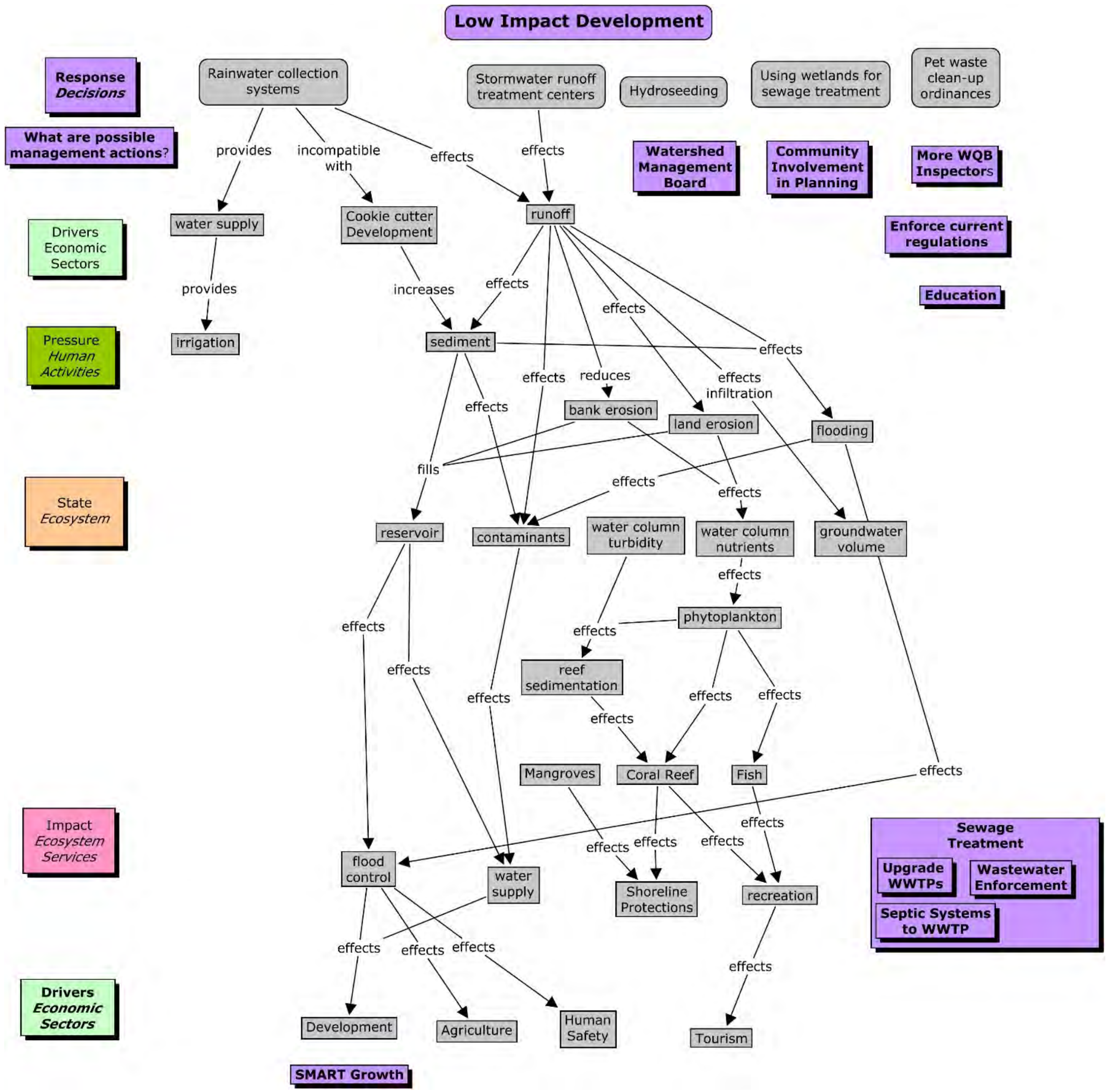

Figure 3-26. Additional decision points and management actions not identified in the Guánica Bay Watershed Management Plan that relate to LID

By the end of the breakout group session, the group had produced a basic DPSIR for LID in the Guánica Bay Watershed (**Fig. 3-27**).

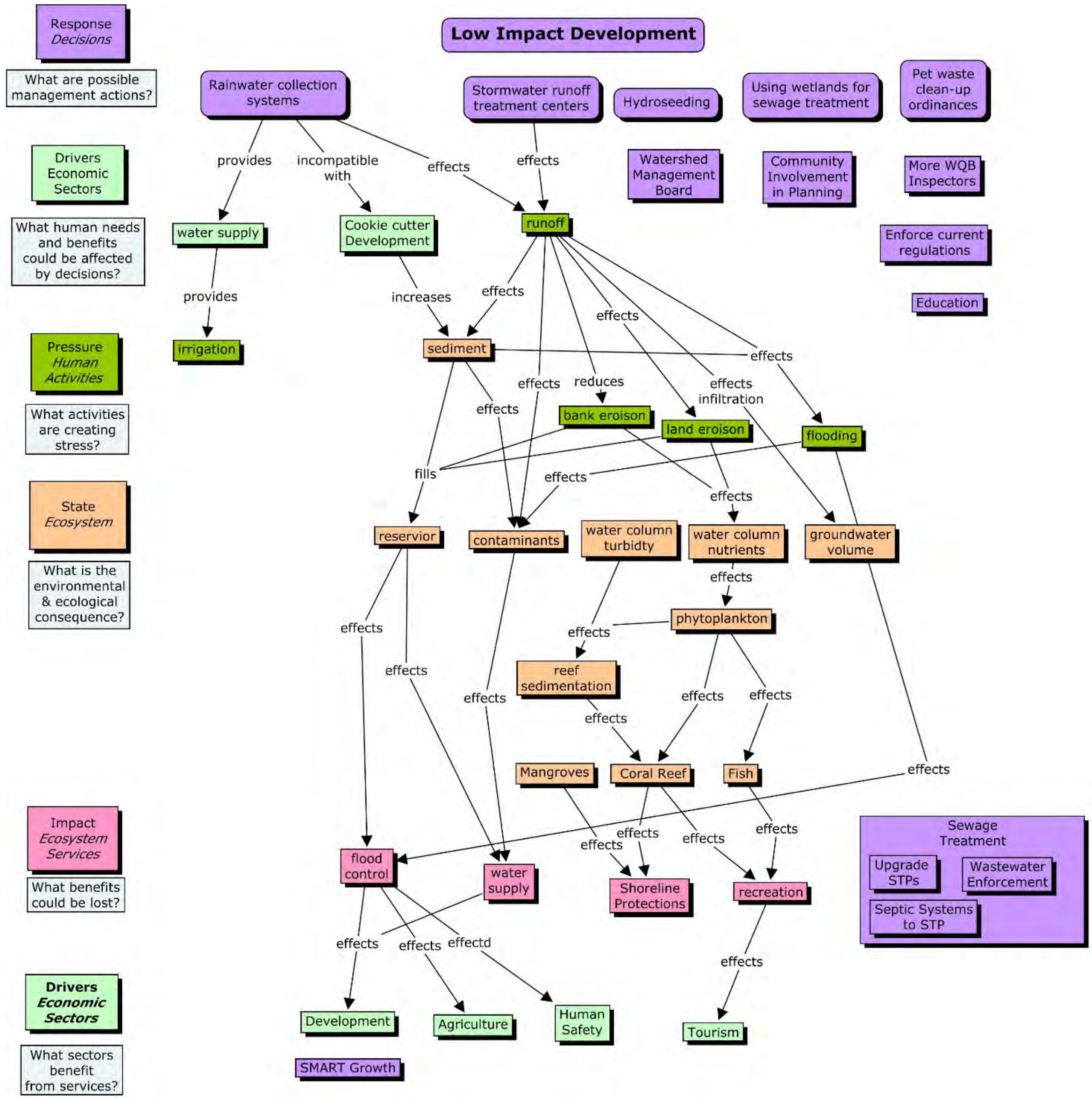

Figure 3-27. Final DPSIR (developed during the LID breakout group session)

The group focused largely on stormwater and those discussions were captured fairly well in the DPSIR concept map. Wastewater was also discussed but not reflected in the concept map that was developed during the breakout session. However, this discussion was captured on a flipchart (**Table 3-3**), and was incorporated into the final consolidated DPSIR for the Guánica Bay Watershed (**Figs. 3-28a and b,** see pages 55 and 56).

Table 3-3. Topics captured on the flipchart but not necessarily included in the basic LID DPSIR

LID		Wastewater				
Issues	**Management Actions**	**Issues**	**Management Actions**	**Ecosystems**	**Reservoirs**	**Human health & well-being**
Landfills	Pervious parking lots	Septic and unsewered wastes	Education and outreach	Sediment in rivers	Sediment from development	Flooding (mold, contaminants, safety)
Less stress on water supply	Revise codes to allow rooftop capture	Can have non-PRASA outside of network	Enforce regulations (inspectors)	Turbidity	Reduced water supply	Chemical spill in Bay in 1979
	Centralize infrastructure when possible		Watershed board or mgmt. group	Reef sedimentation		
	Education & outreach			Mangroves (services & restoration)		
	Smart growth policies			Sea grass beds		
	Enforce regulations (inspectors)					
	Research					

3.3 Guánica Bay Watersheds DPSIR

Each breakout group presented their DPSIR concept map when the participants regrouped. There was additional discussion about the lagoon restoration, particularly about how the flooding of the lagoon might impact existing farms (e.g., salinity and production). There was also discussion about the fact that once a decision has been made and implemented, like the decision in the 1950s to drain the lagoon, it becomes politically difficult to reverse the decision.

Participants overall appreciated the DPSIR breakout session.

- They articulated the need for a holistic, integrated decision-making framework, like the DPSIR systems approach, for the entire watershed.
- There have been numerous studies that provide data and information, but these are not organized in a coordinated system. The studies could, however, have been organized around the DPSIR framework to provide more transparency and utility.
- The Guánica Bay watershed is a complex system for which any decision will have trade-offs. The DPSIR systems approach can help to identify potential trade-offs.
- There is a need to focus on benefits and not just costs of environmental protection. The DPSIR framework can help with this.
- Construction of a DPSIR can begin at any point by asking a series of simple questions.

Subsequent to the workshop, EPA developed the ReefLink Database, which is now available on the web at: http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=242306. This database is built around a generic coral reef DPSIR. The ReefLink Database provides a navigable hierarchy of related topics and information for each topic including concept maps, scientific citations, management options, and laws related to coral reefs. DPSIR definitions are provided in a glossary that will resolve terminology issues.

The three DPSIRs and the information from the discussions were used to develop a DPSIR for Guánica (**Figs. 3-28a and b**).

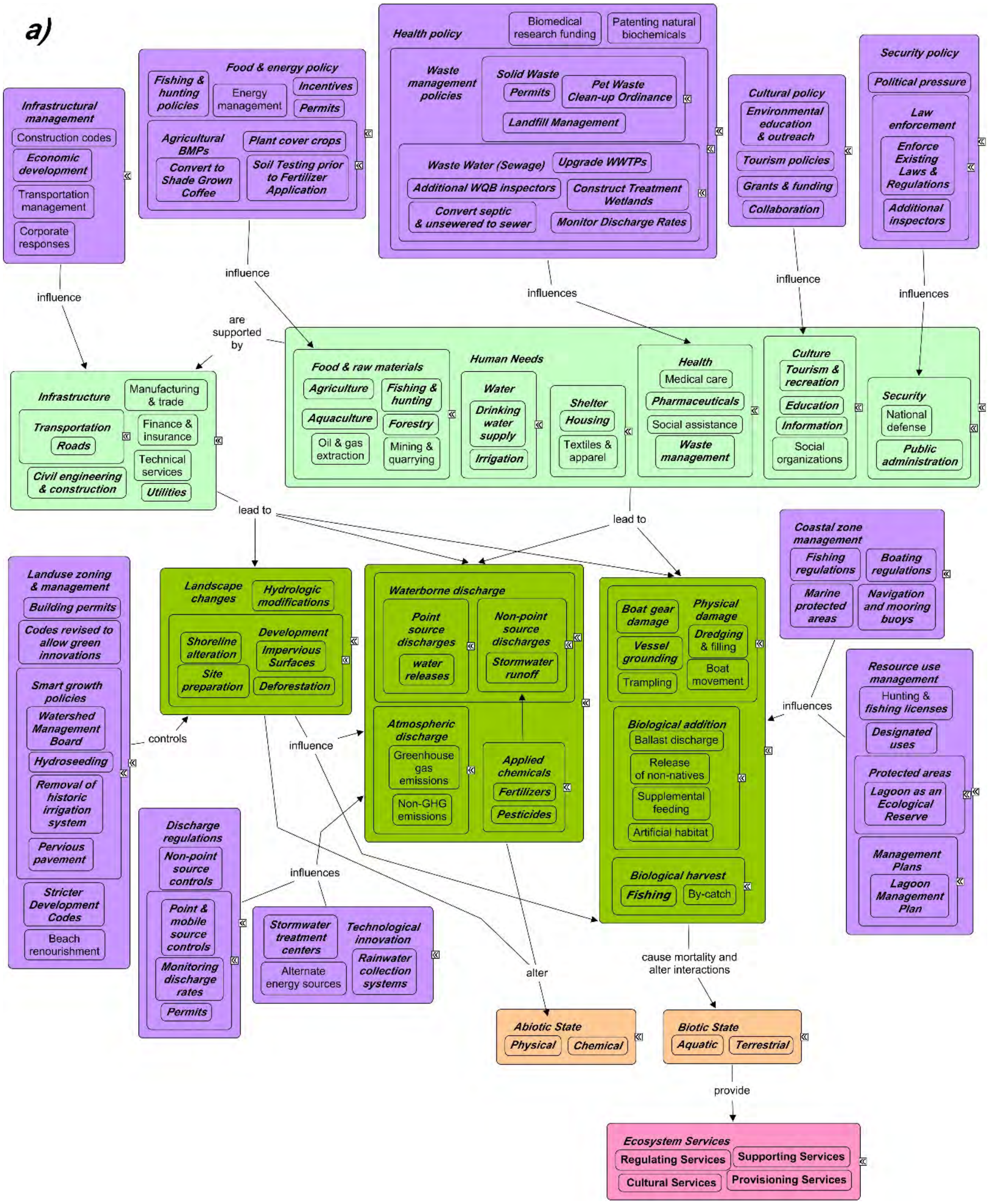

Figure 3-28a. Guánica-specific DPSIR concept map developed by EPA based upon information from the Decision-support Workshop, showing details for Drivers, Pressures, and Responses to each (source Bradley et al. 2013). Boxes are color-coded to follow the scheme used in Figure 3-9 (e.g., light green=Driving forces; dark green=Pressures; orange=State; pink=Impacts; and purple=Responses)

The nodes presented here link with those in **Fig. 3-28b**.

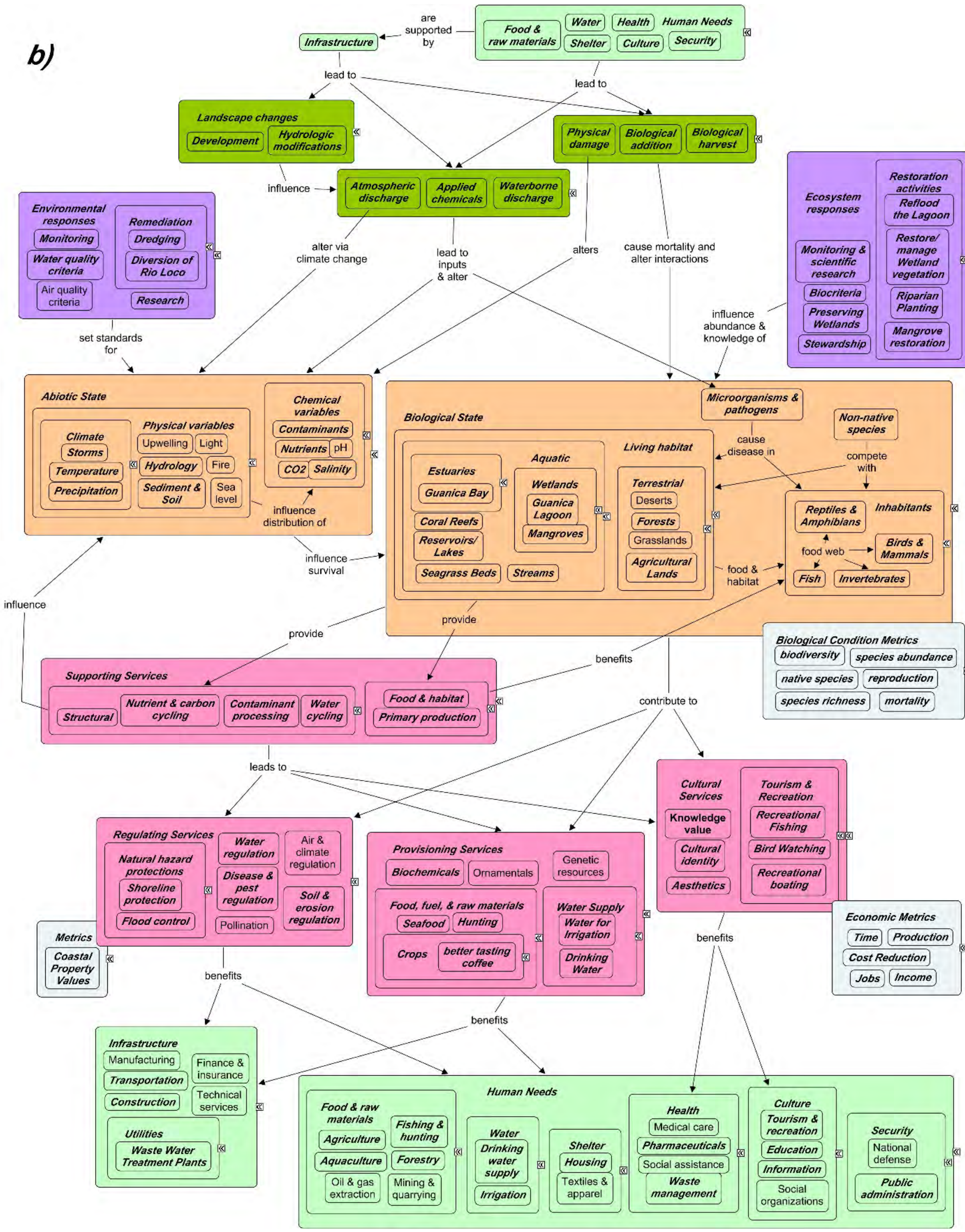

Figure 3-28b. Guánica-specific DPSIR concept map developed by EPA based upon information from the Decision-support Workshop, showing details for State, Impact, and benefits to Drivers (source Bradley et al. 2013). Boxes are color-coded to follow the scheme used in Figure 3-9 (e.g., light green=Driving forces; dark green=Pressures; orange=State; pink=Impacts; and purple=Responses)

Chapter 4. A Decision-Analysis Framework for Coastal Watersheds

The second day of the workshop was designed to introduce the concepts of decision analysis and walk through the first three steps of the decision support framework for science-based ecosystem services assessment and multi-stakeholder deliberation. To initiate the topic, 'homework' from the first day was presented and discussed by participants (Section 4.1, below). This was followed by small group discussions throughout the day, interspersed with presentations on related topics. These included presentations on social network analysis, uncertainty and the value of information, adaptive management and a decision support tool that uses a structured decision analysis framework. In the afternoon, there were three breakout groups focused on different types of decisions–permitting and enforcement decisions, natural resource decisions, and scientific support. A summary of the homework results, presentations and breakout group deliberations is provided below.

4.1 Homework Assignment

At the end of the first day, participants had been asked to write down the top 2-3 objectives for coastal ecosystem health of their organization or constituents and possible measurable endpoints. A summary of these follows:

Objectives

- Land-use planning
- Environmentally sensitive development
- Soil conservation and farm land quality
- Water quality
- Bay (H_2O and sediment)
- Inland
- Drinking
- Marine
- Law and regulation enforcement
- Community awareness/education
- Quality of life
- Recreation
- Aesthetics
- Economic well-being
- Fisheries
- Tourism
- Response to oil spills/boat groundings

Measurable Attributes:

- Coral ecosystem health
- Oyster egg count
- 3-dimensional coral cover
- Leaf area index
- Density of corals/seagrass/etc.
- Disease
    - Presence or absence
    - Extent
- Epibiont cover (seagrass)
- Sediment type and cover
- Reproduction (presence or absence)
    - Coral recruits (number of)
- Tissue Nitrogen levels
- Species (richness and abundance and size/age structure)
    - Coral (soft and hard)
    - Fish
    - Invertebrates
    - Algae
    - Seagrass
- Extent (spatial coverage); 7 acres = WAG at current status; (could research historical size of seagrass coverage–using sediment cores)

Participants also identified some possible goals for some of the measurable attributes:

- Percent increase in coverage
- Return to historical levels
- Sustainable queen conch habitat
- New/shifting species

4.2 Social Network Analysis

Ms. Patricia Bradley, Dr. Marilyn ten Brink & Dr. Tom Stockton (presenter)

Social Network Analysis (SNA) is a method to map and measure the relationships and interactions among people, groups, organizations, computers, URLs, and other connected information/ knowledge entities in order to identify knowledge flows (Krebs 2002). SNA has been used in business since the 1930s to improve production and organizational structure. It is a tool that can be used to support strategic collaboration, facilitate knowledge creation and transfer, and increase our capacity to manage ecosystems and resources.

SNA is: (1) guided by formal theory organized in mathematical terms, and (2) grounded in the systematic analysis of empirical data. SNA views social relationships and interactions in terms of network theory about nodes and links. The nodes in the network are the people and groups while the links show relationships or flows between the nodes (**Fig. 4-1**). SNA provides both a visual and a mathematical analysis of human relationships (Krebs 2008).

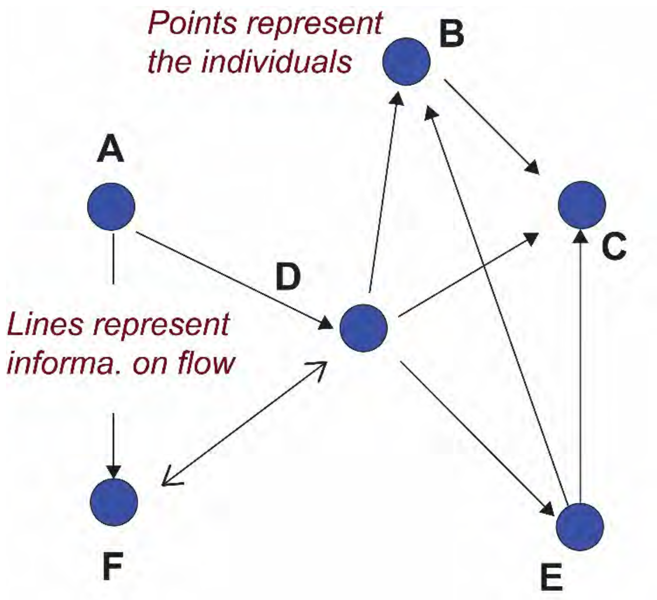

Figure 4-1. Social network analysis views social relationships and interactions in terms of network theory about nodes and links

To understand networks and their participants, SNA identities the *location of actors in the network*–who are the leaders, bridges, isolates, where are the clusters of actors and who is in them, who is in the core of the network, and who is on the periphery? SNA also identifies the *direction of information flow in the network*–who generates information, who receives information?

For this workshop, EPA demonstrated how SNA could help:

- Identify and support leadership functions and identify gaps
- Increase participation by reconnecting isolated teams or individuals
- Detect information bottlenecks
- Identify opportunities for improving the flow of knowledge
- Accelerate the flow of knowledge and information across functional and organizational boundaries
- Improve the effectiveness of formal communication channels
- Target opportunities through which increased knowledge flow will have the most impact
- Raise awareness of existing informal networks
- Identify types of information that are communicated or not

In a workshop exercise, participants were asked:

- With whom they communicated most frequently and second most frequently
- The topic of communication
- The importance of the communication (very, average, minor)
- The frequency with which they communicated (scale of 0-8, once a year to many times per day)
- The types of information they received from each person

An SNA software program (NodeXL) was used to provide mathematical and statistical routines for exploratory analysis and visualization of the network. NodeXL is a free and open network overview, discovery and exploration add-in for Excel 2007/2010 (Smith et al. 2010). The data were compiled into an Excel spreadsheet, and a clustering algorithm was run on the network. Individuals in the network were identified by their institution or role (**Fig. 4-2**). The thickness in arrows represents how often communication occurred (the thicker the arrow, the more often the communication).

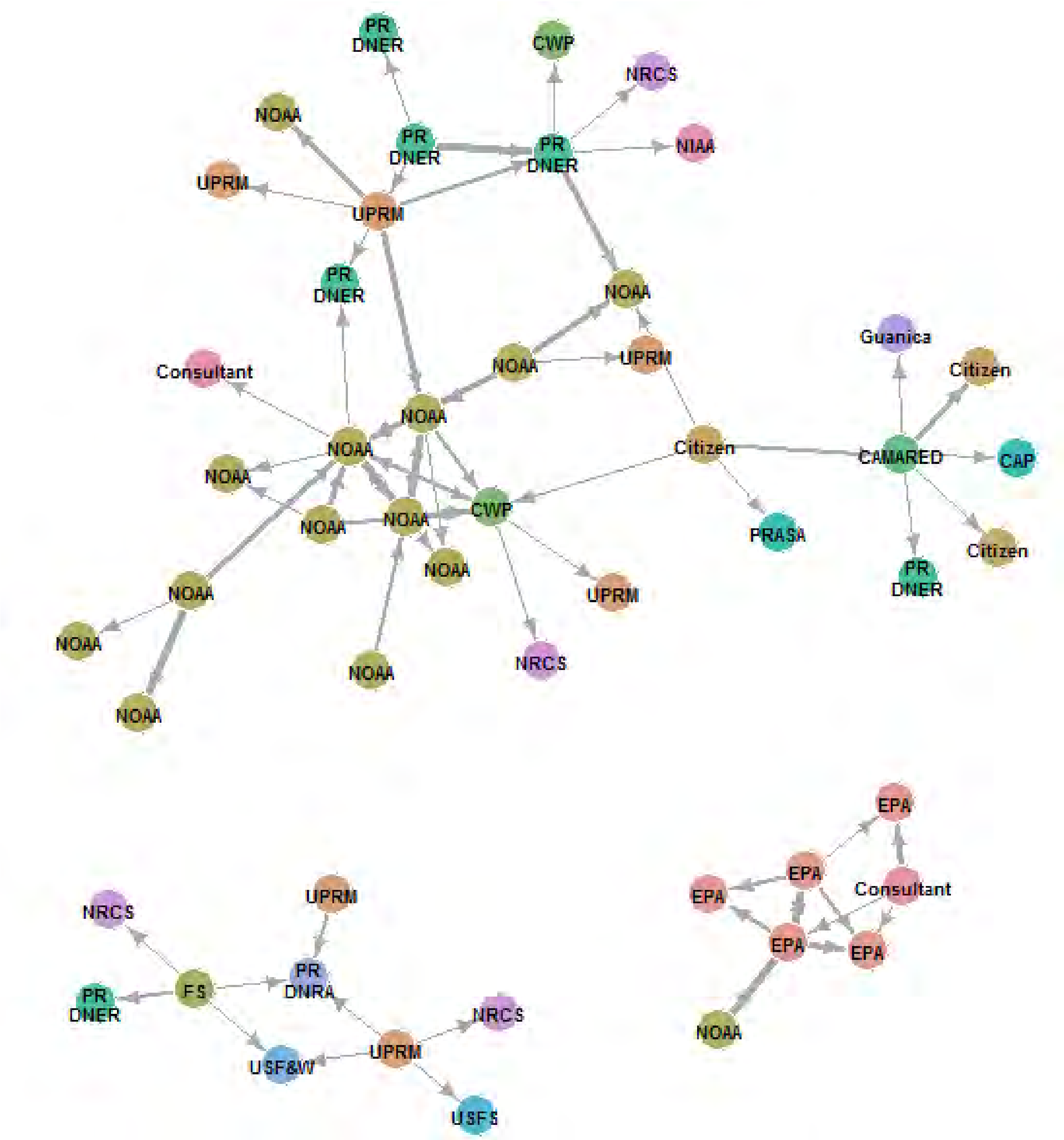

Figure 4-2. Preliminary social network based on responses from workshop participants who are identified by institution or role. Line width is proportional to importance. (Tom Stockton, Neptune and Company, Inc.)

The preliminary SNA was based only on the input of the workshop participants and did not represent the many other people who are involved in decision-making in the Guánica Bay Watershed. Results from the analysis allow exploration of patterns:

- Does the communication network serve needs well?
- Are any individuals or clusters of individuals poorly connected?
- Is critical information held outside the information network?
- Does the network support learning?

There are several clusters that are not connected to each other. There is a large cluster, where individuals from NOAA are playing central roles. The NOAA employees appear to be communicating well with each other and are receiving information from other groups but have limited outgoing communications to other groups. There is a smaller network of mostly EPA employees that work interactively but have connection with only one external participant (NOAA). The lack of connection to a larger network is a concern, because EPA has both a mission and regulatory responsibility for managing and regulating land-based sources of pollution. Similarly there is a smaller, unconnected network of individuals representing Puerto Rico departments that are interactive with FWS and NRCS but not with the broader NOAA network.

From the preliminary SNA, EPA hoped to identify strengths and weaknesses in communication within the Guánica Bay Watershed management and stakeholder community that can be modified to better support sharing of information and values. A more inclusive and comprehensive SNA would be extremely value in this respect. Increased understanding by participants of information flow in the GBW aided in planning of future workshops.

4.3 Uncertainty and the Value of Information (VOI) in Multi-stakeholder Environmental Decision Making

Dr. Amanda Rehr (presenter) and Dr. Mitchell Small, Carnegie Mellon University/US EPA Special Government Employees

In decision analysis, each alternative must be evaluated by appraising it against criteria. This step is challenging for two reasons because: 1) each stakeholder has their own set of values and would apply their own weights to the criteria and 2) there is almost always some uncertainty about the consequences of a proposed management action. Ideally, this uncertainty can be reduced by additional scientific study. In practice, scientific studies and their interpretation are sometimes as much a point of contention as the decisions they are designed to inform. Arguments over the objectivity, validity, and relevance of scientific findings are now common in debates regarding climate change, energy exploration, nuclear power, chemical regulation, food safety, and other domains with high stakes and high uncertainty. Nonetheless there is value in information and the credibility it brings to valuing outcomes (i.e., applying weighting criteria).

In the section of the workshop described here, participants were guided through a process for designing a system model that could be used to predict the outcomes of alternative management options aimed at protecting important resources. The process concluded with a method for identifying where additional information could add the most value to decisions and resolve possible conflicts over preferred management actions.

Step 1 - Identifying important resources and outcomes

During the workshop, participants were led in a discussion about which resources and outcomes should be considered in decision-making for environmental quality and coral reef management in the Guánica Bay Watershed in terms of their importance and value. Responses are grouped into categories of *Higher* and *Lower Priority* roughly based on how often they were mentioned by participants (**Table 4-1**). This first step acts as a preliminary brainstorming exercise. The eventual system model included a further-reduced set of important resources and participants were asked in a later step to rate each one relative to others.

Table 4-1. Important resources and outcomes in the Guánica Bay Watershed

Higher Priority Resources and Outcomes	Lower Priority Resources and Outcomes
▪ Coral reef health ▪ Guánica Bay water quality ▪ Fisheries (Commercial) ▪ Drinking water quality ▪ Agriculture ▪ Tourism ▪ Construction and development	▪ Offshore water quality ▪ Soil conservation and farmland quality ▪ Quality of life ▪ Rapid response to oil spills ▪ Other community awareness ▪ Aids to navigation ▪ Law and regulation enforcement ▪ Planning–before construction ▪ Aesthetics and public resources ▪ Seagrass and other benthic communities other than coral reefs ▪ Fisheries (Recreational and Artisanal) ▪ Vegetative communities in watershed ▪ Community surrounding areas ▪ Home sewers connected to rivers, lakes, sea ▪ Bay sediment quality

Step 2 - Identifying cause-effect relationships that impact resources and outcomes

During the workshop, participants were led in a discussion of cause-effect relationships believed to impact resources and outcomes of importance in the Guánica Bay Watershed. A consensus-based assignment of relationship strength was employed.

Table 4-2 includes a summary of participants' best estimates (min, mean and max) on a scale of 0-100 and associated confidence (slightly, somewhat or very) regarding the strengths of these relationships. It was discussed how the reported distributions would later be translated into probabilistic assessments of the causal relationships between variables in the eventual system model.

Table 4-2. Workshop participants' best estimates (on a scale of 0-100) and associated confidence (slightly, somewhat or very) regarding the strengths of the cause-effect relationships that impact important resources and outcomes in the Guánica Bay Watershed (N=25)

Environmental Threat (Driver/Pressure)	Affected Resource/Outcome (States/Impact)	Strength of Relationship			Confidence (slightly, somewhat, very)
		Min	Mean	Max	
1. Sewage and wastewater treatment plant loadings	Reservoir and drinking water quality	10	40	85	somewhat/very
2. Sewage and wastewater treatment plant loadings	Bay water quality	40	60	85	very/somewhat
3. Agrochemical discharges	Reservoir and drinking water quality	35	50	85	somewhat
4. Agrochemical discharges	Bay water quality	40	55	85	somewhat/very
5. Sediment loadings	Reservoir and drinking water quality	15	50	85	somewhat/very
6. Sediment loadings due to clear-cutting	Bay water quality	20	55	85	very/somewhat
7. Sediment loadings due to building construction	Bay water quality	20	50	85	somewhat/very
8. Bay water quality (nutrient level)	Coral reef health	35	60	85	somewhat/very
9. Bay water quality (sediment level)	Coral reef health	45	70	85	very
10. Bay water quality (toxics and pathogens)	Coral reef health	10	60	85	somewhat/very
11. Ocean acidification	Coral reef health	10	50	85	somewhat
12. Ocean temperature rise	Coral reef health	35	60	85	very
13. Coral reef health	Fisheries	30	65	85	very
14. Coral reef health	Tourism	10	50	85	somewhat/very

Step 3 - Identifying management actions considered effective for reducing threats

During the workshop, participants were led in a discussion about which management actions were considered to be viable and effective for reducing threats or ensuring important resource outcomes in the Guánica Bay Watershed. **Table 4-3** shows participants' best estimates and associated confidence regarding the effects of these management actions on important outcomes. Participants were asked to indicate the amount of improvement that resource outcomes (drinking water quality, bay water quality, and coral reef health) would benefit from by implementing specified management actions. The amount of improvement was defined qualitatively ("A Little", "Moderately", and "A Lot"). A consensus-based assignment of the effects was employed with the average of the responses being recorded here.

Table 4-3. Workshop participants' best estimates and associated confidence regarding the effects of management actions for reducing threats to resource outcomes in the Guánica Bay Watershed

<table>
<tr><th rowspan="2">This Affected Resource Outcome</th><th colspan="3">Will be improved by this management action:</th></tr>
<tr><th>A Little</th><th>Moderately</th><th>A Lot</th></tr>
<tr><td>Reservoir and Drinking Water Quality</td><td></td><td>▪ Restrictions on agrochemicals (somewhat)</td><td></td></tr>
<tr><td>Bay Water Quality</td><td></td><td>▪ Wastewater treatment wetlands (somewhat)
▪ Rio Loco stream bank riparian plantings (somewhat)
▪ Hydro-seeding of areas with bare soil in high elevation erodible soil areas (somewhat)
▪ Cover crop outreach and cost share to high elevation coffee farms
▪ Restoration of Guánica Lagoon
▪ Reef education for youth and their parents
▪ Subsidy for shade grown coffee</td><td>▪ Advanced wastewater treatment (very)</td></tr>
<tr><td>Coral Reef Health</td><td></td><td></td><td>Marine protection areas (somewhat)</td></tr>
</table>

Step 4 - Identifying scientific uncertainties and studies to reduce uncertainties

During the workshop, participants were led in a discussion about the key data gaps or scientific uncertainties they believed limited the ability to understand and manage the coral reefs and related ecosystems in the Guánica Bay Watershed. For each, they also suggested additional monitoring or scientific studies that would likely reduce these uncertainties.

A summary of the critical uncertainties and suggested research studies is shown in **Table 4-4**, roughly in order of a combination of how often they were mentioned (most often to least often) and their strength in reducing the associated uncertainty (a lot to a little). This ranking provides an initial prioritization of the perceived needed studies to reduce uncertainty for decision-making. As data and quantified results are generated, more formal VOI methods can be used.

Table 4-4. Critical uncertainties and suggested research studies

Addressing	Research Tasks
Pollutant Sources	▪ Land use–hydrology studies ▪ Wet vs. dry weather sampling of streams ▪ Lake/Rio Loco/other surface water flow path studies
Pollutant Loadings	▪ Model scenarios for watershed mgmt. options ▪ Stream gauging in Rio Loco ▪ Calibration & use of SPARROW ▪ Monitoring sediment & nitrogen in Rio Loco
Pollutant Fate	▪ Stream sediment studies ▪ Marine stable isotope studies
Coral Reef Impact	▪ Coral reef toxicological studies ▪ Coral reef ecological studies
Stakeholder Participation/Deliberation	▪ Stakeholder engagement in effect mgmt. options ▪ Survey residents and visitors for their values ▪ Survey of decision makers (interviews) ▪ Decision flow charting
Human Activity Studies	▪ Mapping current uses and impact ▪ Tracking temporal trends in uses and impact

Demonstrating a new method: Value of Information for Conflict Resolution

During the workshop, Drs. Rehr and Small presented and demonstrated a new decision support method called Value of Information for Conflict Resolution (VOICR) for identifying where additional scientific research may be needed to support better-informed decisions and resolve possible conflicts over preferred management actions. The method combines and builds on aspects of multiple stakeholder deliberation, multiple criteria analysis, Bayesian Belief Networks, and value of information (VOI) analysis. In the simplest context, a value of information analysis can show whether a decision is likely to be the same regardless of the effort to acquire additional information. In more complex analysis, it can help to focus where to focus the effort on acquisition of information that will influence the decision.

A subset of the workshop participants (seven) participated in the VOICR demonstration. The demonstration centered on the important subject reducing loadings from three sources: sewage, agriculture, and development. The scenario assumed that loadings would be reduced incrementally from each source through a series of management steps, which would be ranked in order of maximizing benefits. Importantly, the loading rates from each source were not known and research to determine those rates had not been conducted.

The exercise combined the DPSIR conceptual model of the Guánica Bay Watershed developed earlier in the workshop, with participant preferences for outcomes (coral reef health, tourism and fisheries) and beliefs about science drawn from workshop discussions (% loadings from sources, effectiveness of a lagoon at filtering out pollutants, and the probabilities that stressors will produce different outcomes) into a probabilistic Bayesian Belief Network (BBN). The final outcome, "Benefits", was computed as x*Tourism + y*Fisheries + z*Coral Health*Ecosystem Services, where x, y, and z were the weightings assigned by participants to these different resource outcomes. Drs. Rehr and Small used a set of additional face-to-face elicitation questions to inform the BBN (as follows). **Figure 4-3** shows a BBN for one of the seven participants who participated in the exercise.

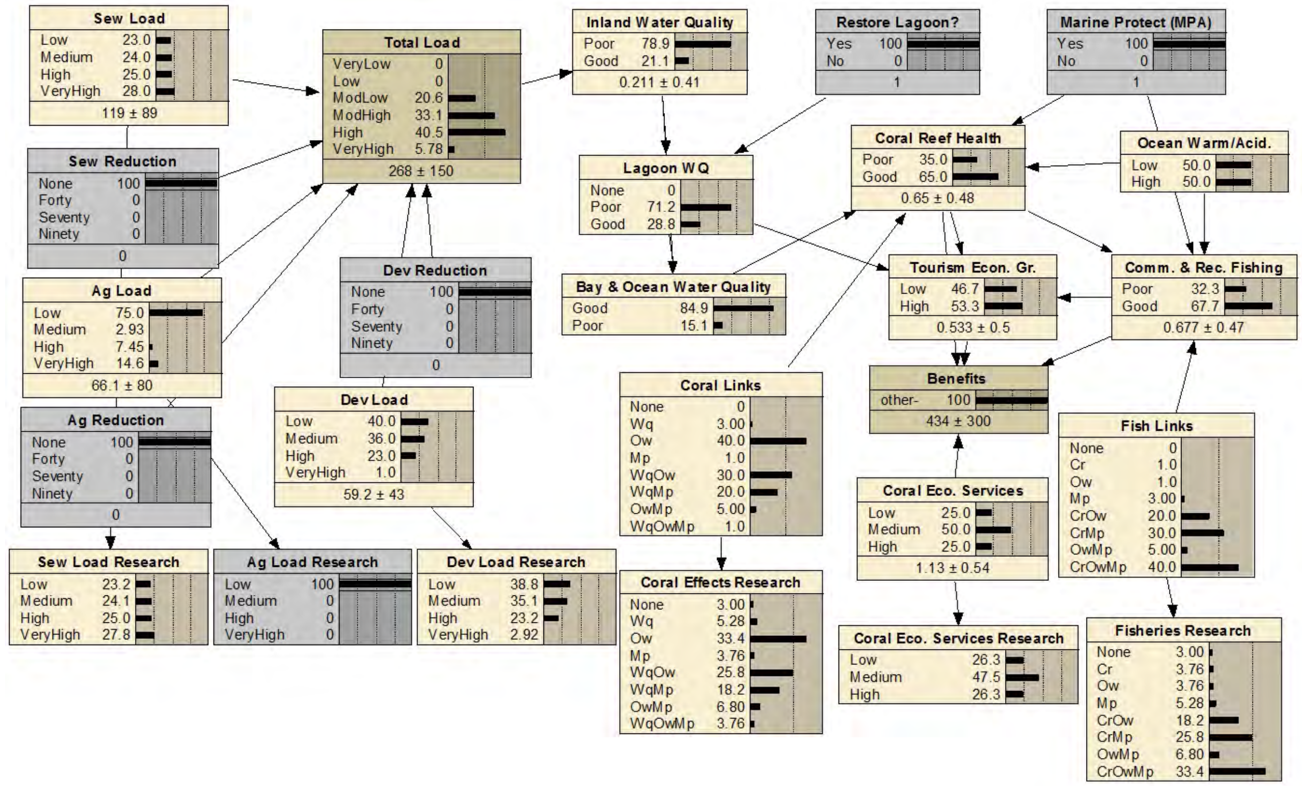

Figure 4-3. Bayesian Belief Network (BBN) developed at the workshop for a participant. (The BBN is a system model of the Guánica Bay Watershed, in this case focusing on loadings, with five possible management levers (in light blue), five research effects nodes, and an end node, Benefits, which is computed by: x*Tourism + y*Fisheries + z*Coral Health*Ecosystem Services, where x, y, and z were the weightings assigned by participants to these different resource outcomes. The BBN was designed to be used for computing the preferred management option based on maximizing benefits and then comparing results between without- and with-information conditions.

A BBN consists of a graphical structure and a probabilistic description of the relationships among variables in a system, and presents an effective way to represent uncertainty in environmental decision problems. Variables, in this case coral reef health, tourism, and fisheries, and their associated stressors, are represented as nodes. Causal relationships, the stressor-outcome relationships in this instance, are represented as directed links between the nodes and are specified by conditional probability distributions.

BBNs can be used to estimate the probability of a decision option having a particular outcome, and the corresponding stakeholder valuation of that outcome. A BBN is especially useful when individual nodes of the network will be updated with evidence or new information to see how these change the preferred management strategy. The expected increase in value of the optimal decision informed by the knowledge, compared to the choice made under the pre-information state is the VOI.

The participants responded to the following four face-to-face elicitation questions to inform the conditional probability tables of nodes in the BBN:

1) How would you rate the following outcomes in relation to one another? (A score of 1 for tourism and a score of 2 for fish indicate that fish health is twice as important as tourism health).
   a) Tourism –
   b) Fish –
   c) Coral –
2) What percentage of the total loadings (nutrient and sediment) to the Guánica inland water system comes from development, agriculture, and sewage, respectively? (percentages must sum to 100%)
   a) Development –
   b) Agriculture –
   c) Sewage –
3) How sure are you that the lagoon will work (i.e., be effective in reducing loadings that enter the Bay)?
   a) I am ___% sure that the lagoon will work.
4) Are the probabilities that the following sets of environmental stressors would produce: a) good/bad coral reef health; and b) good/bad fisheries health, respectively? (percentages should sum to 100%)
   a) Stressors for coral reef health:
      i) Water quality (WQ),
      ii) Ocean warming/acidification (OW)
      iii) Marine Protected Areas (MPA)
   b) Stressors for fisheries health:
      i) Coral reef health (CR)
      ii) Ocean warming/acidification (OW)
      iii) Marine Protected Areas (MPA)

      Example 1 - If water quality is considered to be most responsible, followed by ocean acidification/warming, and then marine protection areas (considered useless in this example), and no synergism is assumed, the following probabilities could apply:

      25% WQ/OW/MPA
      20% WQ/MPA
      25% WQ/OW
      5% MPA/OW
      20% WQ
      0% MPA
      5% OW

      Example 2 - If water quality combined with ocean warming/acidification and MPAs is thought to be the most important set of stressors contributing to coral health, followed by water quality and ocean warming/acidification, and then followed by water quality and MPAs, and assuming synergism among the various factors, the following probabilities could apply:

      50% WQ/OW/MPA
      30% WQ/OW
      10% WQ/MPA
      4% MPA/OW

3% WQ
2% MPA
1% OW

c) Probabilities that these sets of stressors lead to good/bad coral reef health:
% that it's all 3 (WQ/OW/MPA) -
% that it's these 2 (WQ/MPA) -
% that it's these 2 (WQ/OW) -
% that it's these 2 (MPA/OW) -
% that it's only 1 factor (WQ) -
% that it's only 1 factor (MPA) -
% that it's only 1 factor (OW) –

d) Probabilities that these sets of stressors lead to good/bad fisheries health:
% that it's all 3 (CR/OW/MPA) -
% that it's these 2 (CR/MPA) -
% that it's these 2 (CR/OW) -
% that it's these 2 (MPA/OW) -
% that it's only 1 factor (CR) -
% that it's only 1 factor (MPA) -
% that it's only 1 factor (OW) -

The facilitators used the BBN to determine how the participants' beliefs regarding current resource conditions and responses to alternative management options may change given different possible outcomes of new research (**Fig. 4-3**). The goal of the analysis was to identify where additional scientific research would support better-informed decisions and resolve possible conflicts over preferred management actions. The exercise can be summarized as follows:

Assuming that two stakeholders have different prior beliefs:

1. Identify their initial preferences for options aimed at reducing loadings.
2. Assess agreement without and with new research result that clarifies the levels of loadings from sources.
3. Identify the capacity of research projects to promote agreement.

In the VOI exercise, for this set of participants and assumptions, it was shown that in terms of prioritizing a research agenda to reduce uncertainty and resolve conflicts, stakeholders would pursue determining loadings from agriculture and sewage, and would likely forego research to determine loadings from development, since the latter was not predicted to make a difference. The detailed results of this exercise have since been published in a journal article (Rehr et al. 2014).

4.4 Adaptive Management (AM)

Kelly Black, Neptune and Company, Inc.

Ms. Black gave a brief presentation on AM to provide a general background for workshop participants. The Guánica Bay Watershed is a complex decision landscape with many stakeholders, different interests and different value sets that result in complex issues that are responsive to management interventions but subject to uncertainties about the impact. The challenges presented by these complexities and uncertainties require an AM approach.

AM is a structured, iterative decision-making process where decision-makers learn from experience and modify subsequent behavior (improve on decisions) in light of that experience. AM relies on partnerships of managers, scientists, and other stakeholders working together on how to create and maintain sustainable ecosystems by applying the following principles:

- Use of a scientific-based approach to address the objectives;
- Use of feedback loops that iteratively feed new information into the decision-making process;
- Use of an open, inclusive, and integrative process; and
- Emphasis on collaboration and conflict resolution in order to reconcile competing objectives.

AM has been successfully applied in natural resource management since the 1950s (Beverton and Holt 1957; Holling 1978; Walters and Hilborn 1978; Walters 1986; Lee 1993; Failing et al. 2004; Gregory et al. 2006; Goffredo and Lasker 2008). The Conservation Measures Partnership (CMP) developed the Open Standards for the Practice of Conservation (CMP 2013), a compilation and adaptation of best practices and guidelines across several fields and across several organizations within the conservation community. The Open Standards lay out 5 main steps to an AM project cycle (**Fig. 4-4**).

Figure 4-4. CMP Adaptive Management Cycle (CMP 2013)

"Adaptive Management:

- Helps science managers maintain FLEXIBILTY in their decisions, knowing that uncertainties exist and provides managers the latitude to change direction
- Will improve UNDERSTANDING of ecological systems to achieve management objectives
- Is about taking ACTION to improve progress towards desired outcomes" (DOI 2010).

AM can be applied throughout the structured decision process.

4.5 DASEES: Decision Analysis for a Sustainable Environment, Economy and Society

Dr. Tom Stockton, Neptune and Company, Inc.

To better enable environmental decision-making, EPA has developed an open-sourced web-based structured decision making tool - DASEES (**D**ecision **A**nalysis for a **S**ustainable **E**nvironment, **E**conomy, and **S**ociety). An integrated trans-disciplinary research team of EPA, university, and private company researchers is developing DASEES. DASEES will support any Web 2.0 compliant web browser that also supports Adobe FLASH technology (Stockton et al. 2011). The framework outlined in this chapter serves the process for working through complex, multi-dimensional decision problems. Tracking progress through this decision process can be greatly facilitated with these framework tools accessible to stakeholders via the Web.

DASEES is organized around the five steps of the Structured Decision Process (see Chapter 1). DASEES consists of a set of guidance and software tools designed both to educate decision-makers in using the structured decision process and to allow them to create their own decision-specific conceptual model using interactive tools to input data and generate graphs, charts, and statistical analyses. By using these tools, different decision options can be quantified and evaluated in the larger context of the conceptual model. In addition, DASEES houses case studies that demonstrate how the tools and guidance can be applied to specific real-world decisions. The case studies can be used as the building blocks for the upper levels of DASEES.

In terms of site navigation, the structure described above has been implemented as a series of tabs (**Fig. 4-5**). Each top-level tab contains sub-tabs housing tools useful in the decision process. The "DASEES steps" contains an overview tab, which provides an introduction to the individual steps. Each of the sub-tabs contains its own sub-tabs, housing guidance or tools. Requirements for each tab and sub-tab depend on whether they contain guidance or house a software tool, or both.

Step 1 - Understand the decision context

DASEES provides a suite of tools to assist users to establish the context within which the management problem is contained.

- A **Decision Landscape** Section allows users to summarize the political, regulatory, social, institutional and scientific context of the decision.
- A **Social Network Analysis (SNA)** tool provides a visual insight into who is, and more importantly, who is not sharing in the information flow for the decision at hand.
- Complementary to these approaches are systems-based cognitive maps. DASEES allows users to characterize the activity with the **Drivers-Pressures-States-Impacts-Response (DPSIR)** model that enables causal understanding in the decision context. Other selected aids in this step include GIS-based visualization tools and a Sandbox area for exploring and recording thoughts and ideas that arise during deliberation.

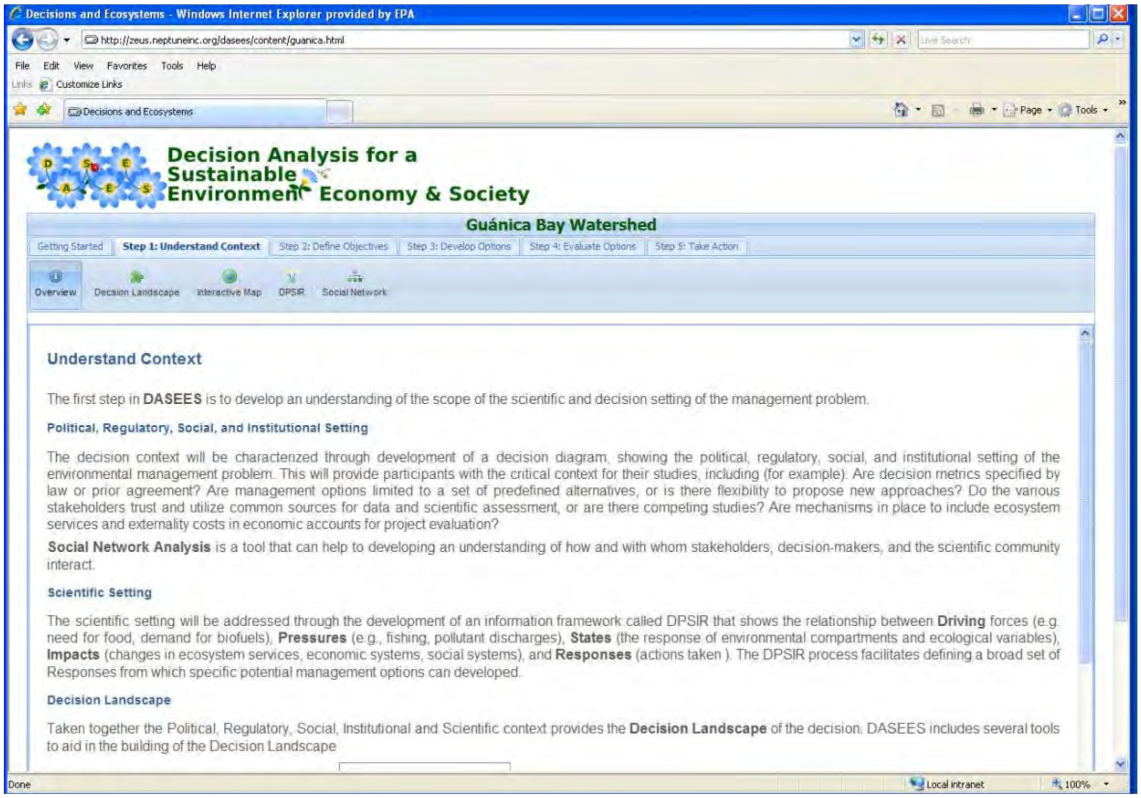

Figure 4-5. DASEES Webpage design

Step 2 - Define objectives

DASEES provides several tools for documenting and organizing stakeholder values and organizing the values into an objectives hierarchy.

- A tool to create a list of **Objectives**. The tool allows the user to add or re-arrange objectives by dragging and dropping.
- The Objectives Tool supports development of **Measures** for an objective. Each of the final objectives should have measures for assessing whether the objective is attained. A good measure should be 1) interpretable, 2) meaningful, 3) operational and 4) measurable.
- An **Objectives Preference Tool** supports ranking objectives by selecting and applying a suite of criteria.
- A **Scratch Pad** where users can collect their thoughts about objectives.
- An **Objectives Import Tool** that allows the user to import a list of objectives from Microsoft Word. Once imported, the user can insert the objectives into the Objectives Hierarchy for the project.

Step 3 - Develop options

In the third step, alternatives to achieve the objectives are identified.

- The **Means Objectives Tool** supports development of a suite of means objectives for each of the final objectives identified in Step 2. Means objectives help to identify how to achieve fundamental objectives. The Means Objectives Tool also supports the identification of management options or alternatives.

- A **Management Scenario Tool** that assists users in creating competing collections of management options reflecting identified means objectives and aimed at achieving final objectives in Step 2.

Step 4 - Evaluate alternatives (management options)

The next step is to assess the options and assemble or provide scientific information to address critical unknowns.

- A **Bayesian Network Tool** for causal assessments of management scenario alternatives. A Bayesian approach supports explicit consideration of uncertainty, and provides a normative framework for integrating science-based information and user defined option preference valuation.
- A **Decision Map** that allows the user to move through the Objectives Hierarchy and Means-End Networks.

Step 5 - Take action

Finally–the decision-makers begin implementation. Monitoring and adaptive management should accompany implementation.

- DASEES provides some guidance for implementing **Adaptive Management**.

4.6 Decision Breakout Session

On the morning of the second day, there were two breakout sessions. The first breakout session, *Decision-making in Practice*, was designed to gain an understanding of how the workshop participants currently make decisions regarding issues that impact coastal ecosystem health. The discussions focused on six questions regarding decisions:

1) What decisions need to be made?
2) Who makes those decisions?
3) What information is needed to make the decisions?
4) What level of accuracy or confidence is needed for the decisions?
5) What tools are needed to assist in making these decisions?
6) What would help them make better decisions?

The second breakout session, *Develop Options*, was designed to identify alternative management strategies or policy options that can be implemented to address threats to coastal ecosystems.

Group 1. Permitting and Enforcement Decisions

Facilitator: Ms. Kelly Black; Note-taker: Dr. William Fisher

Background

The objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical and biological integrity of water resources, including the biological inhabitants of coral reefs. The CWA requires that states have water quality standards, monitor conditions regularly, and submit reports summarizing water quality assessments (usually every two years).

Under section 303(d) of the CWA, states are required to develop lists of impaired waters. These are waters that are too polluted or otherwise degraded to meet the water quality standards set by the state. The law requires that the state establish priority rankings for waters on the list and develop TMDLs for these waters. A Total Maximum Daily Load, or TMDL, is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards.

Puerto Rico's Environmental Quality Board (EQB) is the commonwealth agency with responsibility under the CWA. EQB issued the most recent Puerto Rico Water Quality Standards Regulation on March 31, 2010. The goal of this regulation is to "preserve, maintain and enhance the quality of the waters of Puerto Rico in such manner that they be compatible with the social and economic needs of the Commonwealth of Puerto Rico. The purposes of this regulation are: (1) designate the uses for which the quality of the water bodies of Puerto Rico shall be maintained and protected; (2) prescribe the water quality standards required to sustain the designated uses; (3) identify other rules and regulations applicable to sources of pollution that may affect the quality of the waters subject to this regulation; and (4) prescribe other measures necessary for achieving and maintaining the quality of the waters of Puerto Rico" (PR 2010).

Under the CWA, EPA works in partnership with EPA Regions, states, local governments, Tribes, the private sector, and non-governmental organizations to regulate discharges into surface waters. EPA controls storm water and wastewater discharge and treatment through the National Pollutant Discharge Elimination System (NPDES). While EPA has delegated primary NPDES program responsibility in most states and territories, EPA retains lead responsibility for developing and enforcing NPDES permits in Puerto Rico.

Decision-making in practice

The PR EQB prepares the bi-annual water quality report.

- The Rio Loco is listed as impaired on the 303(d) list. Sources of pollution include urban runoff/storm sewers, land disposal, onsite wastewater systems, hydro-modification, and upstream impoundment. Causes of pollution include: pathogens (fecal coliforms), metals, arsenic, low dissolved oxygen, other inorganics, and manganese. Workshop participants felt that more effective enforcement of wastewater treatment systems and residential septic systems was a key management action.
- Guánica Bay (an estuary) and the adjacent marine waters are not listed as impaired on the 303(d) list. They are not monitored as part of EQB's water quality monitoring program.

The PR Department of Natural and Environmental Resources (DNER) is the agency representing Puerto Rico on the USCRTF. In this capacity, DNER formed a multi-agency group to help develop the Local Action Strategies (LAS) in 2003 and 2011. Two primary focus areas in the 2003 LAS were 1) land-based sources of pollution and 2) overfishing. The LAS focused on improved enforcement of existing laws and regulations and non-regulatory best management practices (BMPs). The multi-agency group has been instrumental in non-regulatory activities, such as building partnerships, securing project funding, and community outreach and education. The group also identified decisions/issues that were not regulatory/permitting, including the numerous scientific studies that have been conducted in the Guánica Bay Watershed (baseline characterization, 1979 inventory, coral reef extent), the lack of water quality information for the watershed, and a pervasive lack of personnel to get the work done.

Alternative management strategies or policy options

Several alternative management strategies were proposed by the group: development of a TMDL for the Rio Loco, forest management plans, the Forest Legacy Program, the Community Forest and Open Space Conservation Program, and the addition of water quality monitoring stations on the Rio Loco. These proposals are summarized below.

Total Maximum Daily Loads (TMDL). The CWA requires states to establish a priority ranking for waters on the 303(d) list of impaired waters and establish Total Maximum Daily Loads (TMDLs) for such waters. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still safely meet water quality standards. A TMDL will identify clear targets for guiding pollutant cleanup activities. A TMDL for the Rio Loco would address some or all of the pollutants of concern: pathogens (fecal coliforms), metals, arsenic, low dissolved oxygen, other inorganics, and manganese. Since the Guánica Bay and marine waters are not in the 303(d) list of impaired waterbodies, a TMDL is not required.

Establish Non-Point Source Monitoring Stations in the Rio Loco. EQB is the Commonwealth government agency with the legal responsibility to implement federal and state laws and regulations concerning pollution in Puerto Rico. EQB collects surface and ground water quality data both from its own water quality monitoring network and from monitoring stations operated by the United States Geological Survey (USGS). There are currently no USGS water quality monitoring stations and no EQB stations in the Rio Loco, Guánica Bay, or marine waters off Guánica Bay. A more comprehensive monitoring program, similar to that established in the Río Grande de Loíza, Río De La Plata and Río Grande de Arecibo basins and the San Juan Bay Estuary, should be established in the Guánica Bay Watershed, including the Rio Loco. This is an important management action, since these waterbodies are not in the 303(d) list of impaired waterbodies, even though they may actually be impaired.

Forest Management Plans. Forest landowners value their land for many reasons: from realizing an economic return (from timber or other sources) to providing ecological values (wildlife habitat, water and soil protection, carbon storage) and personal enjoyment (for recreation, solitude or other purposes). A comprehensive forest management plan should provide the information necessary and a flexible framework for achieving the landowner’s goals including: statements of goals and objectives, current condition of the forest and potential for future benefits, possible actions to achieve objectives, and environmental laws that might apply. Some landowners develop their own plans but most hire a licensed forester. DNER foresters can help landowners with resource inventories and management planning and also can help landowners apply for cost-share or conservation easement programs such as the Forest Legacy Program.

Forest Legacy Program (FLP). The FLP was established in the 1990 Farm Bill to protect environmentally important forest areas that are threatened by conversion to non-forest uses and to promote forestland protection through the use of conservation easements and fee-simple purchase. The FLP provides an incentive-based mechanism to protect critical important fish and wildlife habitat, conserve watershed functions, and maintain recreation opportunities. PR DNER, as the custodian of the Commonwealth’s forest resources, could apply for FLP grant funds to acquire land, or interests in land, and hold title.

Community Forest and Open Space Conservation Program (CFP). The CFP, established in the Food, Conservation, and Energy Act of 2008, is a grant program that authorizes the U.S. Forest Service to provide financial assistance to local governments, Tribal governments, and qualified nonprofit entities to establish community forests that provide continuing and accessible community benefits. Community forests provide many benefits, including: economic benefits from sustainable forest management and tourism; environmental benefits from natural resource conservation, such as storm water management, clean air and water, and wildlife habitat; forest-based educational programs; model forest stewardship activities; and recreational opportunities. The community is involved in the establishment of the community forest and long-term management decisions. Public access to the community forests is required and intended to enhance public health and wellbeing. The program pays up to 50% of the project costs and requires a 50% non-federal match. In addition, the program authorizes funds to state/territorial foresters for technical assistance to implement community forest projects.

Development Planning. A Land Use Management Plan was created for the town of Guánica that reflected the ongoing economic activities at the time (fishing, tourism, recreation). It was agreed that the Land Use Management Plan was going to be integrated into future decision-making, but that has not occurred. Subsequently, the Commonwealth made the decision to allow a fertilizer plant (i.e., Ochoa Fertilizer Plant, which was not in the plan). Workshop participants felt that this fertilizer plant possibly contributed to the deterioration of Guánica Bay and the town's economy. Workshop participants felt that use of the Land Use Management Plan to guide future development was important.

Education and Outreach. Workshop participants emphasized the need to inform, engage, and motivate water quality managers, elected officials, stakeholders, regulated industries, and the public to take positive personal actions and work together to improve and preserve water quality and natural resources in the Guánica Bay Watershed.

Group 2. Natural Resource Decisions

Facilitator: Ms. Leah Oliver; Note-taker: Dr. Tom Stockton

Background

The Department of Natural and Environmental Resources of Puerto Rico (DNER) is the executive department of the territorial government tasked with protecting, conserving, developing, and managing the natural and environmental resources of Puerto Rico. The U.S. Fish & Wildlife Service, U.S. Forest Service, and Conservation Trust of Puerto Rico are also land managers (Gould et al. 2012), and the Caribbean Fisheries Management Council is responsible for fisheries management in federal waters extending from 16.7 km to 370.4 km (the Federal Exclusive Economic Zone or EEZ).

Decision-making in practice

It is U.S. policy that regulatory decisions must be based on the best available science (EO 13563 2011). Workshop participants felt that comprehensive monitoring (including baseline and effectiveness monitoring) and laboratory studies would provide the scientifically credible information needed for decision-making. They also felt that resource users (commercial fishers, famers, etc.) should be involved in decision-making. The group gave several examples of typical decisions:

- **Beach Cleaning**. Beach cleaning involves removing broken glass, cigarette filters, syringes, stones, weeds, wood, pop-tops, hardened tar balls, animal droppings, etc., from beaches. There are limited resources to accomplish beach cleaning, and decisions must be made about which beaches, when and how to clean.
- **Beach Closure**. When water quality standards (fecal coliform and enterococcus) are exceeded at a particular beach, Puerto Rico requires beach managers to post an advisory or closure. An advisory warns people that there is an increased health risk associated with entering the water, and a closure warns people to completely avoid contact with the water. Once a beach is deemed "unsafe", it remains on that list until further testing shows that the bacterial levels have dropped into the "safe" zone. Only two beaches are monitored in the Guánica municipality: Playa Santa and Balneario Caña Gorda. The workshop participants felt that additional beaches should be monitored.
- **Manage Stakeholder Conflicts**. Resource carrying capacity is an issue, along with the decision of how many and which types of users can use the resource. There needs to be more and better communication with stakeholders to manage/minimize/restrict resource use.
- **Regulation/Law Enforcement**. More resources are needed to enforce existing regulations and laws. The enforcement personnel also need additional physical tools (boats, cars, etc.). Collaboration between the various managing agencies (Puerto Rico DNER, NOAA, etc.) could help to address some of the resource deficiencies. Information on regulations can be hard to find – better outreach and education are needed to ensure that the users are informed. Some significant data gaps exist, including the lack of a license system for fishing, diving or snorkeling.
- **Research and Monitoring Support**. The decisions about which research will be conducted and by whom is another decision area. There has been a long history of environmental research in Puerto Rico, and multiple government agencies, academic institutions, and NGOs are currently conducting research in the Guánica Bay Watershed. A research planning process needs to be established, including prioritizing the research, determining who should conduct the research, securing adequate funding and resources, and releasing research results to the public, including some sort of report card on how the natural resources are doing. Tools such as GIS, network analysis, and models can contribute to the research planning.
- **Vessel Groundings**. The coral reefs and seagrass meadows offshore of Guánica are productive habitats that support the fishing, diving, and tourism industries. A boat hitting the reef can topple coral heads or grind coral colonies into tiny fragments, damaging and killing coral that may have taken centuries to build. Vessels that run aground on seagrass cut scars or large swaths through the meadows, creating injuries that may never heal, depriving marine life of important habitat. A program should be developed and implemented to respond to vessel groundings, including those of small recreational vessels. To support this effort, better maps of the marine resources are needed. There also needs to be some way to tease out the stress caused by the physical damage from the more chronic land-based sources of pollution.

Alternative management strategies or policy options

This breakout group developed a list of management strategies, some of which had been discussed earlier in the workshop and some which had not. A brief discussion of each strategy not previously mentioned in this report is provided below.

- **Restoration of the Historic Guánica Lagoon**. This was the highest priority management option in the WMP. The lagoon served as a refuge for native and migratory birds, and filtered sediment and pollutants generated from upstream headwaters. The group felt, however, that there was uncertainty about how the restoration of the lagoon would improve the condition of coral reef ecosystems. There was a lack of scientific study and data gaps.
- **Enforcement of the Clean Water Act (CWA)**. Participants felt that there was inadequate enforcement of the CWA, and this lack of enforcement was endangering human health and the environment. Areas that were emphasized included erosion control, septic tanks, permit compliance and point source discharges (NPDES). The group was concerned that water quality standards were not being met and that lack of water quality criteria or water quality monitoring allowed continued degradation of water bodies.
- **Enforcement of Fishing Regulations**. Puerto Rico has enacted fishing regulations, including the requirement for recreational fishing licenses, prohibition on recreational spear fishing with scuba, prohibition of beach seine nets, size limits and daily quotas on several species, and the requirement for species-specific permits for high-value and sensitive species. The breakout group felt that Puerto Rico needs to strengthen enforcement of its existing fishing regulations by improving public awareness, providing further training and support for rangers, and addressing other critical constraints to enforcement.
- **Mooring Buoys**. The Marine Resources Division of the DNER has installed over 270 mooring buoys, which are permanently anchored buoys that allow boaters to moor without damaging the seafloor. In some cases, boaters are not properly using the mooring buoys. Participants felt that additional mooring buoys should be installed and the DNER Rangers should enforce use of the buoys.
- **Aids to Navigation**. The participants felt that additional channel markers were needed. The group also felt that Puerto Rico needed to improve their navigational charts to reflect water depth, coral reefs and other sensitive resources.
- **Scientific Studies**. The group felt that additional scientific studies were needed to provide information for decision-making. They wanted to expand the baseline characterization of the Guánica Bay Watershed, including additional long-term monitoring of water quality and biotic condition of the coral reefs and Guánica Bay. They also felt it important to measure or model base flow, ground water, water replacement times, and currents.
- **Riparian Restoration**. The diverse vegetation that grows along streams, rivers or reservoirs is known as the "riparian zone". Riparian areas act as protective buffers between the land and the water, slowing runoff that is accelerated by paving of urban areas, filtering chemicals and excess nutrients coming of agricultural lands, and to some extent ameliorating the effects of increased sediment delivery from eroding hill slopes. Riparian restoration can often be the most cost-effective means for restoring water quality in streams impacted by non-point source pollution (EPA 1996). Riparian restoration involves restoring hydrologic processes and geomorphic features, and/or reestablishing native riparian vegetation. The WMP (CWP 2008) recommended riparian restoration along the Rio Loco. Workshop participants supported this action, and felt riparian restoration should be undertaken throughout the Guánica Bay Watershed.

- **Runoff Controls**. Construction activities can produce massive, short-term increases in erosion and sediment, because (1) the stabilizing effect of vegetation is lost, (2) soil surfaces are exposed to direct raindrop impact, and (3) additional precipitation is converted into runoff by impermeable surfaces (UNEP 1994). Runoff control measures and other BMPs (i.e., native vegetation) can be implemented at the time of construction to reduce runoff pollution both during and after construction. The Center for Watershed Protection developed a fact sheet that summarizes the Puerto Rico regulations (CWP 2006). Workshop participants felt that EQB should enforce the requirement for runoff controls and other BMPs at construction sites.
- **Mosquito Control.** Dengue is a prevalent disease in Puerto Rico, where frequent rains allows standing water, which is where mosquitoes breed. *Aedes aegypti*, the principal mosquito carrier of dengue viruses in Puerto Rico, lives in urban areas. An outreach and education program needs to be expanded.

This group also highlighted some of the actions proposed by the first focus group, including development planning and education and outreach. They felt that an outreach plan should be developed for marketing Guánica agricultural products such as shade-grown coffee. They also felt that an educational program should be developed to address the cultural component of some practices, such as the idea of "cleaning the land", which was contributing to sedimentation.

Group 3. Scientific Support

Facilitator: Dr. Amanda Rehr; Note-taker: Mr. Joe Williams

Background

EPA has articulated four core principles of watershed management (EPA 2013b):

- Watersheds are natural systems that we can work with.
- Watershed management is continuous and needs a multi-disciplinary approach.
- A watershed management framework supports partnering, using sound science, taking well-planned actions and achieving results.
- A flexible approach is always needed.

A strong scientific foundation is essential to the formulation of sound decisions. In order to understand how a watershed functions, decision makers need information on watershed dynamics, processes and interactions.

Decision-making in practice

Multiple agencies are partnering in the Guánica Bay Watershed to provide the science and information needed to formulate more sustainable decisions. These include Puerto Rico (DNER and EQB), NOAA, USDA-NRCS, USEPA, and US F&WS. The University of Puerto Rico and several non-profits are also involved, including Ridge to Reefs, Inc., and Protectores de Cuencas. Additionally, NFWF administers grant funding provided by the federal agencies to implement small- to mid-scale projects.

There is not a formal body to make decisions for the Guánica Bay Watershed. Decisions are being made by multiple organizations (DNER, NOA Fisheries, the PR Land Authority, the municipalities). At the time of the workshop, the Center for Watershed Protection (CWP) was coordinating the process, with primary funding through the Coral Restoration Program (NOAA). The coordination responsibility has now moved to Ridge to Reefs, Inc., and Protectores de Cuencas.

The strength of the Guánica Bay Watershed approach is the established partnership that links together organizations providing science and information with those making the decisions. Workshop participants provided some examples:

- Stressor identification procedures will help to identify the different sources within a watershed that may be contributing to biological impairment. It is important to identify stressors and potential sources of stressors so that water quality programs can target limited resources to address these issues. Useful data may come from chemical analysis of effluents, organisms, ambient waters, and sediments; toxicity tests of effluents, waters, and sediments; necropsies; biotic surveys; habitat analyses; hydrologic records; and biomarker analyses. These data do not in themselves, however, constitute evidence of causation. Researchers will have the insight for the usefulness of the information. Decision-makers can then take the appropriate regulatory or non-regulatory approach based upon the source and type of stressor (e.g., sewage could be regulatory–WWTP permit compliance, or a BMP such as composting toilets at state parks and reserves).
- NOAA has mapped the ocean floor, surveyed the fish and other seafloor creatures, and measured contaminants in sediments and corals, nutrient levels in surface waters, and sedimentation rates at coral reef sites. The University of Puerto Rico (Dr. Clark Sherman) has deployed an array of sediment traps at nine reef sites adjacent to Guánica Bay and at two sites within the bay itself to determine both the amount of sediment accumulation and its composition. During the workshop it was identified that watershed modeling was a research gap, and EPA has begun to employ several different models (SWAT, GSSHA, BBNs) to model watershed hydrological and sediment and nutrient transport throughput in the Guánica Bay Watershed. The combined information that will result from these efforts will support decision-makers in making land management decisions.
- Many decisions have a strong social component. For example, the NOAA Caribbean Fisheries Management Council makes regulatory decisions about fishing. They are engaging fishing communities to understand the impact of regulations on those communities. Additionally, University of Puerto Rico (Dr. Manolo Pizzini) is developing a report on the social system for the Guánica Bay Watershed.

Alternative management strategies or policy options

This breakout group developed a list of management strategies, some of which had been discussed earlier in the workshop and some which had not. A brief discussion of each strategy not previously mentioned is provided.

- **Constructed Wetlands.** Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality (EPA 2004). The workshop participants strongly support WMP recommendation #2: a demonstration project where sewage effluent would be treated in a series of treatment wetlands or living machine to reduce nitrogen export.
- **Reforestation.** Reforestation is the natural or intentional restocking of existing forests and woodlands that have been depleted. In the Guánica Bay Watershed, NRCS and USFWS have been supporting farmers in shifting from sun-grown to shade-grown coffee, where a canopy of assorted types of shade trees is created to cultivate shade-grown coffee.

- **Restoration of Guánica Bay Estuary**. Guánica Bay was the focal point around which Guánica and its communities grew. The workshop participants would like a program specifically targeted at restoring Guánica Bay so it can once again provide diverse habitats for wildlife and aquatic life and support local economy through fishing and recreational activities. Participation in a program such as the National Estuary Program would be one way of moving towards a restored Guánica Bay.

A summary of the management options developed by this breakout group is shown in **Table 4-5**. The management options are organized into broad, general categories.

Table 4-5. Management options developed during the workshop

Aquatic Resource Management	Terrestrial Management	Waste Management	Social/Political
Restoration of Guánica Bay Estuary	Reforestation	Constructed WW treatment wetlands	Education and outreach
Develop a TMDL for the Rio Loco	Forest management plans	Enforcement of waste-water treatment systems	Process to manage stakeholder conflicts
Establish non-point source monitoring stations in the GBWS	Forest Legacy Program (FLP)	Enforcement of residential septic systems	Education program to address the cultural component of some practices
Monitor additional beaches for WQ	Community Forest and Open Space Conservation Program (CFP)		Education and outreach on mosquito control
Vessel grounding program	Land use management plan to guide future development		Enforce existing regulations and laws
Additional mooring buoys	Beach cleaning program		More resources for law enforcement
Enforce use of mooring buoys	Riparian restoration throughout the Guánica Bay Watershed		Research planning process
Additional channel markers	Enforce the requirement for runoff controls and other BMPs at construction sites		
Improved navigational charts to reflect water depth, coral reefs and other sensitive resources			
Enforcement of the Clean Water Act (CWA)			
Enforcement of fishing regulations			
Long-term monitoring of water quality and biotic condition of the coral reefs and Guánica Bay			
Scientific studies to measure or model base flow, ground water, water replacement times, and currents			
Implement stressor identification procedures			
Restoration of the historic Guánica Lagoon			

Chapter 5. Conclusions

5.1 Lessons Learned

In April 2010, a Coral Reefs workshop was held in La Parguera, Puerto Rico, at the Magüeyes Island Facilities, Department of Marine Sciences, and University of Puerto Rico.

> The primary goal of the workshop was: To deliver quality information concerning the human-ecosystem relationship so that decision-makers can serve human interests while sustaining ecosystem services.
>
> The purpose of the workshop was: *To facilitate development of a decision support framework with stakeholder/decision-maker input to help address problems related to ecologically-damaging human activities (e.g., agriculture on steep slopes, unbridled development, excess sediment and nutrient loads, stormwater run-off due to impervious surfaces, wetland consumption, etc.)*. Ecological damage includes damage to coral reefs and other ecosystems that provide services to humans.

The three-day workshop was organized as follows (see Appendix D for full agenda):

- Day 1: Framing Knowledge about Coral Reef and Coastal Ecosystems using a Systems Framework (DPSIR)
- Day 2: Decision–Making for Coastal Issues
- Day 3: Optional: Elicitation of Decision Inputs for Coral Reef and Coastal Issues

Based on a compilation of notes during large- and small-group discussions, the following key points can be summarized.

Watershed management should be more inclusive of the stakeholders

There was a strong feeling that more time was needed to bring stakeholders up to speed on the watershed issues. Stakeholders need to understand both science and management concerns, and scientists and managers need to understand the stakeholders' values and concerns. Scientists, managers, and stakeholders must work together continuously. The Guánica Bay Watershed Management Plan is a good starting point for further discussions; however, when beginning new watershed studies it would be preferable to convene stakeholders prior to issuing a watershed management plan.

Participants felt that a comprehensive and inclusive Social Network Analysis (SNA) for the Guánica Bay Watershed could identify strengths and weaknesses in communication among these groups, although they did not feel that it was a priority.

The Guánica Bay watershed is a complex system and a holistic, integrated decision-making framework is needed

Workshop participants felt that, on the whole, opening-day presentations provided a good overview of the watershed and issues. They felt, however, that the presentations did not address some areas of concern, such as coastal and other development, wastewater, and recreational and commercial uses on land and in the water. Use of the DPSIR decision framework to consider trade-offs could prevent unintended consequences.

An understanding of ecosystem services could enhance the ability for various stakeholders to communicate their concerns on a common level. The decision framework should incorporate ecosystem services into the way people think about their environment. Decision science/analysis is needed to help pull all of the relevant research and valid concerns into a coherent system from which decisions that are protective of ecosystem services can be identified and implemented. The DPSIR framework can help with this and was well received as a potentially beneficial tool by the workshop participants. They appreciated that the DPSIR process allowed folks to consider other points of view. They did feel, however, that the DPSIR session was not long enough. Not all discussion points were incorporated into the DPSIR, and they would have liked more time to focus on additional responses that were not identified in the Guánica Bay Watershed Management Plan.

Feedback about DASEES recognized the value of the tool for decision-making and encouraged continued development of DASEES. Specific suggestions included: a user-friendly interface, clear concise instructions, and case studies. To date, the user-interface has been improved, and instructions and case studies are in development.

We need to move beyond plans into active management of the watershed

Watershed management must be proactive in addition to reactive. It would be preferable to prevent problems from happening in the first place (e.g., the workshop participants felt the Guánica Lagoon should not have been drained).

Stakeholders expressed a desire for a central figure to coordinate all efforts in the watershed. The central figure should also have the support of decision-making agencies, to ensure that the watershed management plan is efficiently and effectively completed.

The participants felt that it was important to identify up front the costs of various alternative management actions and adequate funding needs to be secured. There are currently plans to deal with some problems, but the resources have not been provided. In some cases this is due to lack of political will or deeply rooted social paradigms.

Much is known, but much remains to be learned

The dynamics of the reef ecosystem are not fully understood. More research is needed to understand the system, particularly the impact of land-based activities on the reef ecosystem. Confidence in data for management decisions needs to be considered. In some cases, a high level of accuracy is needed, in other cases, not. It is necessary to balance resources and additional research with the level of accuracy needed. Value of Information (VOI) elicitation may have some utility, but participants felt the presentation was too theoretical. Participants felt the exercise was too complicated.

Once documented, research and resources need to be coordinated to focus on addressing problems within the holistic plan. In other words, we need to determine needs first, and then collect the right data.

Additionally, there are numerous studies that provide data and information, but these are not organized in a coordinated system. Some of the data needed for good decision-making has already been, or is currently being, collected, but many stakeholders were unaware of past or ongoing efforts by other stakeholders. Currently, a few very knowledgeable individuals largely hold the information. A centralized web site for storing relevant information and tools that is accessible to multiple groups would help address this issue.

5.2 Next Steps

While workshop participants seemed comfortable with most proposed actions in the Guánica Bay Watershed Management Plan, several were more controversial (restoration of the historic Guánica Bay Lagoon and creation of wetlands at the waste water treatment plant). Since the workshop, many of the management actions proposed in the WMP have begun. Additionally, some of the additional options suggested during the workshop have also been implemented. A short discussion of these is provided below.

Guánica Bay Watershed coordinators

As part of its commitment to strengthening local management capacity, NOAA funded the CWP to staff an on-site person in the Guánica Bay Watershed to interact with stakeholders. Mr. Roberto Viquiera was hired to serve in that role. Mr. Louis Meyer-Comas was hired to work with Mr. Viquiera. Mr. Viquiera has formed a non-profit organization (Protectores de Cuencas) and has applied for 501(c) status, which is a tax-exempt non-profit that can receive unlimited contributions from individuals, corporations, and unions.

Funding and grants to support restoration efforts in the Guánica Bay Watershed

NOAA and FWS have utilized a public-private partnership with the National Fish and Wildlife Foundation (NFWF) to provide funding through the Coral Reef Conservation Fund and the U.S. Coral Reef Task Force Partnership Initiative for a series of projects in the Guánica Bay Watershed. The Coral Reef Conservation Fund, which is administered by NFWF, awards matching grants for projects that are solicited through a competitive process each year; proposals are selected based on merit and relevance to the priorities of the partnership that are listed in the annual request for proposals. Funding to date has advanced conservation throughout the Guánica Bay/Rio Loco watershed—with more than $1.1 million put on the ground since its initial efforts in 2009. Grants have included projects to reduce sediment erosion through stream bank stabilization, provide incentives or best management practices on agricultural lands, and supported capacity building of management and conservation organizations to sustain conservation outcomes. Information about grants opportunities can be found at: http://www.nfwf.org/Pages/coralreef/home.aspx#

Guánica Lagoon restoration progress

The agricultural establishment (e.g., University Of Puerto Rico professors) has historically not been in agreement with restoring the Guánica Lagoon. Workshop participants felt that the agencies need to better understand how the farmers feel about the Lagoon restoration. **Fig. 5-1** shows the location of the Guánica Lagoon, and **Fig. 5-2** shows aerial photos of the region from 1950 and 2007.

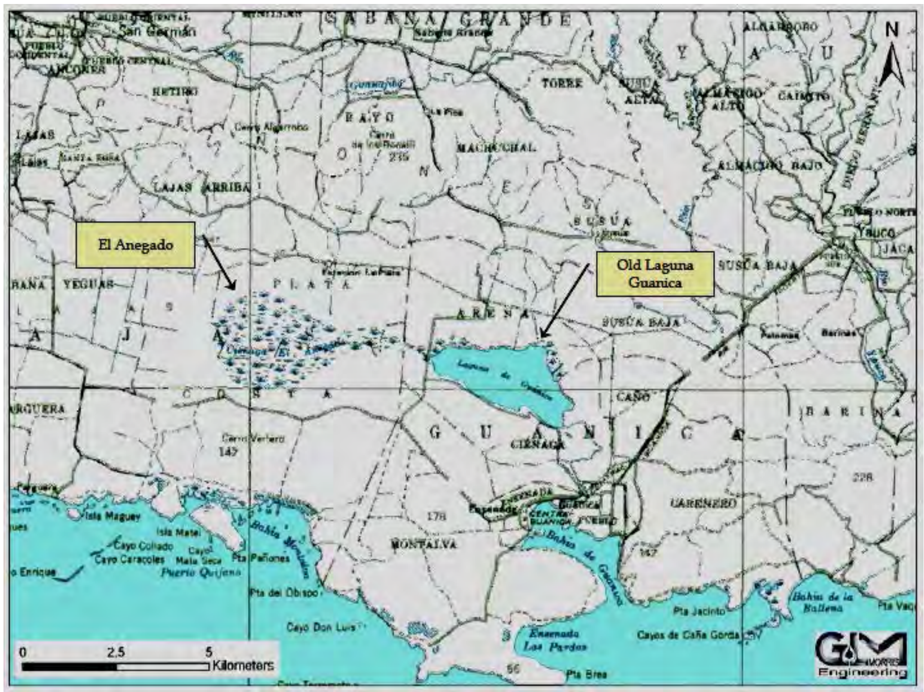

Figure 5-1. Map showing the location of the historic Guánica Lagoon (Greg Morris Engineering)

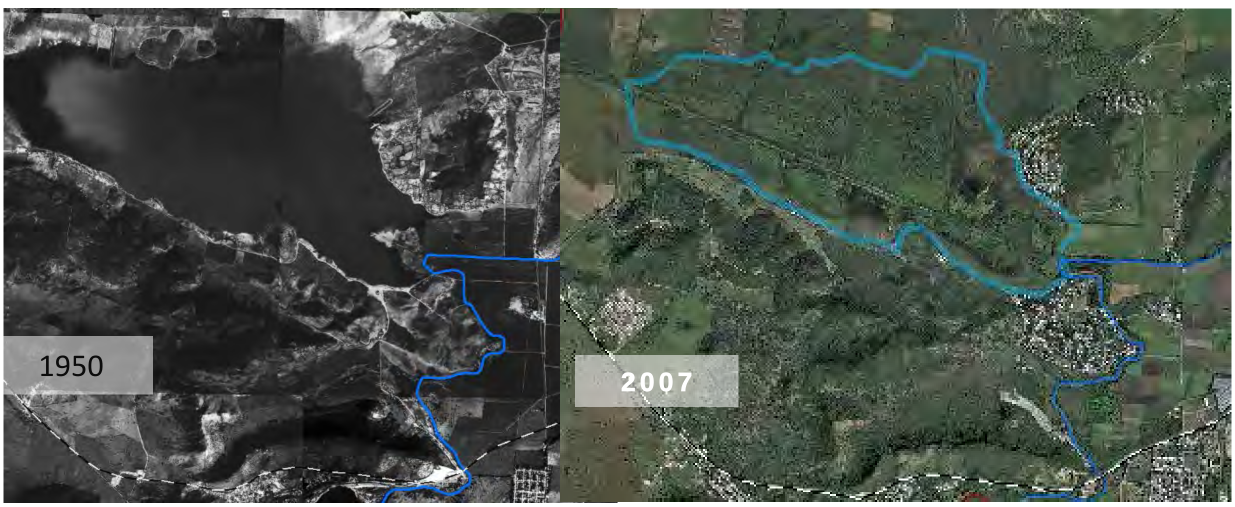

Figure 5-2. Aerial photos from 1950 (left) showing the Guánica Lagoon, and 2007 showing the area that was drained with the lagoon footprint superimposed (right)

Following the workshop, USDA-NRCS and the Center for Watershed Protection held a series of meetings and workshops with farmers in the Lagoon area to share information and better understand their concerns. The major concerns of the farmers are: 1) loss of agricultural production in areas that will be flooded; 2) that restoring the Guánica Lagoon will increase the drainage problems that already exist in the Valley, particularly where the drainage channels have not been properly maintained for the past decades; and 3) that the water table will rise, bringing underground salts to the surface, damaging productive agricultural lands, and causing loss of agricultural production.

To address the farmers' uncertainties, a series of studies were conducted: 1) an inventory of farms, 2) a hydrologic and hydraulic study, and 3) a groundwater and soil salinity study. These studies show more precisely the impact that restoring the Guánica Lagoon may have on the agriculture of the surrounding area.

Inventory of farms

Two open meetings where conducted with farmers to discuss the study and to get the farmer's support for the survey process. Three other meetings where held with the Guánica Office of the Puerto Rico Land Authority (PRLA) to identify lands owned by PRLA and information about the farmers that are renting the public lands for farming.

Protectores de Cuencas inventoried a total of 179 parcels with an average of 80 acres per parcel. Mr. Viquiera and Mr. Meyer-Comas (Protectores de Cuencas) visited thirty-eight farms between May 12, 2011, and October 18, 2011 (a total 15,678 acres) (**Fig. 5-3**).

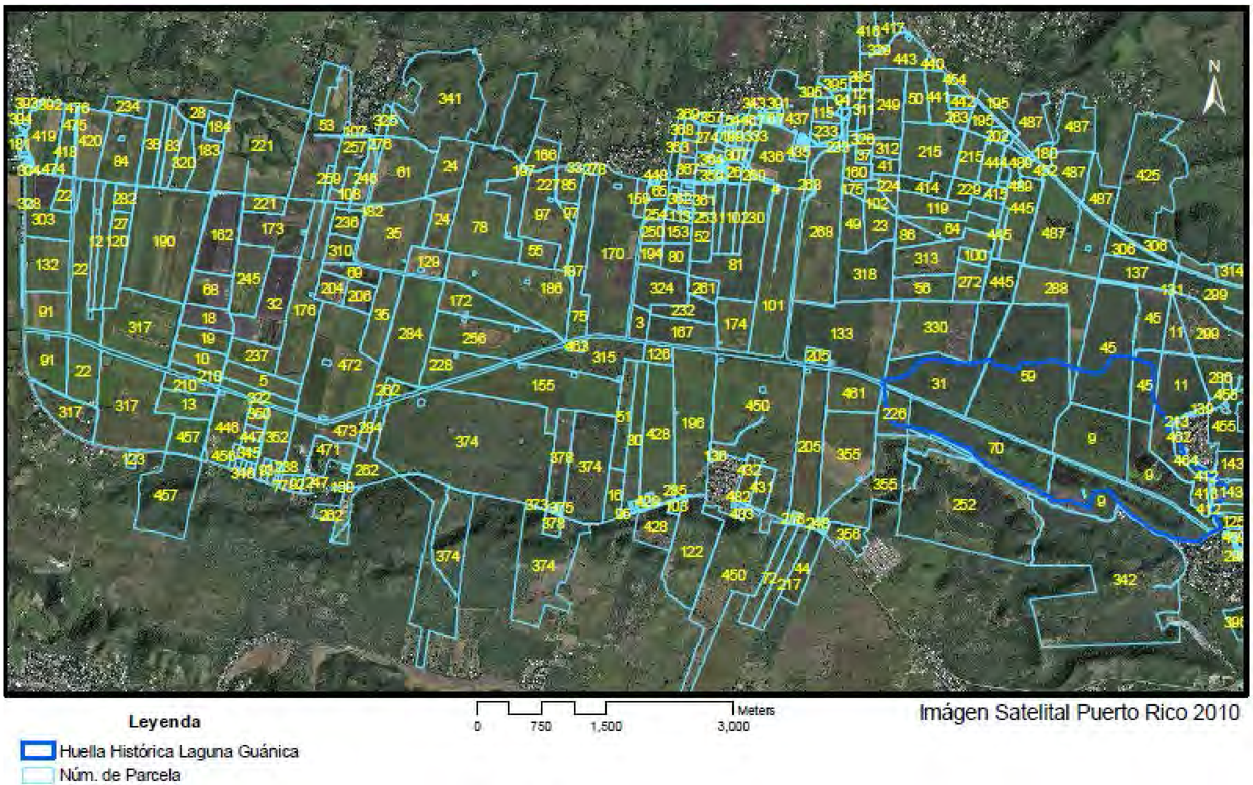

Figure 5-3. Parcels inventoried in the historic Guánica Lagoon region (Viqueira-Rios R and Meyer-Comas L. 2012)

After the inventory was conducted, two additional meetings were held with PRLA personnel to review the information gathered at the farms and farmers' meetings. Another meeting with farmers was conducted after completion of the study to present the results to the farmers.
The data collected on the farm parcels included crops, yields, fertilizer and pesticides, drainage and salinity problems. From that data, summary maps (**Figs. 5-4 and 5-5**) and economic estimates were prepared. Subareas of the Lajas Valley were created to help summarize the information on different areas of the valley–these are shown in **Fig. 5-6**.

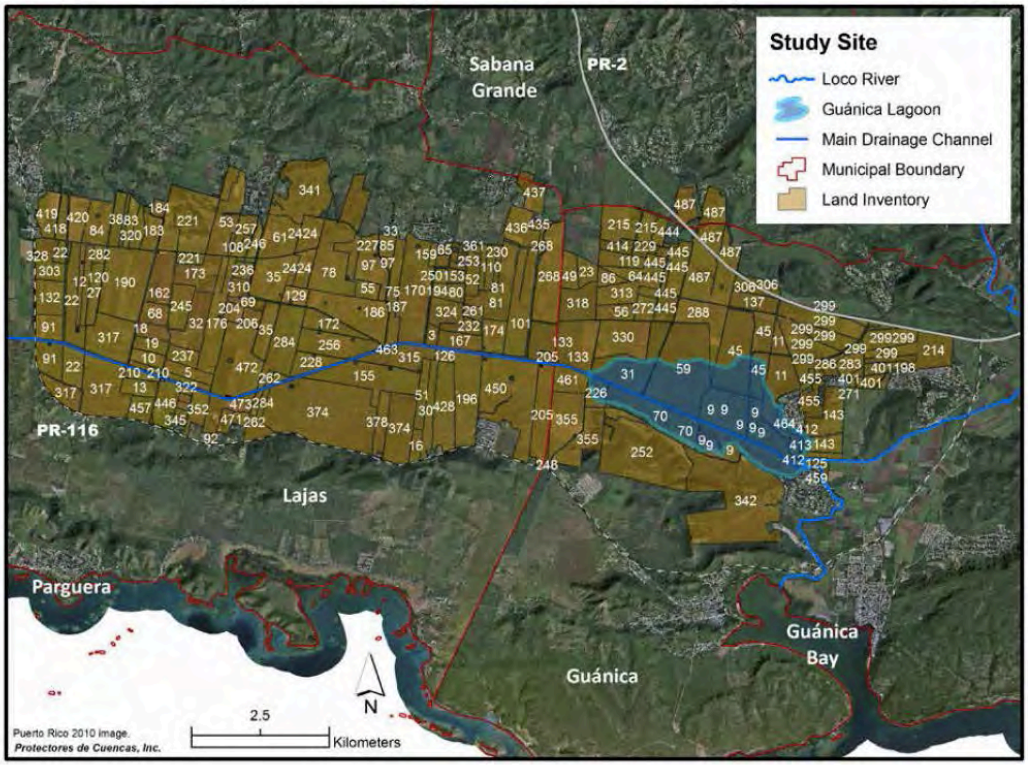

Figure 5-4. The surveyed parcels of the Lajas Valley below 5M elevation and an overlay of the historic lagoon area (Viqueira-Rios R and Meyer-Comas L. 2012)

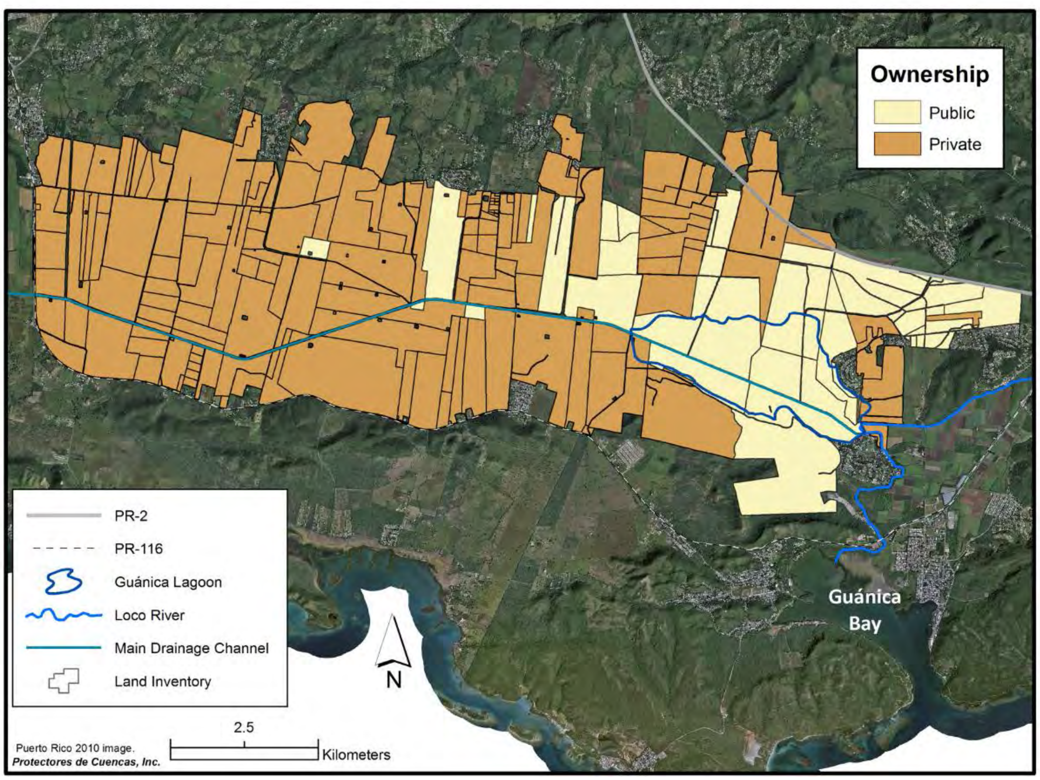

Figure 5-5. Land ownership in the historic Guánica Lagoon footprint (Viqueira-Rios R and Meyer-Comas L. 2012)

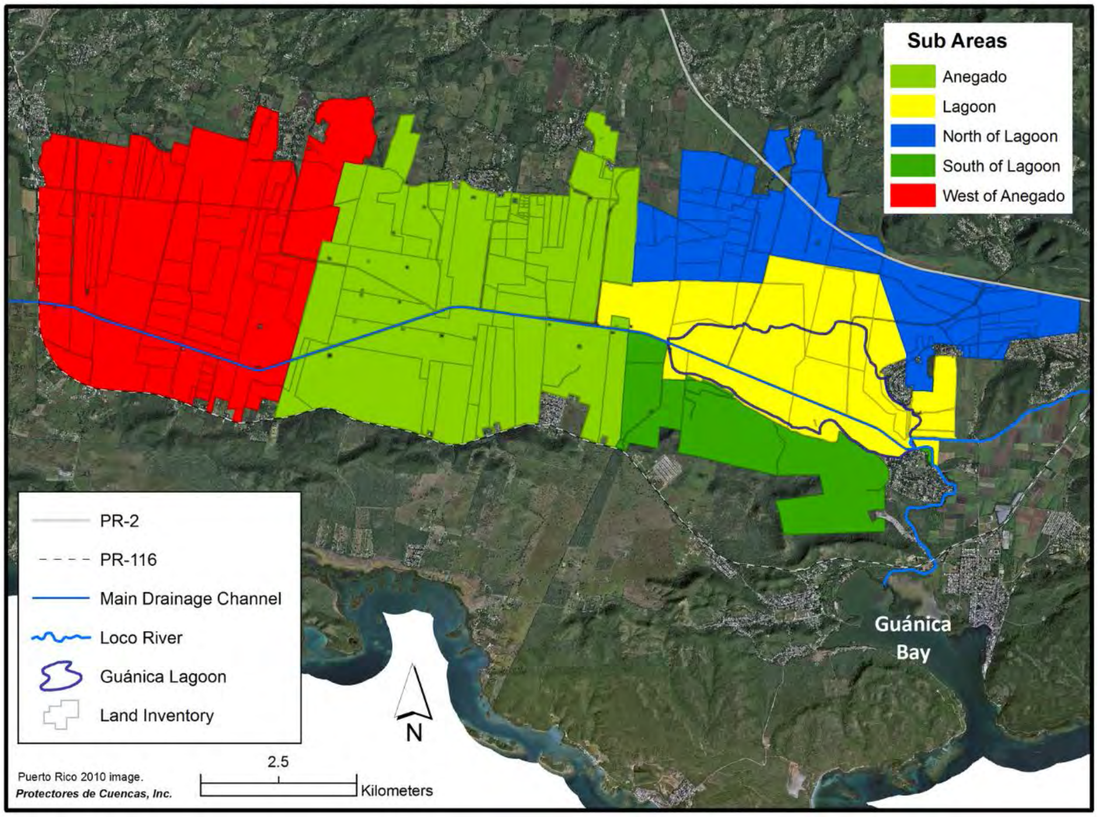

Figure 5-6. Sub areas in the study site (Viqueira-Rios R and Meyer-Comas L. 2012)

A total of 14,932 acres were surveyed. Of these, 5,545 acres are dedicated to forage (hay) production, 4,127 acres are used for grazing meat cattle, 1,288 acres are used for rice seed production, and 123 acres for horse production. Of the total area surveyed, 10,882 acres are privately owned (69%), and 4,050 acres are publicly owned (31%). The area of study generates a total of approximately $8,163,152 of gross income per year, including $259,887 for the lagoon area, $433,244 for south of the lagoon area, $819,522 for north of the lagoon area, $2,778,549 for the El Anegado area, and $3,871,449 for west of the El Anegado area.

Fertilizer and pesticide usage in the study area is relatively low as the inventory shows only 49 of 187 parcels apply fertilizer and generally at relatively low application rates. Fertilizer and pesticide usage is most commonly associated with rice production (100% of farms applying) and to a much smaller degree, hay production.

Based on the inventory, approximately 28 of 179 farms employ conservation practices. This not only indicates the potential for additional conservation measures that could be employed on farms, but also the nature of some of the farm operations, particularly the lack of fertilizer and the preponderance of hay operations and grazing operations in the Lajas Valley. Parcels that are applying conservation practices are in actual contracts with the Natural Resources Conservation Service (NRCS). These include a number of dairy operations where conservation practices are important to manage nutrients in particular.

Summary

- There is very limited annual production in the lagoon area–approximately $259,000 annually compared to the total contribution of over $8.1 million annually of the entire evaluated Lajas Valley area below 5 meters. The lagoon area (parcels adjacent or connected to the historic lagoon) is mostly cattle and hay production on land rented from the Puerto Rico Land Authority, and only a portion of this would be lost with the proposed restoration of the Guánica lagoon.
- Existing water drainage, salinity and water uprising problems are common yet relatively predictable based on soils and landscape position–these are reflected in the soil salinity and hydrologic modeling reports.
- Improved drainage, particularly the ability to more rapidly drawdown large storm events from the Lajas Valley, may help to increase agricultural production–one of the major limitations is that the drawdown happens from only one confined channel. Adding an additional channel that could also be used by migrating fish would help to limit inundation times of the valley.

Hydrologic and hydraulic study

Greg Morris and Associates COOP (GMA COOP) conducted a modeling study to incorporate recent data (1999-present) and to model events of higher frequency (2 to 50 years). GMA modeled 4 different water levels–current, 2.4m, 2.7m, and 3.1m. They also considered an additional secondary scenario, no water in the Rio Loco, to represent localized rain events over the Lajas Valley without the Rio Loco controlling the water levels within the lagoon. The numerical model summarized below demonstrated very little changes in the volume of various flooding events (2yr, 50yr and 100yr) due in part to the small volume of the lagoon compared to the volume associated with larger flow events.

- Numerical Model: ICPR/FLOW-2D
- Rainfall Frequency Data: NOAA Atlas 14
- Recent detailed topographic survey of the Lajas Valley completed for this study
- Models Calibration: Eloisa event from1975 (ICPR) and an isolated event on August 3, 1963 (FLOW-2D)
- Based on input from farmers, a model simulation was also run to determine the duration of inundation to insure the duration of inundation would not be sufficiently changed over existing conditions

A series of outputs from the model runs are shown in **Figs. 5-7 through 5-9**.

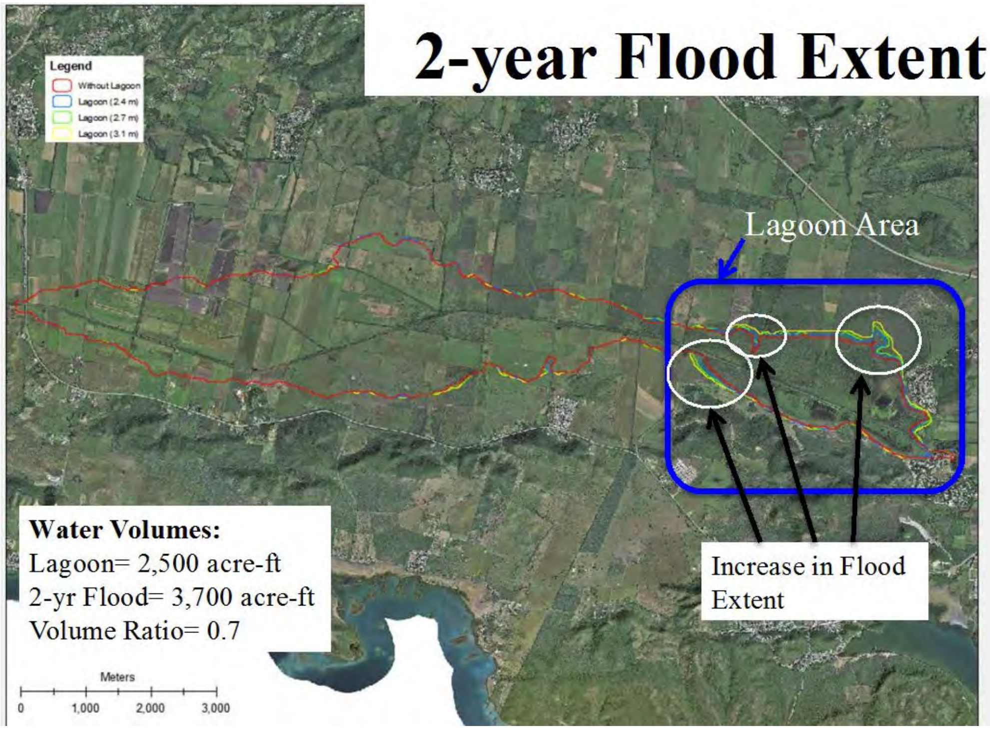

Figure 5-7. Model output for the 2-yr flood event under various lagoon height scenarios (Greg Morris Engineering)

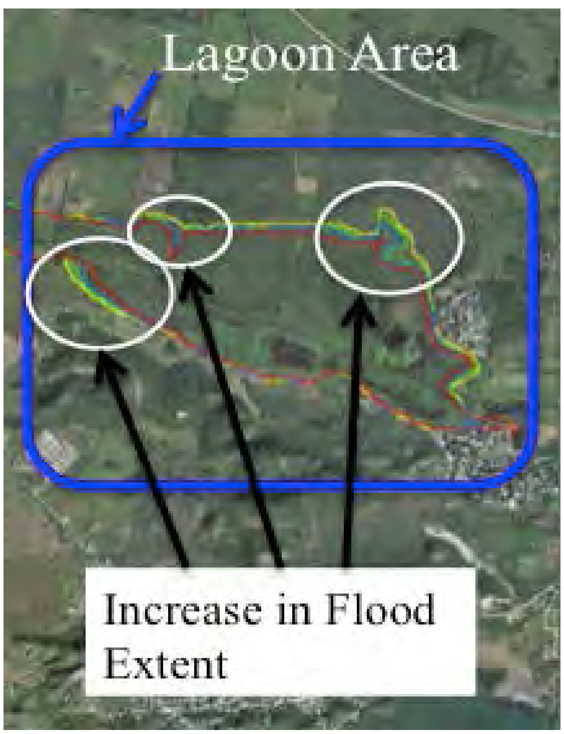

Figure 5-8. The majority of flooding increases takes place on forested land, except for a small portion on the left side of the figure, which is hay land. In total, increased flooding is projected to impact less than 25 acres. (Greg Morris Engineering)

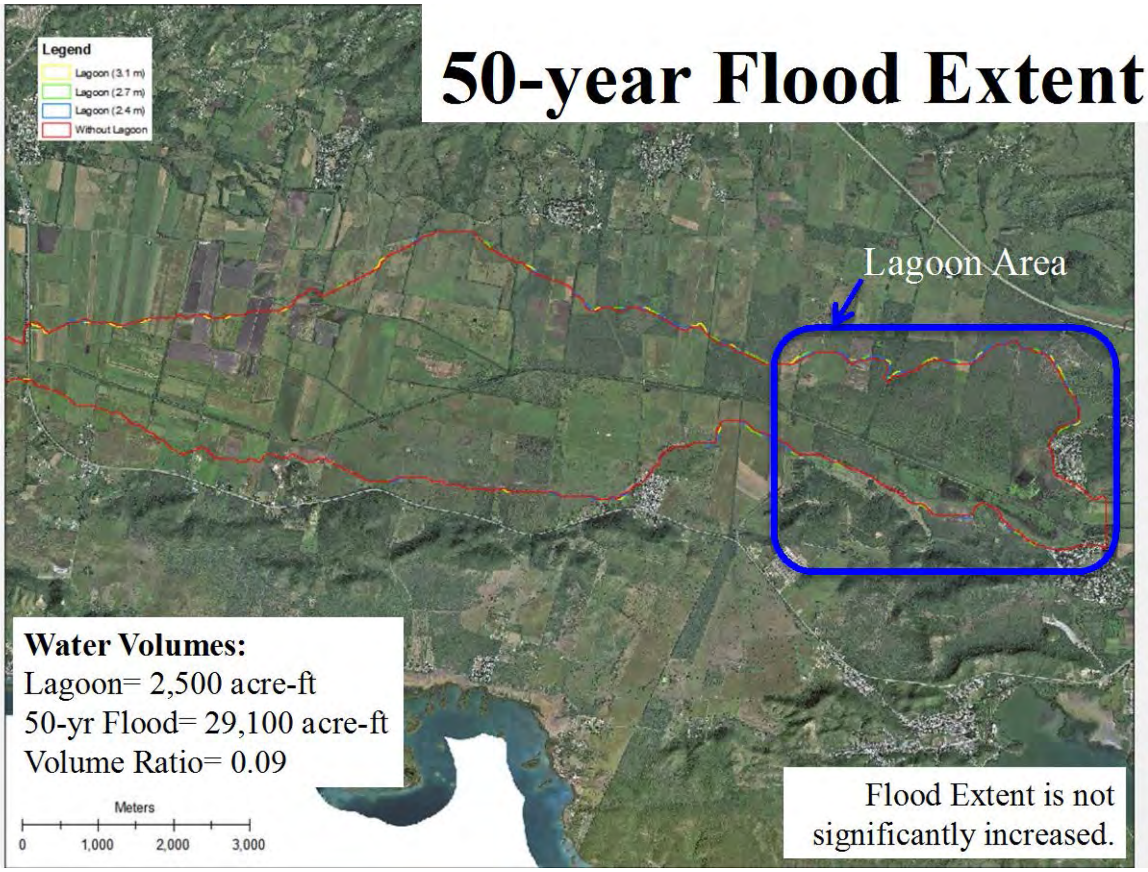

Figure 5-9. The 50-yr flood event projection with no lagoon (current condition in red) vs. the flood projections (thin lines – yellow, green, blue) shows almost no additional flooding. (This is due in part to the small volume of the lagoon compared to the large volume associated with a 50-year event ~8.6%) (Greg Morris Engineering)

Restoration of a 950-acre lagoon versus the historic 1200 acres is estimated to minimize impact to agricultural land and maximize both ecological and economic benefits**.** Evaluated lagoon water level will not increase regulatory flood levels by more than 0.15 m in compliance with Planning Board regulations. Flood extent will not be significantly changed by the increase in flood water levels resulted from the Guánica Lagoon restoration.

Groundwater and soil salinity study

A study was undertaken to better understand the existing impact of salinity and hydrology on the agricultural lands in the valley (**Fig. 5-10**). The study consisted of analyzing the soils and mapping electrical conductivity. Soil analysis included measuring the clay content, mineralogy, salts and moisture content that can influence the electrical conductivity of the soil. Soil salinity was measured using inductive electromagnetic techniques to determine the conductivity of soils. Electrical conductivity devices produce an electric field, which in a salty soil produce a second electric field. In addition, over 90 samples were analyzed using the extracted paste method for soil salinity to provide calibration points for the duel electromagnetic device. The National Soil Salinity Expert at the USDA Central National Technology Service Center (CNTSC) in Texas supervised this work.

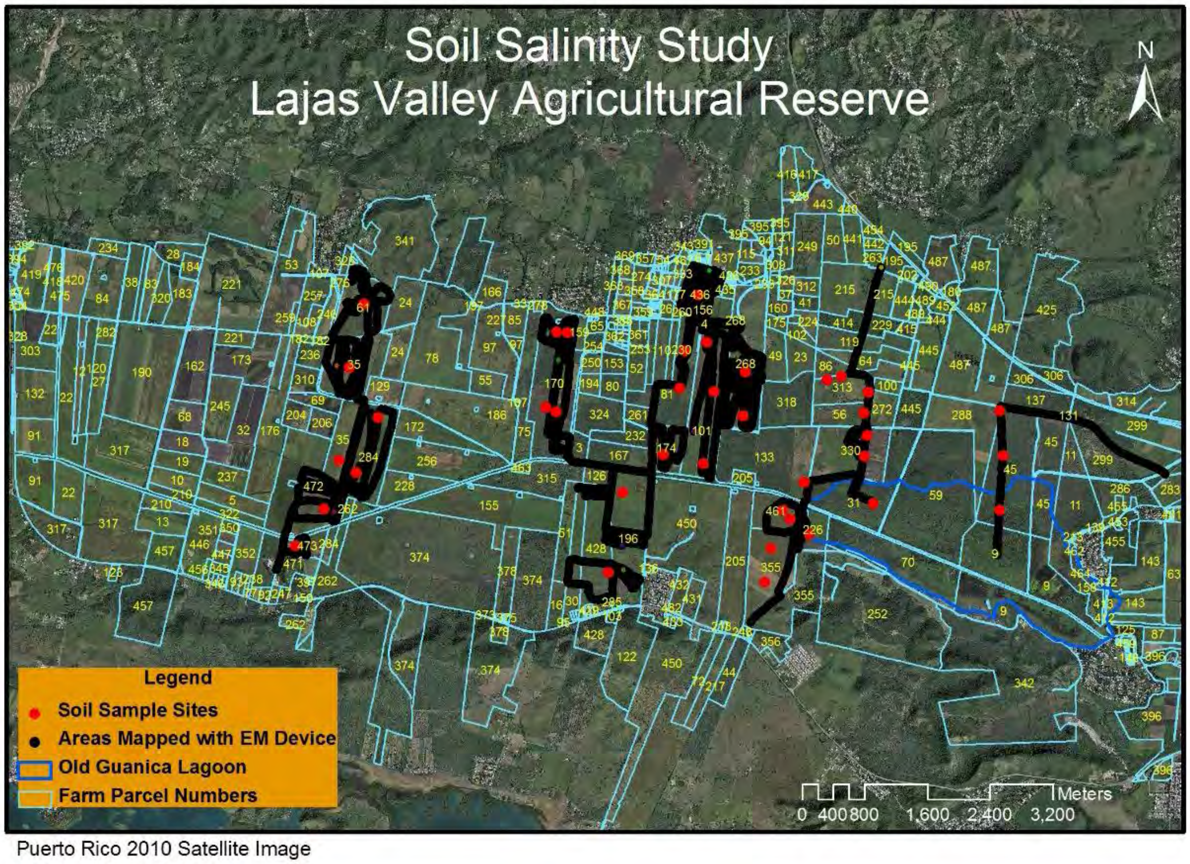

Figure 5-10. Soil salinity study, Lajas Valley Agricultural Reserve (source: Weber 2012)

The soils data for Guánica Clay in Web Soil Survey, the electrical conductivity mapping with the Dual EM, and the soils laboratory analysis mutually support the following conclusions.

1. The Guánica Lagoon existed as a recharge depressional wetland prior to drainage. This wetland received surface runoff from the Lajas Valley and ponded water above a deeper groundwater table, from which it was hydraulically disconnected.
2. Minerals, including salt, which are dissolved with surface runoff water, move slowly downward through very low permeability soils. Vegetation removes water from this unsaturated profile, leaving behind salts.
3. The presence of salts in the soil profile is associated only with areas where surface ponding exists.
4. Since there is no shallow water table capable of moving salt-laden water into or out of the lagoon, there is no potential for groundwater effects to increase salinity levels in land areas outside of ponded areas.
5. The areas subject to increases in salinity from an increase in depth will be limited largely to the areas actually subject to increased inundation only.
6. The restoration of the original hydrology of Guánica lagoon has the potential to provide nutrient cycling for surface runoff originating in the Lajas Valley.

If the lagoon were supplied with groundwater, the groundwater surface profile would be driven upward at the margins of the lagoon because of the planned increase in lagoon depth and duration of ponding. If this groundwater carried concentrations of salts, salinity effects would be felt in areas subject to this groundwater rise. However, evidence provided by soils, electrical conductivity, and soil laboratory analysis mutually support the conclusion that this is not a system supplied by groundwater.

The findings are consistent with a plot of the USDA national soil survey dataset, which demonstrates lower levels of salinity concentration in the historic lagoon area and the presence of groundwater seeps with high salinity levels at some of the historic wetland fringe areas and adjacent to geomorphic features including hillsides which create groundwater artesian pressure (**Fig. 5-11**). High salinity and saline soils are an issue in portions of the Lajas Valley for these reasons, and restoration of the lagoon will not impact or worsen those existing conditions. The soil salinity values were saturated paste data samples reported as Electrical Conductivity (EC) in the USDA/NRCS SSURGO database. The use of this data was coordinated directly with the National Soils Laboratory in Lincoln, NE. Higher concentrations of soil salinity are presumably due to areas of vertical movement due to artesian pressure from the surrounding hillsides and historical wetlands when they fringed the historic sea in the Lajas Valley.

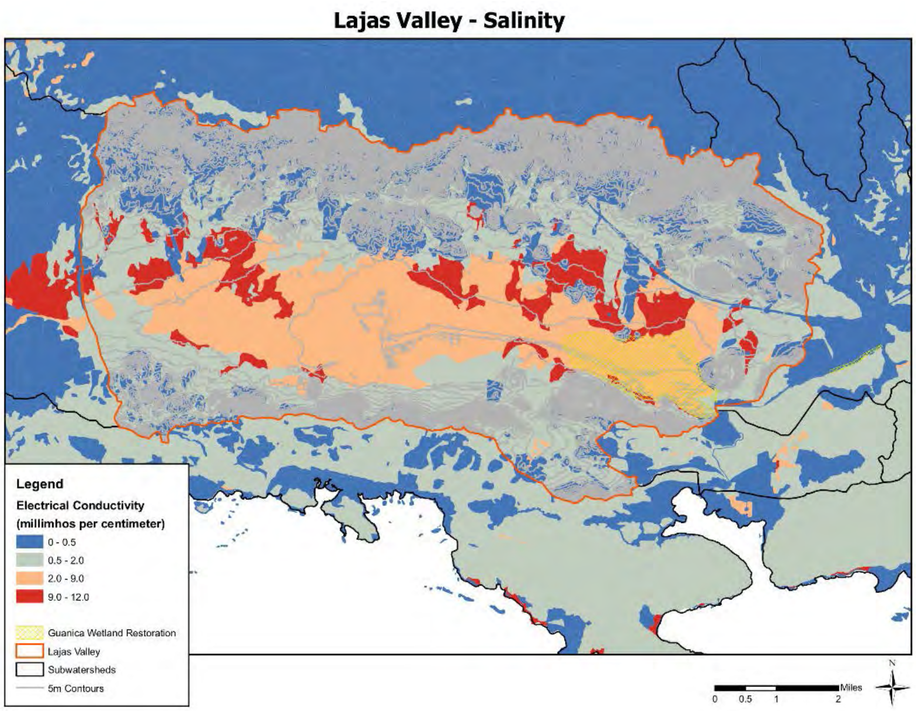

Figure 5-11. The surface salinity layer, Lajas Valley. The areas of highest soil salinity (3.0 - 6.0 mm/cm) in magenta, the areas of medium salinity (0.5-3.0 mm/cm) in yellow/tan, and areas of lowest salinity (<0.5 mm/cm) in blue; in addition 1 meter contour lines based on Lidar data are shown (source: Weber 2012).

Socioeconomic study of the Guánica Lagoon

A socioeconomic study of Guánica lagoon has been funded by PRDNER and is currently underway. It is being led by economist Alfredo Izzarry Mora of the University of Puerto Rico Mayagüez (UPRM) and Protectores de Cuencas. The financial costs and benefits of lagoon restoration are being evaluated and will be summarized in a report. In addition, public meetings of stakeholders are occurring to provide input into the study.

Hydro-seeding *(source: Sturm et al. 2012)*

Ridge to Reefs, Inc. and Protectores de Cuencas held an Exposed Soil Roundtable in the upper Guánica Bay Watershed with experts in plants, soils, restoration, agronomy and erosion and sediment control from NRCS, FWS, NOAA and NC State University. The roundtable proposed several mulch/seed mixtures consisting of local materials that were tailored to high-mountain and dry coastal sites in Puerto Rico.

Ridge to Reefs, Inc., and Protectores de Cuencas purchased a hydro-seeder and established ten plots to test various hydro-seeding mixtures in an effort to determine their effectiveness and cost effectiveness (**Fig. 5-12**). The initial plots were tested at a 70-75% slope with unconsolidated soil and an 85-90% slope with a mix of consolidated (more rock and compacted soil) and unconsolidated (less compacted soil). Together these represent some of the more extreme conditions encountered in the high mountain areas, and if effective, stabilization can occur on these plots–similar methods should be applicable to less severe slopes.

Based on the test results, the methods were used on a larger and broader scale and to diversify the types of sites, which included two farm sites and one commercial site: 1) Finca Santa Rita–a 3-acre site composed of a conveyance channel and a sediment basin; 2) Finca La Paz–a farm site composed of 2 acres of hydro-seeding steep slopes in the Lajas Valley; and 3) Hardware Store (ACE) Ferreteria Solar El Almacigo, where 1 acre of highly erodible bare soil was stabilized very close to a direct tributary of the Rio Loco in Yauco. Each of the sites resulted in very high levels of stabilization and vegetative cover.

These methods are applicable to other sites across the Caribbean and likely also in tropical areas of the Pacific.

Figure 5-12. Protectores de Cuencas and Ridge to Reefs Inc., hydro-seeding a steep slope along the side of a mountain road in the Guánica Bay Watershed (photo provided by Paul Sturm)

Shade-grown coffee initiative

Significant sources of sediment are being addressed by the conversion of sun-grown coffee to shade-grown coffee from the upper Guánica Bay Watershed near the ridges, which receive over 100 inches of rainfall annually. To date, 28 farms have contracts to convert over 1500 acres back to shade coffee as part of NRCS and USFWS Partners in Wildlife efforts. A set of standards has been adopted including best management practices for managing the shade canopy, erosion reduction, and minimizing energy and water use in processing.

Protectores de Cuencas has led a roundtable of coffee farmers, agencies, NGOs and other stakeholders to develop a set of criteria for shade-grown coffee farms (**Fig. 5-13**). Certification labeling and logos have been created and adopted by the roundtable group (**Fig. 5-13**). Next steps include certifying farms, training farmers to manage the transition from sun-grown to shade-grown coffee, training coffee pickers to maximize the coffee's value, and assisting farmers in helping to develop coffee markets both domestically and internationally for the shade-grown coffee market.

Figure 5-13. Shade-grown coffee roundtable and proposed certification label (photos provided by Paul Sturm)

Shade-grown coffee has the potential to improve the economics, habitat and ecological value of the area and increase resilience to drought and temperature fluctuation associated with climate change. It also represents a way for the historic coffee-based communities in Puerto Rico to help address food and economic security while restoring natural functions of the forest, soils, the health of rivers and streams, and ultimately improve nearshore coastal habitat. The effort is in the process of becoming national policy in Puerto Rico, which will benefit other watersheds and coral reef areas.

Together with hydro-seeding of bare soils by Protectores de Cuencas and Ridge to Reefs, the criteria is also being incorporated into the "Bosque Modelo" (Model Forest) criteria for Puerto Rico, which is part of a larger international movement of forest protection. These efforts recognize the need for systemic, institutional changes to achieve long-term sustainability and resilience of forests, adjacent coastal resources, including coral reefs, and local economies.

Baseline assessment

In 2013, NOAA's National Centers for Coastal Ocean Science (NCCOS), in partnership with NOAA's Restoration Center and the University of Puerto Rico at Mayagüez, released the results of an interdisciplinary assessment to help establish baseline conditions in and around Guánica Bay. Scientists assessed habitat types, coral cover, fish and chemical contaminant status in sediment and coral tissues (Whitall et al. 2013). Results from the assessment include:

- The Guánica study region is more degraded than the La Parguera region to the west. Percent-cover of hard corals, gorgonians and seagrass was lower in Guánica than in La Parguera.
- The pollutants measured in the sediments of Guánica Bay were among the highest concentrations of PCBs, chlordane, chromium and nickel ever measured in the history of NOAA's National Status & Trends, a nationwide contaminant-monitoring program that began in 1986.
- Because contaminant threshold values do not exist for coral, it is unclear what effect the observed contaminant levels might have on coral health. Future studies should consider fish tissue contaminants to assess whether there is an ecological or seafood safety issue related to contaminants in the Bay.
  - Accumulated sediment composition (i.e., land-based versus marine) is relatively uniform. Sediments on the reefs are coming from both land-based sources and re-suspension from Guánica Bay.
  - Nutrient concentrations track precipitation patterns, with higher phosphorus, ammonium and urea concentrations during the rainy season. In offshore waters, phosphorus rarely exceeded proposed coral health thresholds, however, nitrogen exceeded thresholds 10% of the time.

The preponderance of evidence presented in Whitall et al. 2013 suggests that this system is experiencing anthropogenic stress, which may be resulting in coral decline. Further monitoring and assessments are needed in order to detect changes in the ecosystem over a variety of time scales ranging from relatively short-term responses in sediment loading, to potentially decadal-long recovery processes for reef systems.

Coastal managers will be able to use the assessment to measure changes resulting from management actions in the Guánica Bay Watershed.

Grounding response program

US reefs are impacted by 3-4 large groundings and hundreds of small incidents annually. In the aftermath of groundings, impacted corals are often broken, dislodged, or flipped over. These fragments are subject to abrasion, scour, and sedimentation, which ultimately result in death. Unchecked, these damages can result in reef loss and instability. However, if dislodged fragments can be collected and stabilized shortly after physical impact then the probability of survival increases substantially (Rinkevich 2005; Edwards and Gomez 2007).

Response to physical impact is a jurisdictional priority in both Puerto Rico and USVI, an identified capacity gap in both jurisdictions, and a priority element of the draft Acropora recovery plan (NOAA 2014). As the primary federal natural resource trustee for coastal resources, NOAA has responsibility for ensuring the restoration of coastal resources injured by releases of hazardous materials and of damage caused by larger ship groundings. The territories are responsible for dealing with smaller groundings and damage caused by anchors and fishing gear. However, Puerto Rico and the USVI have limited funding and staff to deal with the groundings and requested that NOAA provide assistance to help stem the unchecked and unnecessary coral losses that were occurring after physical impact.

In 2009, NOAA established an emergency response support contract with a local firm to respond to physical impact and also provide additional restoration, research and monitoring activities in the region. Funding for this work was provided from NOAA's Restoration Center, the Coral Reef Conservation Program, Protected Resources Division, Assessment and Restoration Division and the South East Regional Office.

Additionally, NOAA and partner organizations have established coral nurseries in Puerto Rico and USVI (**Fig. 5-14**) to grow coral colonies in a relatively protected environment (ideally free of predators, disease, sedimentation, algae, etc.) and provide a source of corals that can subsequently be transplanted back out onto the reef or re-fragmented to expand the nursery (NOAA 2013 and Griffin 2014). In 2012, *Acropora palmata* nurseries were set up in Guánica after *A. palmata* thickets in the area were damaged by tropical storms. In 2014, NOAA began transplanting *Acropora cervicornis* from the nursery in Guayanilla to the reefs in Guánica.

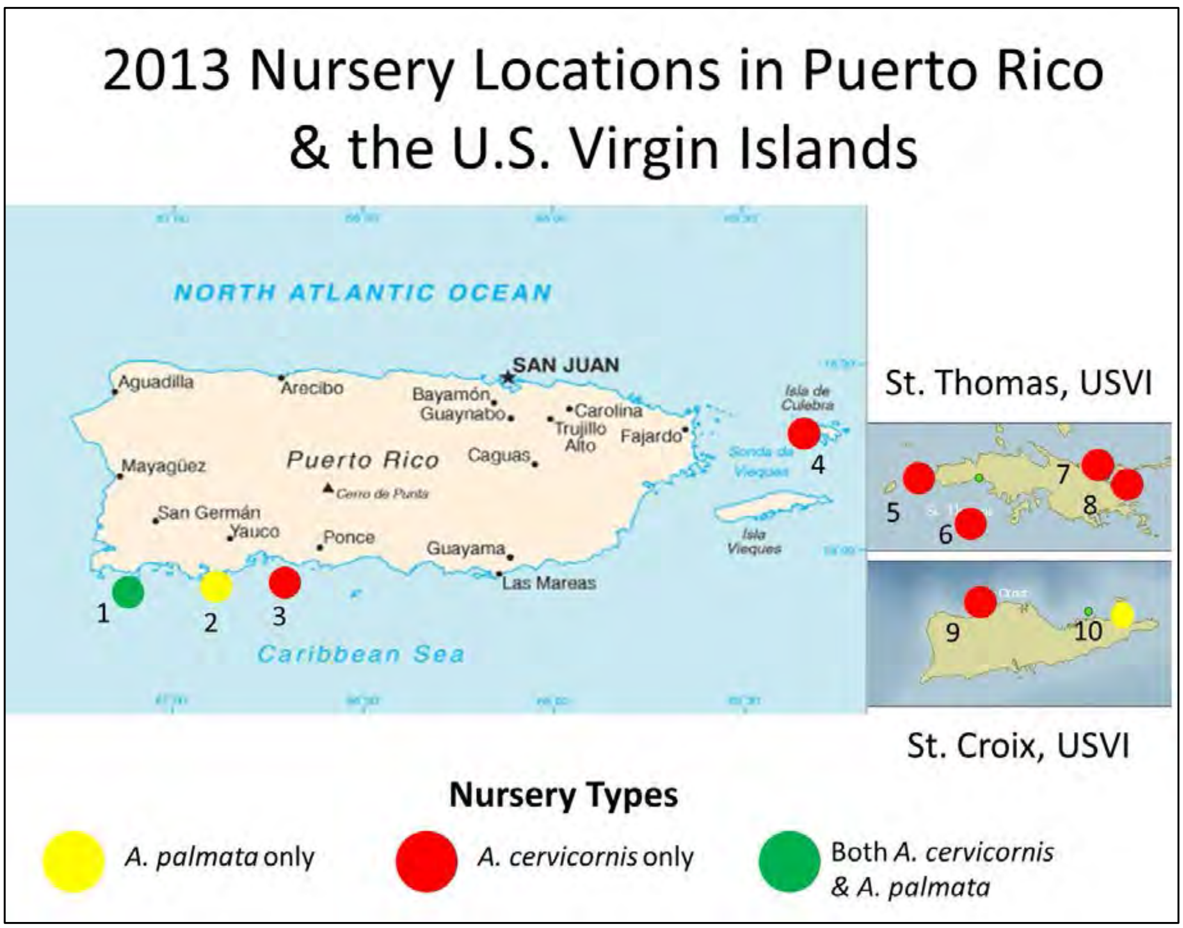

Figure 5-14. Location of coral nursery operations in Puerto Rico and the U.S Virgin Islands during 2013. 1) La Parguera, 2) Guánica, 3) Guayanilla, 4) Culebra, 5) West Cay, 6) Flat Cay, 7) Coki Point, 8) Lindquist Bay, 9) Cane Bay, and 10) Teague Bay (Griffin 2014)

DPSIR coral reef website and decision support

Based on the information gathered from this workshop (and from the previous workshop in the Florida Keys in June of 2009), EPA developed the on-line ReefLink Database (http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=242306) utilizing a systems approach to integrate ecosystem services into the decision process, including elucidating the linkages between decisions, human activities, and provisioning of reef ecosystem goods and services. The database employs the Driver-Pressure-State-Impact-Response (DPSIR) framework as a systems framework to ensure that critical concepts are not overlooked. This scientific and management information database utilizes systems thinking to describe the linkages between decisions, human activities, and provisioning of reef ecosystem goods and services. This database provides a navigable hierarchy of related topics and information for each topic including concept maps, scientific citations, management options, and laws.

The ReefLink Database can be used by: 1) the public to learn how their community may affect or benefit from coral reefs, 2) scientists to identify decision scenarios for which their research may be relevant, and 3) reef managers to understand how systems thinking can aid in identifying alternative management options. Although specifically designed for coral reefs, the database provides an example of using a systems thinking framework to integrate scientific research with decision-making, and in concert with the systems thinking tutorial (http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=235356), presents approaches that are broadly applicable to any environmental management problem. Usage statistics for ReefLink average about 200 hits per month.

EPA also established a project on the EPA's Web-based Environmental Science Connector (ESC). The Coral Reefs Puerto Rico ESC Project is now being used to share information. Documents, presentations, and web-links are all available on the Coral Reefs Puerto Rico ESC Project.

EPA took the workshop participants' ideas and concerns and developed an objectives hierarchy for the Guánica Bay Watershed. An objectives hierarchy arranges objectives from broad, overarching goals to lower-level, specific accomplishments or actions. Objectives in the uppermost levels of the hierarchy reflect broad or inclusive values. Progress towards these objectives is achieved by meeting lower-level, subordinate objectives. This is presented in Carriger et al. 2013.

The participants' response to the proposed decision support framework (DASEES) was very mixed. EPA has overhauled DASEES in response to their comments to try to make the system more responsive to decision-maker and stakeholders needs.

5.3 Summary

Since 2009, when the USCRTF designated the Guánica Bay Watershed as its first priority watershed partnership, a multi-agency and stakeholder partnership has worked together to address land-based sources of pollution. Watershed restoration is challenging and requires a commitment of resources and a willingness to work collaboratively. Watershed restorations are characterized by:

- Complexity and uncertainty
- Difficult judgments
- High stakes
- Limited resources
- Growing expectations

The 2010 Guánica Bay Decision-Making Workshop brought together representatives from federal and territorial government agencies, non-governmental organizations and academic institutions, and Guánica Bay Watershed citizens to develop a decision-analysis framework built upon the Guánica Bay Watershed Management Plan (CWP 2008). The workshop provided a forum for participants to 1) review characteristics of, and threats to the Guánica Bay watershed, coral reefs and coastal ecosystems, and 2) discuss ongoing and future restoration activities in the watershed.

The structured decision-making (SDM) approach demonstrated throughout the workshop helps watershed managers to define the problem(s) under consideration, develop a set of management options, determine who should be involved, create a shared understanding of how people with different interests and perspectives view different options, and compare the trade-offs created by each option. This process can be used in other watersheds to achieve similar objectives.

The Guánica Bay Watershed project has shown that the watershed approach, which includes stakeholder involvement and management actions supported by sound science and appropriate technology, can be used to protect coral reefs from land-based sources of pollution. Based upon the success of the Guánica Bay Watershed project, the USCRTF has designated two additional priority watersheds–Faga'alu, American Samoa in 2010, and West Maui, Hawai'i in 2011.

Appendix A. Puerto Rico Overview

Puerto Rico is an unincorporated territory of the United States of America. Puerto Rico is part of the Antillean archipelago located between the Caribbean Sea and the Atlantic Ocean and consists of the main island of Puerto Rico and a variety of keys and islands, such as the municipalities of Culebra and Vieques to the east, and the uninhabited islands of Mona, Monito and Desecheo to the west. The main and largest island is about one hundred eleven miles (160 km) long, thirty-six miles (60 km) wide, and approximately three thousand five hundred square miles (9,000 km^2) of land area (**Fig. A-1**). The population of Puerto Rico is estimated at 3.7 million people. The capital and largest city, San Juan, is home to over 400,000 people.

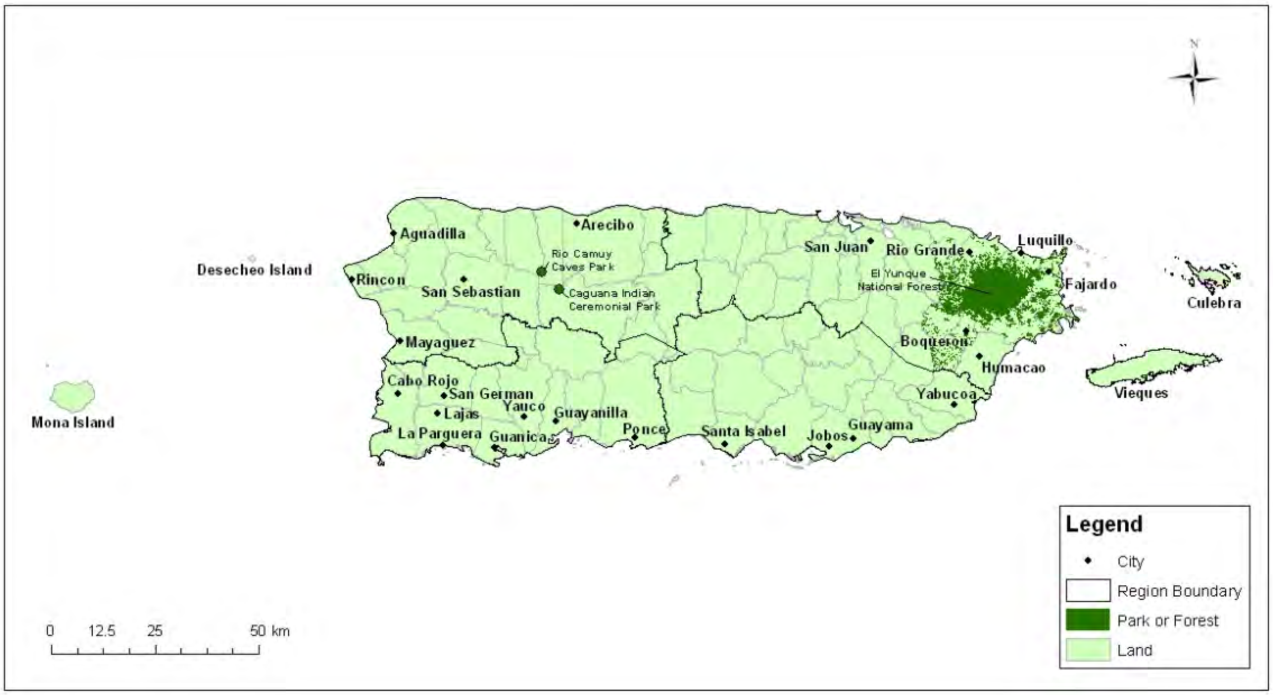

Figure A-1. Map of Puerto Rico showing municipality boundaries and forested areas

History

The earliest known settlers were the Ortoiroid people from the Orinoco region in South America who arrived 4000-5000 years ago. Between the 7th and 11th centuries, the Taíno culture developed on the island. By 1000 AD the Taíno culture was dominant (Rouse 1992). The Taíno called the island Borikén, “the land of the brave lord.”

Christopher Columbus landed in Borikén during his second voyage to the New World on November 19, 1493, and renamed the island San Juan Bautista in honor of Saint John the Baptist. In 1508, Juan Ponce de León founded the first European settlement, Caparra, not far from the modern city of San Juan. The Taíno Chief Agüeybaná welcomed Ponce de León. However, within a year, the Spanish had subjugated a majority of the Taínos and gained control over most of the island. Ponce de León was named Governor in 1509. He abandoned Caparra and relocated the settlement to a nearby coastal islet, named Puerto Rico (Rich Port). In the 1520s, the Spanish renamed the island Puerto Rico, and the port (Puerto Rico) became San Juan. After a Taíno uprising in 1511, a second settlement, San Germán, was founded on the southwestern part of the island.

As early as 1511, Dominican Friars preached against slavery and the inhumane treatment of the Taíno in Puerto Rico and Hispaniola. They were eventually successful in influencing the Spanish crown, however the high death rate among the Taíno due to enslavement and European diseases (smallpox, influenza, measles, and typhus) persisted. King Ferdinand II issued a royal decree that emancipated the Taínos in 1520. However, the harsh working conditions and epidemics of infectious disease had taken their toll on the Taínos–the 1530 census reported the existence of only 1148 Taíno remaining in Puerto Rico (Schimmer 2010).

The Spanish brought African slaves to Puerto Rico in 1513. By 1540 the gold reserves on the island were nearly exhausted. The farms originally established to supply cattle, grain, fruits, and vegetables to the mining camps continued to use slave labor to sustain cash cultivation of cassava, corn, tobacco, plantains, rice, ginger, cocoa, cereals, vegetables, tropical fruits, and medicinal plants (Schimmer 2010). Sugar was introduced in the early 1500s and coffee in 1736.

In 1873 slavery was abolished. In that same year, the first "Centrales" or factories with equipment operated by steam were established, greatly increasing the potential of sugarcane production, and by 1898, sugar was the most important cash crop.

Spain possessed Puerto Rico for over 400 years, despite invasion attempts by the French, Dutch, and British. In 1898, Spain was defeated in the Spanish-American War and ceded Puerto Rico to the United States under the terms of the Treaty of Paris. Since then Puerto Rico has remained under United States rule.

Puerto Ricans were granted U.S. citizenship in 1917 and having become a Commonwealth in 1947, have elected their own governor since 1948. In 1952 the Constitution of Puerto Rico was adopted with a democratically elected bicameral legislature. In November 2012, sixty-one percent of respondents voted in a non-binding referendum for statehood as the preferred alternative to the current territorial status.

Puerto Rico is divided into 78 municipalities, which are comparable to counties in the continental United States. Seven of these municipalities are at least partly in basins that contribute water to Guánica Bay (**Fig. A-2**). An eighth, St. Germán, overlaps only marginally with the Lajas basin, but water from the Lajas irrigation canal is filtered to supply public drinking water used in the city of San German.

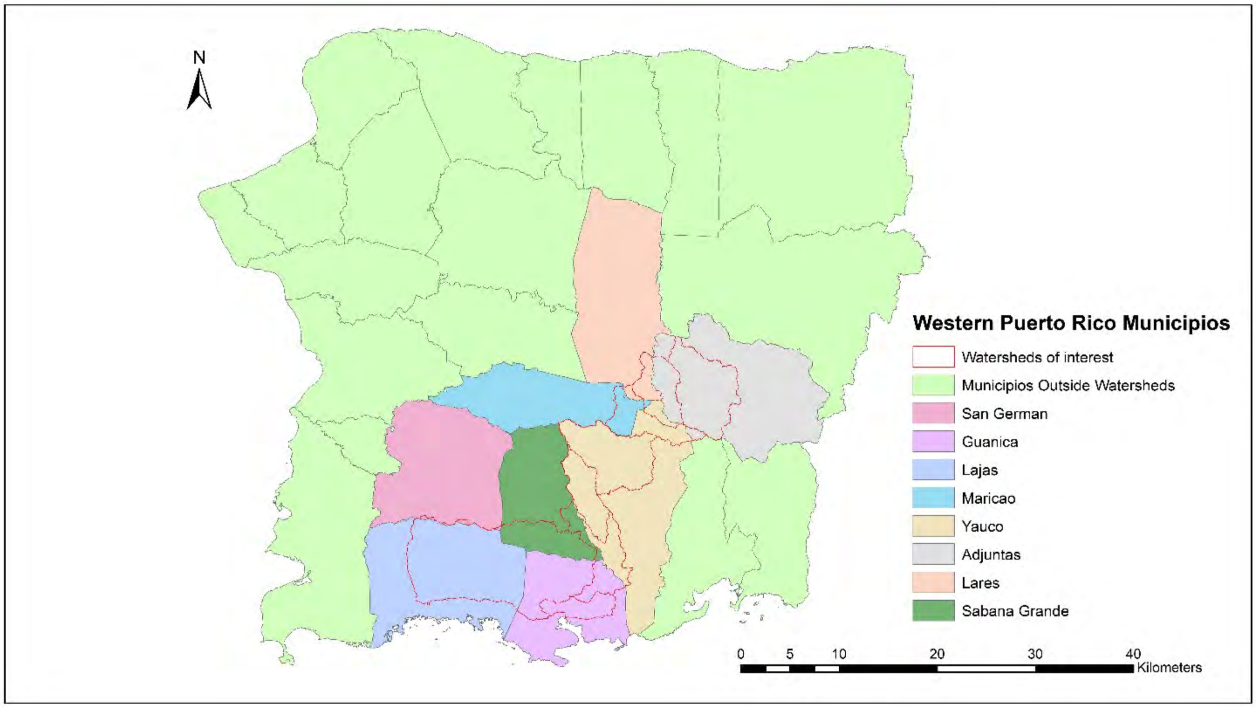

Figure A-2. Map of municipality boundaries (see legend) and watershed basins (red outline) in the Guánica Bay Watershed

Governance

A complex and multi-layered system of laws, organizations, and strategies exists to manage and govern uses of natural resources. Resource management authority is fragmented among a variety of federal, state, and local agencies, often resulting in redundant efforts, inefficiency, and lack of coordination among agencies. The current management framework has evolved through the collection of single-issue management laws and authorities, without regard for the interconnectedness of human activities and biological and physical systems.

U.S. environmental laws and regulations are applicable in Puerto Rico (i.e., Clean Air Act [CAA], Clean Water Act [CWA], Coastal Zone Management Act [CZMA], Coastal Zone Act Reauthorization Amendments of 1990 [CZARA], Coral Reef Conservation Act [CRCA], Endangered Species Act [ESA], Farmland Protection Policy Act, Fish and Wildlife Coordination Act [FWCA], Lacey Act, Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 [MSA], and National Environmental Policy Act [NEPA]).

The U.S. Code also includes a section (48 USC Chapter 4) specially addressing the relationship with Puerto Rico and the authorities of Puerto Rico as a U.S. territory and commonwealth.

Federal organizations with natural resource missions and regulatory authority that operate in Puerto Rico include the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Agriculture (USDA), U.S. Environmental Protection Agency (EPA), and U.S. Fish and Wildlife Service (USFWS).

At the Commonwealth level, the executive branch of Puerto Rico's government operates through two distinct administrative structures that operate independently: the agencies and departments, which constitute the "central government" of the Commonwealth, and the state-owned "public corporations”. The public corporations are usually located outside government departments; a group (as opposed to the governor alone) appoints their boards of directors; and the boards of directors appoint their managers. Currently there are 51 public corporations in operation which generate annual revenues of $8.9 billion, equivalent to approximately 13 percent of Puerto Rico’s GNP (**Table A-1**).

Table A-1. Puerto Rico public corporations

Name in English	English Abbreviation	Name in Spanish	Spanish Abbreviation	Industry
Automobile Accident Compensation Administration	PRAACA	Administración de Compensación por Accidentes de Automóviles	ACAA	Insurance
Agricultural Insurance Corporation	PRAIC	Corporación de Seguros Agrícolas	CSA	Agriculture
Aqueducts and Sewers Authority	PRASA	Autoridad de Acueductos y Alcantarillados	AAA	Public utility
Authority for the Financing of Industrial, Touristic, Educative, Medical and Environmental Control Facilities	AFITEMECF	Autoridad para el Financiamiento de Facilidades Industriales, Turísticas, Educativas, Médicas y de Control Ambiental	AFICA	Banking
Authority for the Financing of Housing	PRAFH	Autoridad para el Financiamiento de la Vivienda	AFV	Banking
Authority for the Financing of the Infrastructure of Puerto Rico	AFI	Autoridad para el Financiamiento de la Infraestructura de Puerto Rico	AFI	Banking
Caño Martín Peña ENLACE Corporation	ENLACE	Corporación del Proyecto ENLACE del Caño Martín Peña	ENLACE	Real estate
Cardiovascular Center of Puerto Rico and the Caribbean Corporation	CCPRCC	Corporación del Centro Cardiovascular de Puerto Rico y el Caribe	CCCPRC	Healthcare
Commission on Traffic Safety	PRCTS	Comisión para la Seguridad en el Tránsito	CST	Insurance
Comprehensive Cancer Center	PRCCC	Centro Comprensivo de Cáncer	CCCPR	Healthcare
Conservatory of Music Corporation	PRCMC	Corporación del Conservatorio de Música	CCM	Education
Convention Center District Authority	PRCCDA	Autoridad del Distrito del Centro de Convenciones	ADCCPR	Travel and leisure

Table A-1 (continued)

Name in English	English Abbreviation	Name in Spanish	Spanish Abbreviation	Industry
Corporation for the Development of Arts, Sciences and Cinematographic Industry	PRCDASC	Corporación para el Desarrollo de las Artes, Ciencias e Industria Cinematográfica	CDACIC	Entertainment
Corporation of Industries for the Blind, Mentally Retarded People, and Other Handicapped People	PRCIBMRPOHP	Corporación de Industrias de Ciegos, Personas Mentalmente Retardadas y Otras Personas Incapacitadas	CIRIO	Industrial development
Credit Unions Supervision and Insurance Corporation	PRCUSIC	Corporación para la Supervisión y Seguros de Cooperativas de Puerto Rico	COSSEC	Insurance
Economic Development Bank	EDB	Banco de Desarrollo Económico	BDE	Banking
Electric Power Authority	PREPA	Autoridad de Energía Eléctrica	AEE	Public utility
Government Development Bank	GDB	Banco Gubernamental de Fomento	BGF	Banking
Health Insurance Administration	PRHIA	Administración de Seguros de Salud	ASES	Healthcare
Highways and Transportation Authority	PRHTA	Autoridad de Carreteras y Transportación	ACT	Transportation
Industrial Development Company	PRIDCO	Compañía de Fomento Industrial	FOMENTO	Industrial development
Integral Development for the Cantera Peninsula Company	PRIDCPC	Compañía para el Desarrollo Integral de la Península de Cantera	CDIPC	Industrial development
Institute of Puerto Rican Culture	IPRC	Instituto de Cultura Puertorriqueña	ICP	Entertainment
Lands Administration	PRLA	Administración de Terrenos	AT	Real estate
Lands Authority	PRLA	Autoridad de Tierras	ATPR	Agriculture
Maritime Transport Authority	PRMTA	Autoridad de Transporte Marítimo	ATM	Transportation
Medical Services Administration	PRMSA	Administración de Servicios Médicos de Puerto Rico	ASEM	Healthcare
Metropolitan Bus Authority	MBA	Autoridad Metropolitana de Autobuses	AMA	Transportation
Municipal Financing Agency	MFA	Agencia de Financiamiento Municipal	AFM	Banking

Table A-1 (continued)

Name in English	English Abbreviation	Name in Spanish	Spanish Abbreviation	Industry
Musical Arts Corporation	PRMAC	Corporación para las Artes Musicales	CAM	Entertainment
National Guard Institutional Trust	PRNGIT	Fideicomiso Institucional de la Guardia Nacional de Puerto Rico	FIGNA	Banking
National Parks Company	PRNPC	Compañía de Parques Nacionales	CPNPR	Real estate
Performing Arts Center Corporation	PRPACC	Corporación del Centro de Bellas Artes	CBA	Entertainment
Ponce Port Authority[1]	PPA	Autoridad del Puerto de Ponce	APP	Transportation
Ports Authority	PRPA	Autoridad de los Puertos	APPR	Transportation
Public Broadcasting Corporation	PRPBC	Corporación para la Difusión Pública	WIPR	Entertainment
Public Buildings Authority	PBA	Autoridad de Edificios Públicos	AEP	Real estate
Sales Tax Financing Corporation	COFINA	Corporación del Fondo de Interés Apremiante	COFINA	Banking
School of Plastic Arts	SPAPR	Escuela de Artes Plásticas	EAP	Education
Solid Waste Authority	SWA	Autoridad de Desperdicios Sólidos	ADS	Public utility
State Insurance Fund Corporation	PRSIFC	Corporación del Fondo del Seguro del Estado	CFSE	Insurance
Symphony Orchestra Corporation	PRSOC	Corporación de la Orquesta Sinfónica	COSPR	Entertainment
Trade and Export Company	PRTEC	Compañía de Comercio y Exportación	CCE	Industrial development
Tourism Company	Tourism	Compañía de Turismo	Turismo	Travel and leisure
Training and Work Enterprises Corporation	PRTWEC	Corporación de Empresas de Adiestramiento y Trabajo	CEAT	Education
University of Puerto Rico	UPR	Universidad de Puerto Rico	UPR	Education

Environmental protection in Puerto Rico is founded on the Public Policy Environmental Act (Law No. 9 of 18 Jun 1970, as amended). The Puerto Rico's Environmental Quality Board (EQB) sets out regulations and guidelines for the environmental protection of the island, reports to the U.S. Environmental Protection Agency (EPA), and must comply with federal requirements.

[1] Owned by the PR Executive Branch, but legally transferred to the municipality of Ponce.

Land-use planning, overseen by the Puerto Rico Planning Board, is an especially difficult problem, since residential, industrial, and recreational developers are all competing for about 30% of the total land area on an island that is already more densely populated than any state of the U.S., except New Jersey.

Puerto Rico has codified their laws, and these are available at: http://www.lexisnexis.com/hottopics/lawsofpuertorico/. The Code is divided into 34 titles (listed below), which deal with broad, logically organized areas of legislation. Titles most applicable to natural resource management and protection have been shown in **bold.**

Title 1. The Commonwealth

Title 2. Legislature

Title 3. Executive

Title 4. Judiciary

Title 5. Agriculture

Title 6. Nonprofit Associations

Title 7. Banking

Title 8. Public Welfare & Charitable Institutions

Title 9. Highways and Traffic

Title 10. Commerce

Title 11. Workmen's Compensation

Title 12. Conservation

Title 13. Taxation and Finance

Title 14. Private Corporations

Title 15. Sports and Parks

Title 16. Election & Registration

Title 17. Housing

Title 18. Education

Title 19. Negotiable Instruments

Title 20. Examining Boards & Professional Colleges

Title 21. Municipalities

Title 22. Public Works

Title 23. Public Planning & Development

Title 24. Health & Sanitation

Title 25. Internal Security

Title 26. Insurance

Title 27. Public Service

Title 28. Public Lands

Title 29. Labor

Title 30. Mortgage Law & Regulations

Title 31. Civil Code

Title 32. Code of Civil Procedure

Title 33: Penal Code

Title 34: Code of Criminal Procedure

Appendix B. Guánica Bay Watershed

Both Columbus and Ponce de Léon landed in Guánica, and Ponce de Léon founded a town called Guaynía on August 12, 1508. The word was derived from the Taíno indigenous culture that is believed to have meant, "Here is a place with water". Guaynía was destroyed during the indigenous uprising of 1511, and throughout the 16th century, was the object of constant threats and attacks from the indigenous Taínos, as well as from pirates and corsairs. The Spanish abandoned the area for some years, during which time San Juan became the capital of the island (Wikipedia 2014).

On July 25, 1898, American forces landed in Guánica during the Spanish-American War. American troops fought a series of battles with the Spanish and Puerto Rican troops, but the war was militarily inconclusive. Instead, it ended when Spain ceded Puerto Rico to the United States in accordance with the Treaty of Paris of 1898. A monument on the waterfront (**Fig. B-1**), a large coral boulder marked by the carved words, "3rd Battalion, 1st U.S.V. Engineers, September 16, 1898" commemorates the invasion. Today, July 25 is a Puerto Rican holiday, commemorating the day of the establishment of the Commonwealth of Puerto Rico in 1952. On March 12, 1914, the Legislative Assembly of Puerto Rico designated Guánica an independent municipality.

Figure B-1. The monument on the waterfront in Guánica, commemorating the U.S. invasion in September 1898 (photo provided by Debbie Santavy)

The Historic Guánica Lagoon

The Guánica Lagoon was a natural freshwater wetland and lagoon system that served as a sink for nutrients sediment and other contaminants (Warne et. al., 2005). The lagoon consisted of Laguna Guánica (a shallow coastal lagoon, **Fig. B-2**) and Ciénaga El Anegado (a freshwater herbaceous marsh dominated by Southern cattail [*Typha dominguensis]).* Ciénaga El Anegado was located about 2.7 km west of the western shoreline of Laguna Guánica (Ortiz-Zayas and Terrasa-Soler 2001). The Guánica Lagoon was drained in 1955 as part of an agricultural development project in the Lajas Valley. There is a proposed plan to restore Guánica Lagoon to reclaim its value as a wildlife refuge and ecological resource (CWP 2010; GME 1999a & 1999b).

Figure B-2. Former Guánica Lagoon area and the adjacent community of Fuig (photo provided by Tom Moore)

Guánica State Forest

Bordering Guánica Bay to the east and west is the Guánica State Forest (**Fig. B-3**), which is a subtropical dry forest. Subtropical dry forests occur in regions where there are several months of severe drought, with most rain falling during a (usually) brief wet season. The absence of precipitation during a prolonged portion of the year is what produces the dry forest, an ecosystem type characterized by plants and animals possessing specific adaptations to survive the dry season.

Guánica Dry Forest is one of fifteen (15) state forests maintained by the Department of Natural and Environmental Resources (DNER). It is the largest tract of tropical dry coastal forest still intact in the world (almost 9,500 acres) and is considered the best example of dry forest in the Caribbean (Ewel and Whitmore 1973). Due to its ecological importance, it has been designated as a United Nations International Biosphere Reserve in 1981 (Miller and Lugo 2009).

The forest offers 36 miles (58km) of trails through four forest types (deciduous trees, a coastal region with tree-size milkweed and nine-foot-tall prickly pear cactus, a mahogany forest, and twisted gumbo limbo trees). More than 700 plant species occur within the forest, 48 of which are endangered and 16 which are endemic to the forest.

Figure B-3. Photos of the Guánica State Forest

Guánica State Forest is home to about half of Puerto Rico's terrestrial bird species, including the Puerto Rican nightjar (*Caprimulgus noctitherus*) and the Puerto Rican emerald-breasted hummingbird (*Chlorostilbon maugeaus*), making it a bird-watcher's paradise (**Fig. B-4**).

Figure B-4. The Puerto Rican nightjar (*Caprimulgus noctitherus*) and the Puerto Rican emerald-breasted hummingbird (*Chlorostilbon maugeaus*) are both found in the Guánica State Forest (photos taken by Mike Morel and Jose Angel Torres)

The Punta Ballenas Reserve (**Fig. B-5**) is along the coast of the Guánica Forest and is managed as part of the forest. It contains a mangrove forest, submerged aquatic vegetation (SAV), and coral reefs (Miller and Lugo, 2009), which provide habitat for many aquatic species including manatees and crested toads, and nesting sites for Hawksbill turtles.

Just a mile off the coast is a tiny, uninhabited island, *Cayo Aurora,* commonly known as Gilligan's Island (**Fig. B-5**), also managed as part of the Guánica State Forest.


Figure B-5. The Punta Ballenas Reserve (left photo) and Cayo Aurora (Gilligan's Island) (right photo)

Ensenada, La Pieza and Fuig

Ensenada is a borough (or unincorporated community) located in the municipality of Guánica. In the 2010 census it had a population of 1705 inhabitants and a population density of 628.75 persons per km².

La Pieza is located on the west side of Guánica Bay at relatively low elevation. All of the homes in La Pieza (approximately 30) have septic systems. In Puerto Rico a septic system is a concrete box with holes. Water quality measurements taken around La Pieza have high levels of bacteria and ammonia, suggesting that many of the septic systems may be failing (Paul Sturm, personal communication).

Fuig is a town located in the municipality of Guánica on the south side of the historic Guánica Lagoon where the existing Lajas drainage channel enters the Rio Loco.

Yauco

The largest city within the Guánica Bay Watershed is Yauco (**Fig. B-6**), named after the Yauco River. Other rivers in the municipality are the Río Chiquito, Río Loco and Río Naranjo. On July 26, 1898, Spanish forces and Puerto Rican volunteers fought against the U.S. invasion forces in what became known as the Battle of Yauco of the Puerto Rico Campaign. The municipality has 20 wards and the main city, or Yauco Urban Zone. The population of Yauco was 42,043 persons in 2010. Yauco's main crops are coffee, plantains, oranges and tobacco. Yauco is known as "*El Pueblo del Café*" (coffee city).

Prior to the arrival of Spanish conquistadors, Yauco was the capital of Puerto Rico and was governed by Agüeybaná, who ruled over all other island chiefs. Agüeybaná received the Spanish conquistador Juan Ponce de Leon upon his arrival to Puerto Rico in 1508. Upon Agüeybaná's death in 1510, his nephew, Agüeybaná II, succeeded him. Agüeybaná II mounted an unsuccessful insurrection against the Spanish in 1511.

Yauco was the location of the first major land battle between Spanish/Puerto Rican and U.S. armed forces in Puerto Rico during the Spanish-American War.

In 1755, the Spanish settlers of the region built a small chapel and requested that the Spanish government allow the establishment of a municipality. In 1756, the King of Spain granted the settlers their request, and the town of Yauco was established.

In the 19th century, Spain issued the Royal Decree of Graces, by which non-Hispanic Catholics were encouraged to move to Puerto Rico for work. This brought an influx of Corsican families who selected coffee as their main crop, and by the 1860s the Corsican settlers were the leaders of the coffee industry in Puerto Rico. This industry was centered in Yauco.

The second and last major revolt against Spanish colonial rule in Puerto Rico, by Puerto Rico's pro-independence movement, known as the "Attempted Coup of Yauco", was staged in Yauco on March 26, 1897. It was during this uprising that the current flag of Puerto Rico was unfurled on Puerto Rican soil for the first time. The local Spanish authorities acted swiftly and put an end to the uprising.

Figure B-6. Colorful houses in Yauco and the Yauco town square

Susúa State Forest

The Susúa State Forest is located between Yauco and Sabana Grande in the foothills of the Central Range (La Cordillera). Elevations range from 262-1551 feet above the sea level. Mean annual precipitation is 56 inches, and mean annual temperature is 75 degrees Fahrenheit. Most rainfall falls as brief showers. Rainfall is generally heaviest in August, September and October and is lightest during February and March. Within the Susúa State Forest boundaries are born four rivers or their tributaries: Coco Rio, Rio Cañas, Rio Loco and Quebrada Grande.

The Susúa State Forest is influenced by a climatic transition zone (dry to moist) and a combination of volcanic and serpentine soils. Two vegetation associations (dry slope forest and gallery forest) have been delineated in the sub-tropical moist life zone. Forest native vegetation is represented by 157 tree species of which 18 species are rare or endangered. The trees are slender, open crowned, and usually less than 39 feet tall. The forest soil supports little herbaceous growth, leaving an open forest floor. The Rio Loco runs through the Susúa State Forest (**Fig. B-7**). Common species found in the Susúa forest include: Gumbo Limbo (*Bursera simaruba)* and Limpleaf spikemoss *(Selaginella laxifolia)*. The forest does not support significant agriculture or forestry.

Figure B-7. The Rio Loco runs through the Susúa State Forest

Forty-four bird species have been found in the Susúa State Forest, including the Puerto Rican nightjar (*Caprimulgus noctitherus*). The forest also supports at least seven species of amphibians and seven species of reptiles, including the Blue-Tailed Ground Lizard (*Ameiva wetmorei*) (**Fig. B-8**).

Figure B-8. The Gumbo Limbo (*Bursera simaruba)* and the Blue-Tailed Ground Lizard (*Ameiva wetmorei*) are found in Susúa State Forest

Lajas

The Lajas Municipality borders the Caribbean Sea, south of San Germán and Sabana Grande; east of Cabo Rojo; and west of Guánica. Lajas is spread over 11 wards plus Lajas Pueblo (the downtown area and the administrative center of the city). Lajas was officially established in 1883. In 2010 it had a population of 25,753.

The Lajas Valley is located in four municipalities: Lajas, Cabo Rojo, Guánica, and Sabana Grande. It is a large plain, ranging from 1.6 to 4.8 km in width, formed by a ridge of hills to the north (max altitude 300 m) and a secondary ridge of hills to the south separating it from the Caribbean Sea (max altitude 285 m) (Sotomayor-Ramírez & Pérez-Alegría, 2011). Lajas Valley lacks rivers, but has areas of very fertile soils. The Lajas Valley Irrigation Project, established in the 1950s, consists of a main canal that starts at a dam regulating the Rio Loco until the entrance to the Valle de Lajas, along the northern border of the valley, next to the base of the hills in Boquerón. The land south of the main canal is served from several lateral branches.

La Parguera, Lajas

South of semi-arid farmland in the Lajas Valley, the fishing village of La Parguera has developed into a popular resort center while maintaining much of its small town atmosphere. Guesthouses and inns, seafood restaurants, water sports and boating centers and small shops fan out from the small plaza (**Fig. B-9**). Although not part of the Guánica Bay Watershed, the coastal waters off La Parguera are impacted by activities within the Guánica Bay Watershed.

Figure B-9. The plaza in La Parguera (left) and stilt homes (casetas) on the bay

La Parguera Nature Reserve includes all the coastline of the municipality of Lajas extending 1 km towards land from the shore and 9 nautical miles offshore. The Department of Natural and Environmental Resources administers La Parguera Nature Reserve. The mangrove forests and estuaries within the reserve make it an ideal location for kayaking through its canals or simply observing local wildlife in its natural habitat. There are about 30 cays and islets, accessible only by boat (**Fig. B-10**).


Figure B-10. Offshore cays and islets (left) and mangroves (right)

In the evening, boats regularly leave La Parguera for the nearby Phosphorescent Bay ("*Bahía Fosforescente*"), where millions of microscopic organisms known as dinoflagellates sparkle when disturbed. This phenomenon occurs only in the tropics, typically in mangrove-protected bays. La Parguera, is one of three areas in Puerto Rico that has this remarkable year-round nighttime attraction. The others are in Vieques and Fajardo.

Paralleling the coast from the seaside village of La Parguera to the city of Ponce, the continental shelf drops off precipitously, producing a dramatic wall 20 miles long where visibility can exceed 100 feet. The wall descends in slopes and sheer drops from 60 to 120 feet before disappearing into 1,500 feet of sea. Scored with valleys and deep trenches, it is cloaked in deep-water gorgonians and other coral formations (**Fig. B-11**) (Morelock et al. 1977).

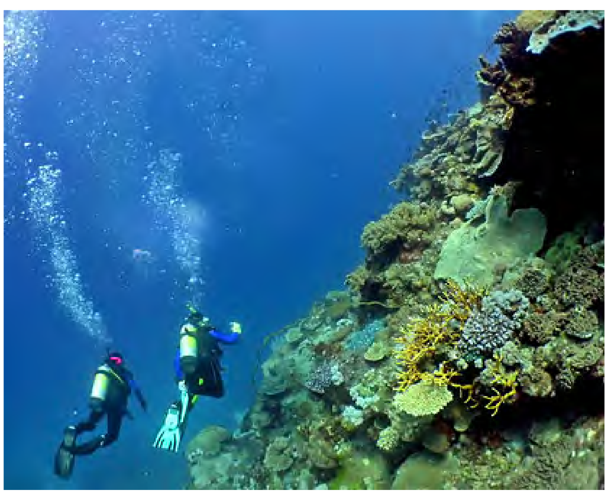


Figure B-11. The wall off La Parguera is a world-class dive destination

Appendix C. Socioeconomics of the Guánica Bay Watershed

The population of the Guánica Bay Watershed in 2010 was 19,427, decreasing from 21,888 in 2000 (U.S. Census Bureau 2012). Communities in the Guánica Bay watershed are relatively rural, with low population densities compared to the rest of Puerto Rico (**Table C-1**). There are, however, some population centers: Yauco is the 17th largest city in Puerto Rico with a population of 20,295, San German 12,055 (#25), Guánica 9,224 (#36), and Sabana Grande 8,961 (#38).

Table C-1. Demographic information for GB/Rio Loco municipalities and Puerto Rico

Municipality	Pop. 1990	Pop. 2000	Pop. 2010	Area (Km2)	Density 2010
Adjuntas	19,451	19,143	19,483	172	113.3
Guánica	19,984	21,888	19,427	138.35 (96)	140.4
Lajas	23,271	26,261	25,753	199.04 (158)	129.4
Lares	33,016	34,415	30,753	161.18	190.8
Maricao	6,206	6,449	6,276	96.0	65.4
Sabana Grande	22,843	25,935	25,265	96	263.2
San Germán	34,962	37,105	35,527	141.18	251.6
Yauco	42,058	46,384	42,043	178.1 (176.5)	236.1
Puerto Rico	3,522,037	3,808,610	3,725,789	9,104	409.2

Economic Status

Unemployment in Puerto Rico is around 14% but ranges as high as 20% in Guánica and Yauco municipalities. Median income for Puerto Rico is around $22,000, but is much lower ($11,000-15,000) in the Guánica Bay Watershed. Those living below poverty level are higher (~60%) in the region than for Puerto Rico as a whole (45%). By comparison Mississippi (the poorest state) had median household income of $38,014 in 2010, and the U.S. median income for 2010 was $51,625.

Economy

Gold was the first economy of Puerto Rico and the gold was sent to Spain. Puerto Rico's gold mines were declared depleted in 1570.

Initially, Spanish colonists had small subsistence farms. Export markets developed over time with export of three main crops to Europe: tobacco, sugar and coffee. Tobacco dominated early Puerto Rican exports, making up more than half of the export tonnage until the late 1600s. Sugar was first introduced in the early 1500s, and many small landowners relied on its export as a source of income. Coffee plants came to Puerto Rico with immigrants in 1736, but it was grown mostly for personal and domestic use. This changed in the mid 1800s, when French immigrants from the Mediterranean island of Corsica settled around Yauco and became well known as premium exporters to Europe.

The role of the three cash crops changed drastically in 1898 when Puerto Rico was ceded to the U.S. as a result of the Spanish-American War. This opened up U.S. markets for tariff-free trade and made trade with Europe more difficult due to embargoes. In the same year, two devastating hurricanes hit Puerto Rico, which largely destroyed the coffee industry. Sugar became the biggest crop.

Huge sugar mills such as the Central Guánica, located in the town of Ensenada, were established (**Fig. C-1**). It was one of the largest sugar mills in the Caribbean, and prior to World War II, it was one of the largest mills in the world. It ceased operations in 1982.

Figure C-1. View of the Central Guánica circa 1910

During the first decades of the 20th century, the sugar industry continued to develop, and by 1930, there were 44 mills in operation. In the 1940s, however, the mills began to weaken, due to the falling price of sugar, mismanagement by some administrators, the restriction of credit to independent farmers, and strikes by workers.

The first sugar factory closed in 1942, but this didn't mark the decline of the industry, as the record harvest came in 1952. However, it did mark declining support from the government, which had now shifted its focus to industrializing Puerto Rico's economy. Between 1951 and 1968, 17 mills ceased operations, and in 2000 the last mills closed.

In 1948 the United States government began Operation Bootstrap, which enticed U.S. companies to Puerto Rico by providing labor at costs below those on the mainland, access to U.S. markets without import duties, and profits that could enter the country free from federal taxation. As a result, Puerto Rico's economy shifted from agriculture to manufacturing and tourism.

Since that time, the manufacturing sector has shifted from labor-intensive industries (e.g., manufacturing of food, tobacco, leather, and apparel products) to more capital-intensive industries (e.g., pharmaceuticals, chemicals, machinery, and electronics).

However, being an island nation prone to severe floods and droughts, food security is also important. Consequently, Lajas Valley was established as an Agricultural Reserve in 1999, by enabling legislation, Law 277. However, 90% of the food currently consumed in Puerto Rico is imported.

Agricultural production in Lajas Valley is important economically as well. On the lands of the Puerto Rico Land Authority (2818 acres), farm income totaled $4,300,158 annually (2009-2010). Crops include: coffee, citrus, plantains, bananas, tomatoes, peppers, papaya, pumpkins, cantaloupes, and other vegetables. Area farmers also produce beef, pork, sheep, goats, and eggs.

Tourism is an important component of Puerto Rican economy supplying an approximate $1.8 billion annually. Between 2000 and 2005, an average of 3,407,483 overnight visitors per year visited Puerto Rico. Three quarters of the visitors were from the Americas. Coral reefs provide substantial benefits to communities throughout Puerto Rico. Coral reef habitats are attractive to tourists and provide essential habitat to a wide range of recreational and commercially important species of fish and invertebrates. The permanent reef structures protect coastlines from ocean storms and floods and have served as a source for many pharmaceutical and cosmetic products.

Appendix D. Workshop Agenda

Goal: To deliver quality information concerning the human-ecosystem relationship so that decision-makers can serve human interests while sustaining ecosystem services.

DAY 1: Framing Knowledge about Coral Reef and Coastal Ecosystems Issues Using a Systems Framework (DPSIR)

8:00 Registration

8:30 Purpose of the Workshop–to facilitate development of a decision support framework with stakeholder/decision-maker input to help address problems related to ecologically-damaging human activities (e.g., agriculture on steep slopes, unbridled development, excess sediment and nutrient loads, stormwater run-off due to impervious surfaces, wetland consumption, etc.). Ecological damage includes damage to coral reefs and other ecosystems that provide services to humans.

Purpose: This session will introduce the overall purpose of the workshop.

Desired Outcomes: A “roadmap” of what lies ahead for the next two days.

8:45 Introductions (incorporating themes from the objectives in introductions)

Purpose: Get to know who is attending/who they represent/what their main interests are.

Desired Outcomes: Relaxed, friendly atmosphere.

9:15 Baseline Information. Presentations will provide everyone with information regarding the state of the coral reefs/coastal ecosystems; threats to these systems (including an overview of the Guánica Watershed Management Plan); and USDA plans for the watershed.

Presentation #1: Status of Southwest Puerto Rico’s Coral Reef and Coastal Ecosystems

Presenter: Dr. Jorge (Reni) García Sais, University of Puerto Rico, Mayagüez

9:45 Presentation #2: Threats to Southwest Puerto Rico’s Coral Reef and Coastal Ecosystems from the Agricultural/Urbanizing Watershed and the Guánica Watershed Management Plan

Presenter: Mr. Paul Sturm, Center for Watershed Protection

10:15 BREAK

10:45 Presentation #3: USDA’s Detailed Plans for the Guánica Watershed

Presenter: Mr. José Castro, USDA NRCS

11:15 Introduce Organizational Framework for Human-Reef Interactions

Presenter: Dr. William Fisher, U.S. EPA

Purpose: Introduce the concept of ecosystem services and the DPSIR (Driving forces, Pressures, State, Impact and Response) organizational framework as a tool for linking ecological and socioeconomic factors.

Desired Outcomes: Participants will have seen the DPSIR framework and can think about it during lunch.

11:30 LUNCH

1:00 Example DPSIR and Charge to Break-Out Groups

Purpose: Walk through an example DPSIR, demonstrating how it might be used to display knowledge about coral reef and coastal ecosystems and linkages between human-ecosystem interactions. For the demonstration and break-out groups, we will focus on coral reef ecosystems.

Desired Outcomes: Understanding of the DPSIR framework and how it might be used to display knowledge about coral reef and coastal ecosystems and linkages between human-reef interactions.

1:30 Break-Out Groups

Decisions that influence human-reef interactions. We will break into 3 focus groups to look at topics that are addressed in the Guánica Bay Watershed Management Plan–agricultural practices, lagoon restoration, and low impact development.

These groups will be charged with:

1) Brainstorming what fits in all sections of the DPSIR framework related to their topic, including linkages. Generate a DPSIR graphic for 2–3 issues of importance and identify the linkages. (Target 60 min.)
2) Identify decision points in the framework. (Target 10 min)
3) Briefly characterize the decision that might be made at these decision points. (Target 10 min)
4) Prioritize the decisions/decision points based on their importance for overall health and maintenance of the coral reef and coastal ecosystems. (Target 10 min.)

Purpose: To characterize, using the DPSIR framework, information related to a management response (agricultural practices, lagoon restoration, low impact development) and the effects on persistence of reefs and the delivery of ecosystem services. Identify the current state-of-knowledge on human-environmental relationships affecting coral reef and coastal ecosystems management in Southwest Puerto Rico. Summarize this knowledge in a framework that links the various components of the human-environmental system in Southwest Puerto Rico.

Desired Outcomes: For EPA–to fill in the DPSIR with the participants understanding of the aspect of the system on which they are focused, and to understand where they see decision points. For the participants–to learn how the DPSIR framework can be a convenient way to organize information.

3:00 BREAK

3:30 Decisions that Influence Human-Reef Interactions: Reports from Break-out Groups

Purpose: Relate findings of breakout groups to all participants for corroboration and to explore missing linkages, concepts, decision alternatives, and decision characteristics.

Desired Outcomes: Shared understanding of the linkages, decision alternatives, and decision characteristics.

5:00 Wrap-up with Overview of Day 2. Each participant will be given their original VOI exercise back in light print so that they can see their original responses. They will revise that exercise to show if they have had any changes based on Day 1 of the workshop.

Purpose: Orient the participants to how what they did today will dovetail into Day 2. Identify values, preferences, and objectives for coastal ecosystems outcomes.

Desired Outcomes: Warm fuzzies that Day 1 was beneficial, anticipation of Day 2, and revised ücompleted by morning to assist in the Day 2 sessions.

CCRI Reception hosted by the Department of Marine Science, University of Puerto Rico, Mayagüez

DAY 2: A Decision Analysis Framework for Coastal Ecosystems (with an Emphasis on Coral Reefs)

8:30 Social Network Analysis (SNA)

Presenter: Dr. Tom Stockton, Neptune and Company Inc.

Purpose: Share results of SNA pre-workshop exercise and generate discussion of the identified actors and critical missing actors.

Desired Outcomes: Shared understanding of the actors and their relationships and how an SNA could be useful in decision-making.

8:50 Decision Making in Practice–Small Group Discussion

Purpose: Gain an understanding of how decisions are currently made by the workshop participants.

Desired Outcomes: 1) For the participants–a cursory understanding of their own decision-making process and how it differs from others. 2) For EPA–an understanding of the range of decision-making styles in practice. This information will inform tool development.

9:45 DASEES – Decision Analysis for a Sustainable Environment, Economy, and Society

Presenter: Dr. Tom Stockton, Neptune and Company, Inc.

Purpose: Preview the remainder of this day's activities, and to provide an understanding of a decision-making process that allows one to include ecosystem services, societal needs, and economic viability all at the same time.

Desired Outcomes: Understanding of a decision process that allows incorporation of ecosystem services, societal needs, and economic viability, being aware of the interrelationship between the DPSIR and decision-making. Set the stage for the rest of Day 2.

10:15 BREAK

10:45 Develop Options–Small Group Discussion

Purpose: Identify alternative management strategies to address threats to coastal ecosystems.

Desired Outcomes: A list of management or policy options for each break-out group.

11:15 Certainty/Uncertainty and Value of Information (VOI) for Conflict Resolution

Presenter: Dr. Amanda Rehr, Carnegie Mellon University/U.S. EPA Special Government Employee

Purpose: Explain how uncertainty plays a role in decision-making. Identify the value of further information (e.g., monitoring, surveys, and scientific studies) for clarifying environmental conditions and the likely effects of management options on these conditions.

Desired Outcomes: Understanding of how what we don't know can be as important as what we do know.

12:00 LUNCH

1:30 Applying the Objectives as Criteria for Decision Making–Small Group Discussion

Purpose: Use all of the previously gathered info (the DPSIR framework, the management or policy options, the objectives, and DASEES) to evaluate options and recommend appropriate actions.

Desired Outcomes: A set of recommended actions (recognizing that this is based on just a day and a half of discussion and these aren't meant to be the best possible recommendations because on the limited input).

2:30 BREAK

2:50 Recommended Actions: Reports from Small Group Discussions

Purpose: Learn from each group how they applied the objectives as criteria and what recommended action(s) they reached.

Desired Outcomes: Proposed actions. (Note that these are not to run out and implement the next day, but to demonstrate the process of reaching them. They may be very valid, but further assessment and thought would definitely be needed before moving forward with them.)

4:00 Adaptive Management

Presenter: Ms. Kelly Black, Neptune and Company, Inc.

Purpose: To discuss what triggers or timeframe should cause decisions to be reconsidered.

Desired Outcomes: Revision of recommended action based on uncertainties.

4:30 Recap of Decision Process, Overview of Day 3 activities, and many thanks for participating! Complete evaluations.

Presentation: Dr. William Fisher, U.S. EPA

Purpose: To briefly review the DPSIR as a framework for organizing information, DASEES as a method for making decisions (including the importance of stakeholder interactions in defining objectives), and to thank the participants for applying both to Southwest Puerto Rico coastal ecosystems issues over the past two days.

Desired Outcomes: A feeling of accomplishment and understanding of how what we've discussed might be useful as the participants return to their ongoing projects.

PM Phosphorescent Bay Trip (prior registration required)

DAY 3: Synthesizing the Input into DASEES

The third day of the Workshop will involve summarizing the information and stakeholder inputs compiled during the first two days of the meeting, in the context of decision analysis and decision support tools and assessments. Core Decision Support and Coral Reef researchers will participate in this effort. Other Workshop attendees may also participate at their option, but this will not be expected. Decision makers and other stakeholders who do participate will provide useful input for interpretations (e.g., "No, I don't think that is what she meant to imply when she said XYZ"), and will benefit from seeing how their input is being analyzed using decision support tools and methods.

The objective of the working session will be to formulate and code:

1. An updated version of the Social Network Analysis diagram for participants in Southwest Puerto Rico coastal ecosystems management.
2. A decision analysis framework (DASEES) for coastal ecosystems management in Guánica. Information from the workshop will be incorporated into DASEES and next steps will be discussed.

AGENDA:

9:00 Facilitated Discussion about the Workshop

9:15 Social Network Analysis–Gaps

9:30 Complete Objectives and Identify How to Measure Success

10:15 BREAK

10:30 DPSIR, Bayesian Belief Net, and Measures Consistency

11:45 Close workshop. Thanks to participants! Complete evaluations.

12:00 Adjourn

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Appendix F. Glossary

Bayesian belief network (BBN) or Bayesian network – a graphical network in which the nodes represent random variables, and the connections describe relationships between them.

Brainstorming – a group problem-solving technique in which members spontaneously share ideas and solutions.

Coral reef – a complex tropical marine ecosystem dominated by soft and hard (stony) corals, anemones and sea fans. Stony corals are small animals with an outer skeleton of calcium carbonate that form colonies and are responsible for reef building.

Decision landscape – a decision support framework for capturing the physical, legal, and institutional environment in which a particular management choice is made; it includes identification of management and policy options, outcomes of interest, and stakeholder valuation of outcomes, as well as the key participants involved in making the decision (decision makers, information collectors, and stakeholders), the information they use to inform the decision and its associated uncertainty, and the methods of assessment they use to evaluate outcomes.

Decision maker – a person(s) entrusted with the responsibility to make a decision. Decision makers include federal, territorial and governmental managers, corporations, non-governmental organizations and the general public.

Decision-making – an outcome of mental processes leading to the selection of a course of action among several management options.

Decision point – a key step in the decision making process.

Decision support framework (DSF) – an organizing structure to support decision making.

Decision support tools – software, models, data sets, maps, etc., to support decision-making.

DPSIR – a decision support framework for capturing the physical and human processes in a decision process; it includes the identification of the **D**rivers (socioeconomic sectors that drive human activities), **P**ressures (human activities that stress the environment), resulting environmental and ecological **S**tates (reflect condition of the natural and living phenomena), **I**mpact on services and values (effects of environmental degradation of ecological attributes and ecosystem services), and **R**esponses to those impact (policies and responses).

Drivers – socioeconomic sectors that drive human activities (waste disposal, agriculture, construction, fisheries, and tourism).

Ecosystem – includes the plant and animal communities in an area together with the non-living physical environment that supports them. Ecosystems have physically defined boundaries, but they are also dynamic: their boundaries and constituents can change over time. They can import and export materials and energy and thus can interact with and influence other ecosystems. They can also vary widely in size.

Ecosystem services – the products of ecological functions or processes that directly or indirectly contribute to human wellbeing (clean air and water, food and fiber, erosion and flood control, habitat and biodiversity, climate stability, and aesthetic enjoyment).

Granularity – the extent to which a system is broken down into small parts, either the system itself or its description or observation. It is the extent to which a larger entity is subdivided**.** Coarse-grained systems consist of fewer, larger components than fine-grained systems; a coarse-grained description of a system regards large subcomponents while a fine-grained description regards smaller components of which the larger ones are composed.

Hydro-seeding – a planting process which utilizes a slurry of seed and mulch, which is transported in a tank, either truck- or trailer-mounted, and sprayed over prepared ground in a uniform layer.

Impact – effects of environmental degradation on ecosystem functioning, affecting the quality and value of ecosystem services.

Lagoon – a body of comparatively shallow salt or brackish water separated from the deeper sea by a shallow or exposed barrier beach, sandbank of marine origin, coral reef, or similar feature.

Management and policy options – a number of alternatives that are under the control of decision makers and from which one or a combination of several of them (to be implemented as a strategy) can be chosen.

Model – a physical, mathematical, or logical representation of a system of entities, phenomena, or processes, i.e., a simplified abstract view of the complex reality.

Outcomes – the results, impact or consequences of making a decision.

Pathogen – microorganisms (e.g., bacteria, viruses, or parasites) that can cause disease in humans, animals and plants.

Pressures – human activities that stress the environment (discharge, boating activities, climate change, land use/land cover change, and coastal erosion).

Riparian – of or relating to or located on the banks of a river or stream.

Social network – a decision support framework for capturing the people involved in a decision-making process and the relationships between them, such as who has authority to make decisions and who they work or interact with. Social relationships are typically depicted in terms of nodes (individuals within networks) and ties (relationships between the individuals).

Stakeholders – individuals, groups, or organizations impacted by a management choice.

States – reflect condition of the natural and living phenomena (such as air, water and soil parameters and growth, survival and reproductive parameters).

Strength or magnitude of the relationship (between variables) – the degree to which one variable is associated with or can cause a change in a second variable (i.e., between decisions and outcomes).

Toxics – poisonous chemicals.

Uncertainty – inability to predict outcomes due to random variability (for example, stream flow is sometimes high and sometimes low) or incomplete scientific knowledge regarding causal relationships (for example, how a given concentration of sediments in the harbor affects coral reef growth rates).

Appendix G. References

Aronson D. 1996. *Overview of Systems Thinking*. URL: http://www.thinking.net/Systems_Thinking/OverviewSTarticle.pdf

Bernstein BB, Thompson BE and Smith RW. 1993. A combined science and management framework for developing regional monitoring objectives. *Coastal Management* **21(3)**:185−195.

Beverton RJH and Holt SJ. 1957. On the Dynamics of Exploited Fish Populations. *Fishery Investigations Series II Volume XIX*. Chapman and Hall, Blackburn Press, 2004.

Bradley P, Fisher W, Dyson B, Yee S, Carriger J, Gambirazzio G, Bousquin, J and Huertas E. 2013. *Application of a Structured Decision Process for Informing Watershed Management Options in Guánica Bay, Puerto Rico*. U.S. Environmental Protection Agency, Office of Research and Development, Narragansett, RI. Internal Report. 158 pp.

Burke L and Maidens J. 2004. *Reefs at Risk in the Caribbean*. World Resources Institute, Washington, DC. 81 pp.

Cañas AJ, Hill G, Carff R, Suri N, Lott J, Gómez G, Eskridge TC, Arroyo M and Carvajal R. 2004. CmapTools: A Knowledge Modeling and Sharing Environment. In Concept Maps: Theory, Methodology, Techn*ology, Proceedings of the First International Conference on Concept Mapping*, ed. A.J. Cañas, J.D. Novak, and F.M. González, 125−133. Pamplona: Universidad Pública de Navarra.

Caraco D. 2001. *The Watershed Treatment Model*. Center for Watershed Protection. Ellicott City, MD.

Caribbean Coastal Marine Productivity Program (CARICOMP). 2001. *CARICOMP Methods Manual Levels 1 and 2: Manual of Methods for Mapping and Monitoring of Physical and Biological Parameters in the Coastal Zone of the Caribbean*. CARICOMP Data Management Center, Centre for Marine Sciences, University of the West Indies Mona, Kingston, Jamaica.

Carriger J and Benson WH. 2012. Restoring and Managing Gulf of Mexico Fisheries: A Path toward Creative Decision-Making. In: *Estuaries, Classification, Ecology, and Human Impacts*. Nova Science Publishers, Inc., Hauppage, NY. pp. 291−334.

Carriger JF, Fisher WS, Stockton TB and Sturm PE. 2013. Advancing the Guánica Bay (Puerto Rico) Watershed Management Plan. *Coastal Management* **41**:19−38.

Center for Watershed Protection (CWP). 2006. *Erosion Control 101 for Puerto Rico-Factsheet*. Ellicott City, MD.

Center for Watershed Protection (CWP). 2008. *Guánica Bay Watershed Management Plan: A Pilot Project for Watershed Planning in Puerto Rico*. Ellicott City, MD.

Conservation Measures Partnership (CMP). 2013. *Open Standards for the Practice of Conservation, Version 3.0*. The Conservation Measures Partnership. 51 pp.

Curran MA. 2009. Wrapping our brains around sustainability. *Sustainability* **1**:5−13.

Dietz T. 1994. What should we do? Human ecology and collective decision-making. *Human Ecology Review* **1**:301−309.

Dunning DJ, Ross QE and Merkhofer MW. 2000. Multiattribute utility analysis for addressing Section 316(b) of the Clean Water Act. *Environmental Science and Policy* **3**:S7−S14.

Edwards A and Gomez E. 2007. *Reef Restoration Concepts and Guidelines: Making Sensible Management Choices in the Face of Uncertainty*. Coral Reef Targeted Research & Capacity Building for Management Programmes: St. Lucia, Australia. 38 pp.

European Environment Agency (EEA). 1999. *Environmental Indicators: Typology and Overview*. Technical report No 25. URL: http://reports.eea.eu.int/TEC25/en/tab_content_RLR.

Ewel JJ and Whitmore JL. 1973. *The Ecological Life Zones of Puerto Rico and the U.S. Virgin Islands*. USDA Forest Service, Institute of Tropical Forestry, Research Paper ITF-018.

Executive Order (EO) 1356. 2011. *Improving Regulation and Regulatory Review*. Federal Register **76(14)**:3821−3823.

Failing L, Horn G and Higgins P. 2004. Using expert judgment and stakeholder values to evaluate adaptive management options. *Ecology and Soci*ety **9**:13. URL: http://www.ecologyandsociety.org/vol9/iss1/art13.

García-Sais J, Appeldoorn R, Battista T, Bauer L, Bruckner A, Caldow C, Carrubba L, Corredor J, Diaz E, Lilyestrom C, García-Moliner G, Hernández-Delgado E, Menza C, Morell J, Pait A, Sabater J, Weil E, Williams E and Williams S. 2008. The state of coral reef ecosystems of Puerto Rico. In: *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008*, ed. J.E. Waddell and A.M. Clarke, 75-116. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD.

García-Sais J, Esteves R, Williams S, Sabater-Clavell J and Carlo M. 2014. *Monitoring of Coral Reef Communities from Natural Reserves in Puerto Rico*. Final Report–NOAA Grant NA07NOS4260055, 307 pp.

García-Sais JR and Sabater J. 2004. *Distribution and Biological Characterization of Major Marine Habitats in the Nature Reserve of La Parguera, Lajas, PR*. Final report to DRNA, San Juan, Puerto Rico. 140 pp.

García-Sais JR, Castro R and Sabater J. 2001a. *Coral Reef Communities from Natural Reserves in Puerto Rico: A Baseline Quantitative Assessment for Prospective Monitoring Programs. Vol. 1-Cordillera de Fajardo, Guánica, Bahía de Mayagüez, Caja de Muertos.* US Coral Reef Initiative Program, NOAA-DNER. 232 pp.

García-Sais JR, Castro R, Sabater J and Carlo M. 2001b. *Coral Reef Communities from Natural Reserves in Puerto Rico: A Baseline Quantitative Assessment for Prospective Monitoring Programs. Vol. 2-La Parguera, Boquerón, Isla de Mona, Isla Desecheo*. US Coral Reef Initiative Program, NOAA-DNER. 193 pp.

García-Sais JR, Castro R, Sabater J and Carlo M. 2001c. *Coral Reef Communities from Natural Reserves in Puerto Rico: A Baseline Quantitative Assessment for Prospective Monitoring*

Programs. Volume 3-Guayanilla, Ponce, Guayama, Arroyo. US Coral Reef Initiative Program, NOAA-DNER. 147 pp.

García-Sais JR, Castro R, Sabater J and Carlo M. 2001d. *Baseline Characterization of Coral Reef and Seagrass Communities from Isla de Vieques, Puerto Rico*. US Coral Reef National Monitoring Program, NOAA, DNER. 108 pp.

García-Sais JR, Castro R, Sabater J and Carlo M. 2004. *Inventory and Atlas of Corals and Coral Reefs, with Emphasis on Deep-water Coral Reefs from the U. S. Caribbean EEZ*. Caribbean Fisheries Management Council. San Juan, Puerto Rico. 36 pp.

García-Sais JR, Castro R, Sabater-Clavell J, Esteves R and Carlo M. 2005. *Monitoring of Coral Reef Communities at Isla Desecheo, Rincon, Mayagüez Bay, Guánica, Ponce, and Isla Caja de Muertos, Puerto Rico*. Final Report. Lajas, PR.

García-Sais JR, Castro R, Sabater-Clavell J, Esteves R and Carlo M. 2006. *Monitoring of Coral Reef Communities from Natural Reserves in Puerto Rico, 2006: Isla Desecheo, Rincon, Mayagüez Bay, Guánica, Ponce and Isla Caja de Muerto*. Final Report submitted to the Department of Natural and Environmental Resources of Puerto Rico. San Juan, PR. 151 pp.

Goffredo S and Lasker HR. 2008. An adaptive management approach to an octocoral fishery based on the Beverton-Holt model. *Coral Reefs* **27**:751−761.

Gould WA, Martinuzzi S and Páres-Ramos IK. 2012. Land use, population dynamics, and land-cover change in Eastern Puerto Rico. Pages 24−42 in: Murphy SF and Stallard RF (eds.) 2012. *Water Quality and Landscape Processes of Four Watersheds in Eastern Puerto Rico*. Professional Paper 1789-B. Reston, VA. US Department of the Interior, U.S. Geological Survey.

Gregory Morris Engineering (GME). 1999a. *Guánica Lagoon Hydrology & Restoration Alternatives*. Prepared for Puerto Rico Department of Natural Resources. San Juan, PR.

Gregory Morris Engineering (GME). 1999b. *Hydrologic and Hydraulic Analysis: Guánica Lagoon Restoration Impacts on Regulatory [Controlled] Flood Levels*. Prepared for Puerto Rico Department of Natural Resources. San Juan, PR.

Gregory R, Failing L and Higgins P. 2006. Adaptive management and environmental decision making: A case study application to water use planning. *Ecological Economics* **58**:434−447.

Gregory R, Failing L, Harstone M, Long G, McDaniels T and Ohlson D. 2012. *Structured Decision Making: A Practical Guide to Environmental Management Choices*. West Sussex, UK: Wiley-Blackwell.

Gregory RS and Keeney RL. 1994. Making smarter environmental management decisions. *Journal of the American Water Resources Association* **38(6)**:1601−1612.

Gregory RS and Keeney RL. 2002. Making smarter environmental management decisions. *Journal of the American Water Resources Association* **38**:1601−1612.

Griffin S, Spathias H, Moore TD, Baums I, Griffin BA. 2012. Scaling Up *Acropora* Nurseries in the Caribbean and Improving Techniques. *Proceedings of the 12th International Coral Reef Symposium* 5 pp.

Griffin S. 2014. *Acropora* Nursery Operations in Puerto Rico and the U.S. Virgin Islands 2013 Annual Report. 8 pp.

Hartemink, A.E. 2006. Assessing soil fertility decline in the tropics using soil chemical data. *Advances in Agronomy* **89**:179−225.

Hillel D. 1998. *Environmental Soil Physics*. Academic Press, San Diego. CA. 771 pp.

Holling CS (Ed). 1978. *Adaptive Environmental Assessment and Management*. Chichester: Wiley, Walters and Hilborn 1978.

Judd NL, Drew CH, Acharya C, Mitchell TA, Donatuto JL, Burns GW, Burbacher TM and Faustman EM. 2005. Framing scientific analyses for risk management of environmental hazards by communities: Case studies with seafood safety issues. *Environmental Health Perspectives* **113(11):**1502−1508.

Keeney RL. 1992. *Value-focused Thinking: A Path to Creative Decision-making*. Cambridge, MA: Harvard University Press.

Keeney RL. 2007. Developing objectives and attributes. In *Advances in Decision Analysis: From Foundations to Applications*, ed. W. Edwards, R. F. Miles Jr., D. von Winterfeldt, 104−128. Cambridge, UK: Cambridge University Press.

Kitchell A and Schueler T. 2004. *Unified Stream Assessment: A User's Manual. Manual 10 in the Urban Subwatershed Restoration Manual Series*. Center for Watershed Protection. Ellicott City, MD.

Krebs V. 2004. *How to do Social Network Analysis*. Orgnet.com. URL: http://www.orgnet.com/sna.html.

Krebs V. 2008. Social capital: The key to success for the 21st Century organization. *IHRIM Journal* **2(5)**:38−42.

Lapointe BE. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. *Limnology and Oceanography* **42**:119−1131.

Lee KN. 1993. *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Washington, D.C. Island Press.

McDaniels TL. 2000. Creating and using objectives for ecological risk assessment and management. *Environmental Science and Policy* **3**:299−304.

Merrick J, Parnell G, Barnett J and Garcia M. 2005. A multiple-objective decision analysis of stakeholder values to identify watershed improvement needs. *Decision Analysis* **2**:44−57.

Miller GL and Lugo AE. 2009. *Guide to the Ecological Systems of Puerto Rico*. IITF-GTR-35. U.S. Department of Agriculture, Forest Service, International Institute of Tropical Forestry, San Juan, PR. 444 pp.

Mollaghasemi M and Pet-Edwards J. 1997*. IEEE Computer Society Technical Briefing: Making Multiple-Objective Decisions*. IEEE Computer Society Press, Los Alamitos, CA.

Morelock J, Ramirez W, Bruckner A and Carlo M. 2001. Status of coral reefs, southwest Puerto Rico. *Caribbean Journal of Science*, Online Special Publication **4**:57. URL: www.uprm.edu/biology/cjs/reefstatus.htm.

Morelock J, Schneidermann N and Bryant WR. 1977. Shelf reefs, southwestern Puerto Rico. *Studies in Geology* **4**:17-25.

National Oceanic and Atmospheric Administration (NOAA). 2013. Coral Nurseries Replant Damaged Caribbean Reefs. *NOAA in the Caribbean* **2(2)**:1.

National Oceanic and Atmospheric Administration (NOAA). 2014. Draft Recovery Plan for Elkhorn coral (*Acropora palmata) and Staghorn coral (A. cervicornis).* Southeast Regional Office, Protected Resources Division, Saint Petersburg, Florida. 162 pp.

North DW and Renn O. 2005. *Decision Analytic Tools and Participatory Decision Process*. Background Paper Prepared for the Panel on Public Participation in Environmental Assessment and Decision Making. National Academy of Sciences, Washington, DC.

O'Connor J and McDermott I. 1997. *The Art of Systems Thinking: Essential Skills for Creativity and Problem Solving*. San Francisco: Thorsons Publishing.

Ortiz-Zayas JR and Terrasa-Soler JJ. 2001. *Allocating Water Resources for Public Supply within a Complex Hydroelectrical System: The Case Study of Yauco, Puerto Rico*. In Latin America Puerto Rico 2001. 2nd Latin American Technical Conference and Exhibition, November 11−14, 2001, San Juan, PR.

Pait AS, Whitall DR, Jeffrey CFG, Caldow C, Mason AL, Christensen JD, Monaco ME and Ramirez J. 2007. *An Assessment of Chemical Contaminants in the Marine Sediments of Southwest Puerto Rico*. NOAA Technical Memorandum NOS NCCOS 52. Silver Spring, MD. 112 pp.

Pastorak RA and Bilyard GR. 1985. Effects of sewage pollution on coral reef communities. *Marine Ecology Progress Series* **21**:175−189.

Payne JW, Bettman JR and Schkade DA. 1999. Measuring constructed preferences: Towards a building code. *Journal of Risk and Uncertainty* **19**:243−270.

Peirce M. 1998. *Computer-Based Models in Integrated Environmental Assessment*. European Environment Agency (EEA). Copenhagen, Denmark.

Puerto Rico Environmental Quality Board (PR EQB). 2010. *Puerto Rico Water Quality Standards Regulation*. 90 pp.

Rehr AP, Small MJ, Bradley P, Fisher WS, Vega A, Black K and Stockton T. 2012. A decision support framework for science-based, multi-stakeholder deliberation: A coral reef example. *Environmental Management* **50(6)**:1204−18.

Rehr AP, Small MJ, Fischbeck P, Bradley P, Fisher B and Vega A. 2014. The role of scientific studies in building consensus in environmental decision making: A coral reef example. *Environment, Systems and Decisions* **34(1)**:60−87.

Rinkevich B. 2005. Conservation of coral reefs through active restoration measures: Recent approaches and last decade progress. *Environmental Science Technology* **39**:4333−4342.

Rouse I. 1992. *The Taínos: Rise and Decline of the People Who Greeted Columbus*. Yale University Press. 232 pp.

Schimmer R. 2010. *Puerto Rico*. Genocide Studies Program, Yale University. URL: http://www.yale.edu/gsp/colonial/puerto-rico/index.html.

Smeets E and Weterings R., 1999. *Environmental Indicators: Typology and Overview*. European Environment Agency, Copenhagen. Report No. 25, 19 pp.

Smith M, Milic-Frayling N, Shneiderman B, Mendes Rodrigues E, Leskovec J and Dunne C. 2010. *NodeXL: A free and open network overview, discovery and exploration add-in for Excel 2007/2010*. Social Media Research Foundation. URL: http://nodexl.codeplex.com/.

Smith M, Shneiderman B, Milic-Frayling N, Rodrigues E, Barash V, Dunne C, Capone T, Perer A and Gleave E. 2009. Analyzing (Social Media) Networks with NodeXL. *Proceedings of the Fourth International Conference on Communities and Technologies,* pp. 255−264.

Sotomayor-Ramírez D and Pérez-Alegría L. 2011. *An Assessment of Agricultural Activities in the Eastern Portion of the Lajas Valley Agricultural Reserve, within Lajas and Guánica Municipalities*. University of Puerto Rico, Mayagüez, Agricultural Experiment Station, Unpublished Manuscript.

Stockton T, Dyson B, Houghteling W, Black K, Buchholtz ten Brink M, Canfield T, Vega A, Small M and Rehr A. 2011. *Decision Support Framework Implementation of DASEES: Decision Analysis for a Sustainable Environment, Economy, and Society*. U.S. Environmental Protection Agency, Cincinnati, OH, EPA/600/R-12/008.

Sturm P, Viqueira R, Ferguson R and Moore T. 2012. Addressing Land Based Sources of Pollution in Guánica, Puerto Rico. *Proceedings of the 12th International Coral Reef Symposium,* 5 pp.

Sutherland KP, Shaban S, Joyner JL, Porter JW and Lipp EK. 2011. Human pathogen shown to cause disease in the threatened eklhorn coral *Acropora palmata*. *PLoS ONE* **6(8)**:e23468.

United Nations Environment Programme (UNEP). 1994. *Guidelines for Sediment Control Practices in the Insular Caribbean*. Caribbean Environment Programme, CEP Technical Report No. 32.

United Nations Environment Programme (UNEP). 1998. *Best Management Practices for Agricultural Non-Point Sources of Pollution*. Caribbean Environment Programme, CEP Technical Report No. 41. 141 pp.

United Nations Environment Programme (UNEP). 2007*. Global Environment Outlook GEO4, Nairobi and Valletta.* URL: www.unep.org/geo/geo4/.

US Census Bureau. 2012. *America Community Survey*. URL: http://www.census.gov/acs/www/#.

US Environmental Protection Agency (EPA). 2004. *Constructed Treatment Wetlands*. EPA/843-F-03-013, Washington, DC.

US Environmental Protection Agency (EPA). 1996. *Ecological Restoration: A Tool to Manage Stream Quality*. Washington, DC. EPA/841-F-95-007.

US Environmental Protection Agency (EPA). 2009. *USEPA Office of Research and Development Ecosystem Services Research Program (ESRP): Decision Support Framework (DSF) Team Research Implementation Plan*. EPA/600/R-09/104, Office of Research and Development, Cincinnati, OH.

US Environmental Protection Agency (EPA). 2011. *Keeping Raw Sewage & Contaminated Stormwater out of the Public's Water*. Region 2. New York, NY. 23 pp.

US Environmental Protection Agency (EPA). 2012. *Benefits of Low Impact Development: How LID Can Protect Your Community's Resources*. Office of Wetlands, Oceans, and Watersheds. EPA 841-N-12-003A. Washington, DC.

US Environmental Protection Agency (EPA). 2014a. *Tutorial on Systems Thinking using the DPSIR Framework*. URL: http://http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=235356.

US Environmental Protection Agency (EPA). 2014b. *Puerto Rico–US Virgin Islands Change Detection Viewer*. URL: http://gispub4.epa.gov/PR-USVI/.

US Environmental Protection Agency (EPA). 2014c. *National Enforcement Initiative: Keeping Raw Sewage and Contaminated Stormwater Out of Our Nation's Waters*. URL: http://www2.epa.gov/enforcement/national-enforcement-initiative-keeping-raw-sewage-and-contaminated-stormwater-out-our.

Viqueira-Rios R and Meyer-Comas L. 2012. *Farm Inventory of the Lajas Valley Agricultural Reserve Guánica Lagoon and El Anegado Areas Guánica, Puerto Rico*. Protectores de Cuencas. 33 pp.

Walters CJ and Hilborn R. 1978. Ecological optimization and adaptive management. *Annual Review of Ecology and Systematics* **9**:157−188.

Walters CJ. 1986. *Adaptive Management of Renewable Resources*. New York, NY: McGraw Hill.

Warne AG, Webb RMT and Larsen MC. 2005. *Water, Sediment, and Nutrient Discharge Characteristics in Rivers of PR and Their Potential Influence on Coral Reefs*. USGS Science Investigative Report 2005−5206.

Weber RA. 2012. *Guánica Lagoon Area Salinity Study Final Report*. National Resources Conservation Service (NRCS), Central National Technology Support Center, Fort Worth, TX. 37 pp.

Whitall D, Bauer LJ, Sherman C, Edwards K, Mason A, Pait T and Caldow C. 2013. *Baseline Assessment of Guánica Bay, Puerto Rico in Support of Watershed Restoration*. NOAA Technical Memorandum NOS NCCOS 176.

Wikipedia. 2014. *Guánica, Puerto Rico*. URL: http://en.wikipedia.org/wiki/Gu%C3%A1nica,_Puerto_Rico.

Wilkinson C (Ed.). 2004. *Status of Coral Reefs of the World: 2004. Vol.1*. Townsville, Queensland, Australia: Australian Institute of Marine Science. 316 pp.

Wright T, Swann C, Cappiella K and Schueler T. 2004. *Unified Subwatershed and Site Reconnaissance: A User's Manua*l. Manual 11 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.