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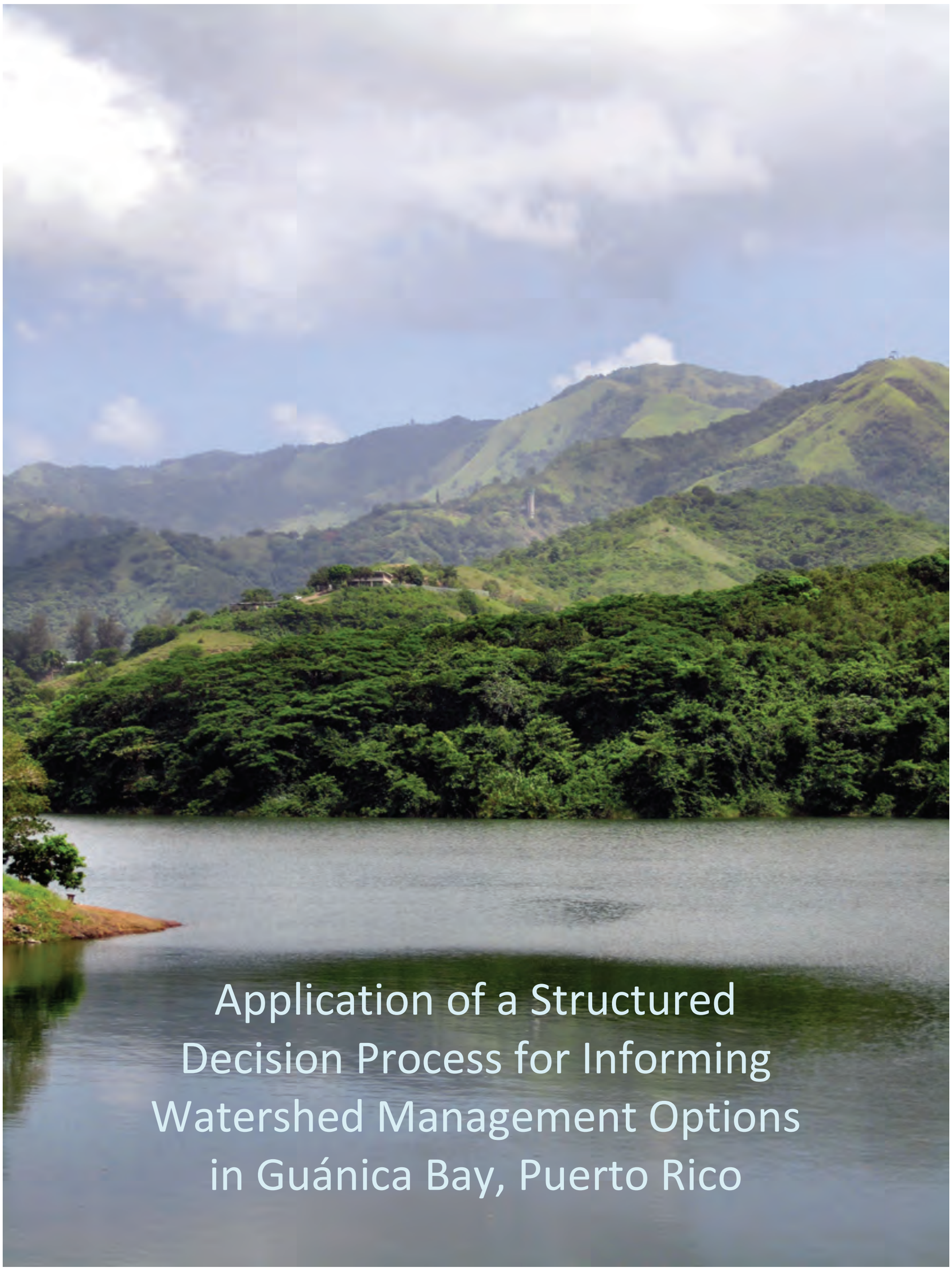

Application of a Structured Decision Process for Informing Watershed Management Options in Guánica Bay, Puerto Rico

Office Research and Development
National Health and Environmental Effects Research Laboratory

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Application of a Structured Decision Process for Informing Watershed Management Options in Guánica Bay, Puerto Rico

by

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Cover photo credit: Deborah Santavy, US EPA, ORD.

Executive Summary

This report demonstrates the application of a structured decision-making (SDM) process in the Guánica Bay watershed (GBW) in southwestern Puerto Rico. SDM is an organized approach for helping people, especially groups, identify creative options and make informed, defensible and transparent choices. It is particularly useful in complex decision situations. SDM has six steps: 1) clarify the decision context; 2) define objectives and evaluation criteria; 3) develop alternatives; 4) estimate consequences; 5) evaluate trade-offs and select alternatives and 6) implement, monitor and review. Key to the SDM process is the engagement of stakeholders, experts and decision-makers in a deliberative environment that deals rigorously with facts and values in decision-making.

The Guánica Bay watershed has been a priority for research, assessment and management since the 1970s, and since 2008, has been the focus of a U.S. Coral Reef Task Force (USCRTF) research initiative involving multiple agencies assembled to address the effect of land management decisions on coastal resources. Municipal and agricultural growth in the Guánica Bay watershed has provided social and economic value but has led to changes in forest cover (highly valued for biodiversity, endangered species and ecotourism), declining quality and availability of drinking water, and increased sediment and nutrient runoff that adversely affects coastal seagrasses, mangroves and coral reefs. Communities in the coastal region, such as the city of Guánica, rely partially on fishing and tourism economies, both of which are adversely affected by diminishing coastal water quality. In 2008, with funding from NOAA's Coral Reef Conservation Program, the Center for Watershed Protection developed a Watershed Management Plan (WMP) that included a suite of proposed management actions to reduce sediment runoff and its harmful effects in the coastal zone. The WMP served as the initial SDM decision context for EPA's research to generate tools and procedures to better inform the decisions made across the watershed and to facilitate complementary actions.

Application of SDM in Guánica Bay included archival research on social and economic history of the region and three workshops with stakeholders, experts and decision-makers to explore past decisions, characterize the decision landscape for the WMP, and better understand what stakeholders value in the watershed. The workshops included detailed discussions of the effects of human activity in the watershed on downstream environmental condition and ecosystem services.

The outcomes of this investigation and these workshops include:

- An improved understanding of multiple values and perceptions of citizens in different communities of the watershed,
- A broader, more comprehensive decision landscape (beyond coral reef protection), and
- A clearer understanding of the decision alternatives and how they might support or conflict with different objectives.

Through this process, EPA scientists and members of the USCRTF gained important insights to the value of engaging stakeholders early and often in the decision process. This report is intended to serve as a demonstration of the techniques and procedures used in SDM.

Chapter 1. Introduction

This report will assist watershed managers, agencies, and organizations involved in watershed management to use structured decision-making (SDM). SDM is an organized approach for identifying and evaluating alternatives and making defensible choices in complex decision situations. SDM has six steps: 1) clarify the decision context; 2) define objectives and evaluation criteria; 3) develop alternatives; 4) estimate consequences; 5) evaluate trade-offs and select alternatives and 6) implement, monitor and review (Gregory et al. 2012). A key aspect of SDM is the engagement of stakeholders, experts and decision-makers to create a deliberative environment that deals rigorously with both facts and values in decision-making (Keeney 1992; Gregory and Keeney 2002; Failing et al. 2007; Gregory et al. 2012).

Objectives are statements of stakeholders' values. Objectives can:

- Help determine what information to seek
- Help explain the final decision(s) to others
- Determine a decision's importance, and consequently, how much time and effort it deserves
- Help define evaluation criteria for identifying and evaluating alternatives

SDM is expected to serve multiple purposes:

1) It will assist decision-makers and stakeholders to assemble information in an organized manner, using a systems framework (in this case the DPSIR [Driving Force, Pressure, State, Impact and Response] framework and the Decision Landscape). Information and knowledge becomes a shared resource, leading to better and more informed decisions.

2) It will provide a formal process to engage stakeholders early and often in the decision process. Stakeholders hold a variety of values and perceptions that may appear to be conflicting. Particularly valuable in this process is the ability of stakeholders to hear other viewpoints in a constructive environment and to recognize that there are ways to move through disagreements. Separating values and objectives from science facts and knowledge is an important step in this process.

3) It will also provide better communication between stakeholders and decision-makers (and between the various federal and territorial agencies) and make the decision-making process more transparent.

4) It will guide strategic thinking by helping decision-makers and stakeholders to understand how decisions are inter-related and to see what tradeoffs might occur under different alternatives.

5) Finally, it will support creation of new alternatives that are directly responsive to stakeholder values, and have a better chance of acceptance and successful outcome.

The process documented in this report serves as a model for future watershed or community studies. The U.S. Coral Reef Task Force members can implement the approaches demonstrated in the report in other priority watersheds. The Appendices provide tools and references that can be used when implementing SDM.

1.1 Sustainability, the watershed approach and structured decision-making

Decisions are most often made within a very narrow context prescribed by the mission or objectives of the decision-maker and decision-making body. The cumulative result is multiple independent decisions made at various spatial and temporal scales with little to no relationship to each other or to a management plan, much less to a sweeping long-term goal like sustainability.

> Sustainability: "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations" EO 13514.

NRC (2011) provided an operational framework for integrating sustainability within the regulatory responsibilities of EPA and recommended that EPAs Office of Research and Development (ORD) develop scientific and analytic tools to support this framework. Suggested research areas included development of:

- A suite of decision-support tools for long-term impact analysis and simple decision tools for use by communities;
- System models capable of providing projections and develop alternative projections for present and future outcomes for key types of issues; and
- Robust methods that could readily incorporate uncertainty, variability, vulnerability, and resilience.

In 2011, ORD redesigned its research programs to advance the science of sustainability, creating six integrated research programs: Air, Climate and Energy; Safe and Sustainable Water Resources; Sustainable and Healthy Communities; Chemical Safety for Sustainability; Homeland Security; and Human Health Risk Assessment. In a systems-based approach, EPA and its partners began to develop integrating decision support tools (models, methodologies, and technologies) and supporting data and analysis that will guide decision makers toward environmental sustainability and sustainable development.

The Guánica Bay research is a case study under the Sustainable and Healthy Communities Research Program (SHCRP). The goal of SHCRP is to inform and empower decision makers to equitably weigh and integrate human health, socio-economic, environmental, and ecological factors to foster sustainability in the built and natural environments. The primary focus of the SHCRP is on developing tools and approaches to help local decision makers understand the effects on sustainability of alternative policies and actions (EPA 2012a).

Since the mid-1980s, EPA has been working with watershed organizations, tribes, and federal, state and territorial agencies to manage water quality through a watershed approach. A watershed is the area of land that contributes water flows to a lake, river, stream, wetland, estuary, or bay (**Fig. 1-1**). Land-based sources of pollution pose a major threat to water quality in the Nation. Land-based pollutants are transported in surface water runoff and by groundwater seepage into coastal waters.

The watershed approach incorporates a broader decision context with explicit consideration of social, economic and environmental values. The stakeholders in the watershed are actively involved in selecting the management strategies that will be implemented to solve the problems. The EPA "Handbook for Developing Watershed Plans to Restore and Protect Our Waters" (EPA 2008) provides information on developing and implementing watershed management plans that help to restore and protect water quality. While each watershed plan will address different issues and reflect unique goals and management strategies, every watershed planning process is iterative, holistic, geographically defined, integrated, and collaborative (EPA 2008).

EPA is conducting research to generate tools and procedures to better inform the decisions made across watersheds, and to facilitate complementary actions and optimal fulfillment of multiple objectives. This report introduces results from that research: an organizational framework (SDM), a method to elicit multiple stakeholder values and objectives, and a method to generate and weigh alternatives that optimally achieve the objectives. The report also provides tools to support the application of SDM in a watershed context.

Figure 1-1. A watershed is an area of land that drains the streams and rainfall to a common outlet, such as the mouth of a bay (credit: Whitewater River Alliance 2015).

The SDM process represents a departure from conventional practices and methods of regulatory and environmental management. SDM can help decision-makers in a variety of ways, including guiding strategic thinking and information collection, improving communication, engaging stakeholders, understanding the interconnectedness of decisions, and creating new alternatives that are directly responsive to stakeholder values.

Successful decision-making is the result of having:

- Clear objectives
- Creative alternatives
- Defensible impact estimates
- Clarity about fundamental trade-offs
- Honest representation of uncertainty
- A way to update information, and perhaps revise decisions over time, to reflect new knowledge.

SDM requires a dedicated management force with a thorough grasp of strategic thinking and structured decision-making. This requires continued exposure to the process, appropriate resources for workshops and public forums, and dedication to improving the manner and method of engaging stakeholders in balanced resource protection.

Chapter 2. The Formal Decision Process

2.1 Background on values and decision-making

The Latin definition of '*decision'* is '*to cut off'* (Merriam-Webster 2013). When faced with a choice, a decision-maker considers alternatives from which one is selected and the others are cut off. Resources are then committed to the selected alternative (Howard 1966). In an environment with multiple stakeholder perspectives and limited resources, the need to clearly establish what to consider (criteria) for choosing among alternatives is necessary to achieve creative, effective, defensible, and robust outcomes (Gregory et al. 2012). Making decisions based on 'what is important' is the basis of *value-focused* decision-making and is fundamentally distinct from the more common *alternative-focused* decision-making that emphasizes the range of possible routes to achieve a single, primary objective.

Key concepts:

- Values are what we fundamentally care about
- Objectives define what matters in the decision and are based upon values
- Alternatives are means to achieve our objectives

Keeney (1992) describes the relationship (**Fig. 2-1**) between values and alternatives as: Values are what we fundamentally care about in decision-making. Alternatives are means to achieve our objectives, which are based upon our values. Alternative-focused decision-making does consider values, but often only implicitly. They may not be clearly stated and thus not fully considered when making a decision.

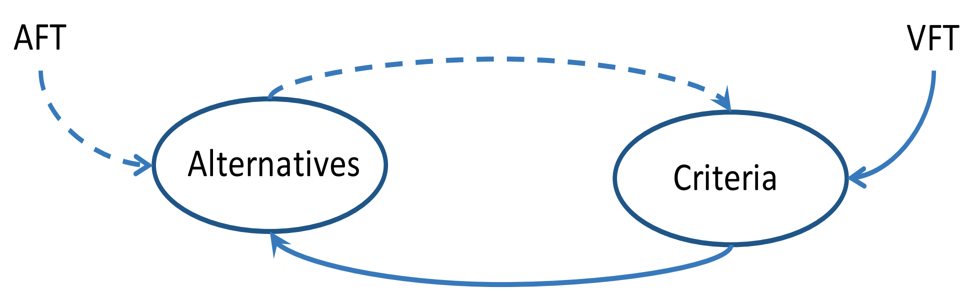

Figure 2-1. Relationship between Alternative-Focused Thinking (AFT) and Value-Focused Thinking (VFT) for decision-making. The common tendency is to start with AFT without first clarifying and explicitly stating the values and criteria that will be used for making a decision. Starting with VFT leads to a more transparent and inclusive decision-making process (adapted from Corner et al. 2001).

Explicitly stating the values, and by extension the objectives and criteria used to define and measure their attainment, promotes a more transparent, inclusive, and defensible process. It helps to create an environment for fostering options with better prospects for desired outcomes and minimal negative impacts (Gregory 1999; Gregory et al. 2012). For a decision-maker faced with a multi-faceted decision context involving several viewpoints across stakeholder groups, it is beneficial that the identification, creation, evaluation and selection of decision alternatives be grounded in the common values of the interested parties. Common values are those that most stakeholders will agree upon, i.e., values that they share even if at different magnitudes. A decision process that incorporates Values-Focused Thinking (VFT) (**Fig. 2-2**) will work toward finding those common values. Although adding an extra step in the decision process, VFT gives decision-makers greater flexibility in finding acceptable solutions to problems.

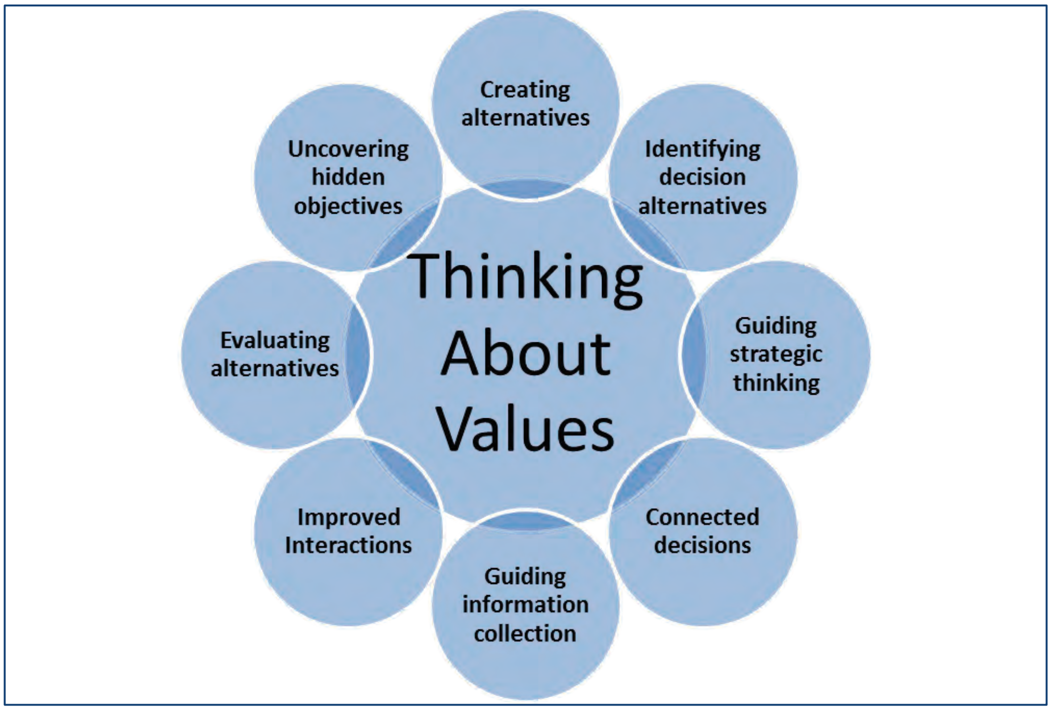

Figure 2-2. Approaching decision-making by thinking about values before developing alternatives, informs every dimension of the decision process. This leads to better alternatives, greater acceptance by stakeholders, and improved chances for successful decision outcomes (adapted from Keeney 1992).

In brief, these advantages include (Keeney 1992):

- **Guiding information collection**: Values help prioritize the spending of limited resources on gathering information relevant to what is important to the stakeholders;
- **Improving communication**: VFT keeps the discussion on what is important to the whole group (all stakeholders) and not on specific, technical aspects of alternatives;

- **Involving stakeholders**: All parties, regardless of education or socio-economic status know what is important to them and can communicate those values in VFT;
- **Recognizing interconnectedness**: Decision-makers make decisions in different contexts. It is important to be able to see if decisions in one context affect how a decision will be made in another;
- **Guiding strategic thinking**: Inter-related decisions show the necessity of clarity of values for strategic level decision-making;
- **Creating alternatives***:* New alternatives can be created that are directly responsive to stakeholder values. These have a better chance of acceptance and successful outcome;
- **Avoiding common traps:** common traps including anchoring on the first proposed alternative can hamper decisions, accepting constraints as immoveable, avoiding discussions of controversial tradeoffs, and rushing to premature solutions (Gregory et al. 2012).

2.2 Description

In many cases, single issue, well-defined decisions do not need a formal methodology for successful outcomes. Everyday decisions (e.g., when to hold a meeting or the best travel route to work) are quickly made with available information and common sense guided by experience. For most environmental decision-making, however, experience alone is insufficient. There are significant information inputs required from environmental, economic, and social sciences, coupled with the inherent uncertainty of natural systems. Keeney (1982) described the emerging discipline of Decision Analysis (DA) as "*a formalization of common sense for decisions that were too complex for the informal use of common sense*."

Applying the ideas of value-based decision-making to complex environmental management problems requires a conceptual framework or formalized process to ensure that a decision is consistent with stakeholder values, cognizant of tradeoffs among alternatives, and accounts for associated uncertainties and risks. While there are several formulations for decision analysis (Gregory et al. 2006; Gregory and Keeney 2002) two formal processes are highlighted here as examples. **Table 2-1** shows the sequential steps in a generic DA process with a brief description of what is entailed in each step.

Table 2-1. A generic formalized decision process consistent with values-based decision-making illustrating the Decision Analysis (DA) concept (source: Carriger and Benson 2012).

Generic steps in a decision analysis process	
Decision context	The reason for a decision opportunity
Objectives	Expressions of what is valued in the decision opportunity
Alternatives	The choices needed to fulfill the objectives
Prospects	The potential outcomes from the decisions and their uncertainties
Trade-offs	The willingness of stakeholders to accept more or less of one objective for another
Recommendations	The optimal strategy for achieving the objectives

Any decision with personal and/or societal ramifications has intended or unintended consequences. The consequences that stakeholders care about are considered values. The decision analysis field provides tools and frameworks for identifying values and making them explicit in a decision context with important ramifications. In multi-stakeholder deliberation processes, the objectives step can be regarded as an opportunity to elicit and include the values of stakeholders within a decision analysis.

The aim of DA is to construct a model of the decision that is amenable to analysis and computation for the evaluation of alternatives (Howard 1966). An overall decision process (e.g., **Table 2-1**) makes the goals of DA possible and is consistent with value-based decision-making, as shown in the Objectives step (expressions of what is valued). A decision process facilitates these goals through the integration of science and fact-based information with stakeholder-derived values in an analytic-deliberative structure (Gregory et al. 2006; Failing et al. 2007).

The SDM approach in Fig. 2-3 (Gregory et al. 2013) is very similar to the process outlined in Table 2-1. The SDM formulation includes the additional step of implementing the decision and monitoring to evaluate the results against stated values. Thus, each management decision sets the context for the next round of decision-making. It is this emphasis on the adaptive nature of environmental decision-making that makes SDM the operational framework for decisions that will be used throughout this report.

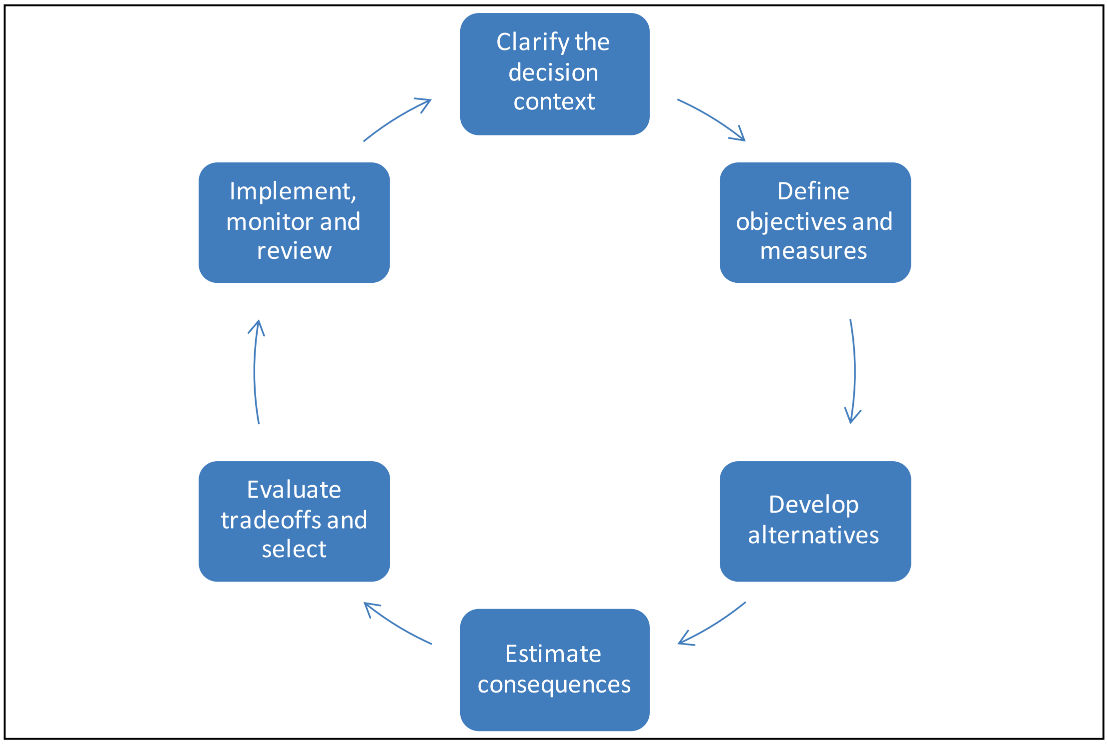

Figure 2-3. The structured decision-making (SDM) formal decision process. This approach exemplifies the iterative nature of environmental decision-making and the need to monitor and adapt to changing conditions (adapted from Gregory et al. 2012).

2.3 Why SDM is needed

A generation ago, environmental degradation had become so widespread that concerted government-mandated remedies became a necessity. For the most acute problems (e.g. untreated sewage in waterways, smog-filled cities and unchecked industrial pollution), science-based, straightforward technical solutions yielded rapid and relatively effective results. Such results were deemed successful when end-of-pipe single pollutant levels in a single medium (i.e. suspended solids in effluent, or sulfur oxides in exhaust) met legislated levels.

As these readily defined, acute problems were being addressed, more intractable problems came into focus with unpopular trade-offs resulting from mandated approaches (Gamper and Turcanu 2007). Increased and better science, and technological innovation can help offset some of the trade-offs, but the future role of science and technology for environmental management will require clarity of values (Gregory et al. 2006) and a logical process for linking values to alternative development and risk-based evaluation (Reckhow 1994; EPA 2009; Rehr et al. 2012).

There is increasing recognition that top-down regulatory and technology-driven responses are not sufficient (Grossarth and Hecht 2007) to address current and emerging environmental challenges such as climate change, sustainable communities and environmental justice (**Fig. 2-4**). Rittel and Weber (1973) describe pervasive environmental problems with economic constraints and conflicting social values as "*wicked*" in contrast to the "*tame*" problems that are amenable to regulation and technical solutions. Management of the Guánica Bay watershed is an example of a "wicked' problem.

Figure 2-4. SDM supports better informed decision-making. People will be better equipped to make tough choices when they have the best alternatives and analyses available (photo credit: Diane O'Keefe).

Such problems require new ways to understand the scientific, economic and social interactions, to develop sustainable solutions and to foster effective environmental decision-making. These new approaches neither negate nor reduce the role of biophysical science; rather there is a need to better integrate biophysical science into an appropriate context for more effective decision-making. Recognizing this need, EPA, a federal agency mandated to regulate and control pollution, is adopting practices to promote sustainability through stewardship and collaborative problem solving (Grossarth and Hecht 2007). Central to these practices is ongoing research into development and use of processes, ideas and tools for incorporating decision, behavioral, and social sciences into existing environmental research (EPA 2009; EPA 2012b).

2.4 How SDM is used

The SDM decision process is "…the facilitated and collaborative application of multi-objective decision-making and group deliberation methods to environmental management…" and is encapsulated in two broad aims (Gregory et al. 2012):

- Build common understanding of a complex problem
- Identify and evaluate management alternatives

The usefulness of an SDM process is based on the rigor it applies to structuring and analyzing the values and preferences of stakeholders. Without this structure, decision-makers may run the risk of applying resources to the wrong problem and potentially exacerbating an already contentious management issue (Carriger and Benson 2012). The broad aims listed are both qualitative (building common understanding) and quantitative (evaluate alternatives), so the tools for SDM include both.

Some of the tools and concepts include:

- **Driving Force, Pressure, State, Impact and Response (DPSIR) model**: This is a conceptual systems modeling approach that seeks to graphically and comprehensively capture the socio-economic, environmental and human health relationships for a decision context (Yee et al. 2011, 2012a, 2014a; Rehr et al. 2012; Bradley et al. 2014b). It also provides a means to begin thinking about remedial actions (Responses) and how they fit in the overall system.
- **Objectives Hierarchies:** A formalized method to identify, describe, and structure the key objectives stemming from the decision context (Gregory and Keeney 2002). An objectives hierarchy organizes objectives from broad, overarching goals (fundamental objectives) to narrower, more specific objectives (means objectives). This formal structure allows decision-makers to view each alternative in context of the broader objective to which it contributes, and also to the specific objectives that contribute to it (Bradley et al. 2014b).
- **Swing Weighting**: A rigorous way to rank and assign relative stakeholder preferences for objectives to be used in a quantitative assessment of alternatives (Gregory et al. 2012). In the swing weight method, stakeholders describe the worst consequences of a decision and then are asked to identify which attribute they would prefer most to change from its worst outcome to its best outcome. Swing weighting ranks objectives by "swinging" the value measure from its worst to its best level.

- **Influence Diagram**: An intuitive visual display of a decision problem that depicts the key elements, including decisions, uncertainties and objectives as nodes of various shapes and colors. It shows influences among them as arrows. Implemented in software applications, they are a powerful way to conduct quantitative assessment of alternatives through the use of multi-objective decision models.

The use of these tools and others within a SDM process have been applied to a wide range of decision problems including management of lake eutrophication (Reckhow 1994), watershed management (Ohlson and Serveiss 2007), dolphin conservation (Conroy et al. 2008), municipal solid waste management (Chambal et al. 2003) and coral reef management (Rehr et al. 2012). With increasing opportunities for collaboration via the Internet, web-based decision-analytic architectures are developing for *e*-participation in decision-making (French et al. 2007; Black and Stockton 2009). EPA is also involved in this area of research with the ongoing development of a web-based application *Decision Analysis for a Sustainable Environment, Economy, and Society* DASEES (EPA 2012b). The DASEES approach is consistent with SDM and utilizes many of the same decision tools in the overall process.

Concerns raised about an SDM process are that it sounds expensive and time consuming (Gregory et al. 2012). Because SDM places emphasis on problem structuring, it can ultimately reduce costs, or minimally shift costs, by helping to focus expensive data gathering efforts on the information most needed for the decision at hand. SDM is a flexible framework that can be adapted to a variety of budgets and timelines (**Table 2-2**), and numerous examples exist of SDM processes ranging from 1 day to 2 years (Gregory et al. 2012). While it is true that an SDM process may require more time in the early stages, the time spent building a common understanding and prioritizing information needs and help streamline later steps.

Table 2-2. Examples of possible SDM processes of varying levels of budget and timeline (source: Gregory et al. 2012).

Timeline or Budget	SDM Meeting Plan
Fast timeline (<6 months) Small budget	1. Decision sketching: Quickly sketch through decision context, objectives, alternatives, consequences, tradeoffs; identify "low hanging fruit" that can be initiated quickly
Medium timeline (6-18 months) Medium budget	1. Clarify decision context, objectives, & alternatives: Develop a work plan; confirm roles and responsibilities; confirm objectives that will be used as evaluation criteria; develop menu of alternatives 2. Review existing information with technical experts: Identify key uncertainties where more information is needed 3. Work with technical experts to conduct assessment of alternatives: Identify performance measures; conduct evaluations (expert opinion, quantitative analyses) to compare alternatives 4. Review consequences of alternatives and make draft recommendations: Uncover tradeoffs and find balance across competing objectives; 5. Make a decision and develop a strategy for implementing the plan: Develop a plan, including plans for monitoring and addressing critical uncertainties moving forward
Slower timeline (1-5 years) Larger budget	1. Decision process: Develop a work plan; confirm roles and responsibilities 2. Decision sketching: Build a common understanding of the scope of the problem 3. Define objectives: Confirm objectives that will be used as evaluation criteria 4. Specify performance measures: Define the evaluation criteria with help from expert judgment 5. Develop alternatives: Develop a preliminary menu of alternatives 6. Identify information needs: Identify key uncertainties where more information is needed 7. Technical working group: Identify technical needs and process 8. Technical field work and analysis: Conduct field work, modeling, or expert groups as needed to evaluate consequences 9. Round 1 alternatives & consequences: Review outcomes from technical evaluations; identify potential tradeoffs; revise objectives, performance measures, or alternatives as necessary; conduct additional technical evaluations as necessary to revise; 10. Round 2 alternatives & consequences: Explore tradeoffs; identify areas of agreement; 11. Make a decision and develop a strategy for implementing: Develop a plan, including plans for monitoring and addressing critical uncertainties moving forward 12. Monitor and review: Conduct technical monitoring and field work to evaluate success of plan; adapt as necessary moving forward

2.5 Guánica Bay, Puerto Rico, case study

In this report, we provide an example of the decision process for an ongoing case study in the Guánica Bay watershed, in southwest Puerto Rico. EPA became involved in this study when the U.S. Coral Reef Task Force (USCRTF) selected Guánica Bay as the first priority watershed in its multi-agency initiative to reduce watershed impacts on coral reefs. The report includes results from a 2010 stakeholder workshop to clarify the decision context (**Chapter 3**), information from archival research into the economic and political history related to the decision context (**Chapter 3**), summaries of two workshops that characterized historical decision-making and better defined stakeholder objectives and values (**Chapter 4**), an overview of ongoing EPA research to provide data, information and tools to forecast the potential outcomes of different decision options (**Chapter 5**) and a synopsis of the Guánica Bay decision landscape as captured by the EPA tool DASEES in a stepwise decision analytic process (**Chapter 6**). A summary evaluation of the process and its apparent utility in the Guánica Bay watershed study is also provided (**Chapter 7**). The Appendices provide supplemental information and tools that can be used in the SDM process.

Chapter 3. Clarify the Decision Context

Environmental decisions, particularly complex intractable decisions with unpopular tradeoffs, will commonly have multiple stakeholder perspectives and require a variety of data and information from environmental, economic and social sciences. Decision-makers can follow a reasonably structured process that assembles information in a manner that facilitates examination of the decision alternatives and likely tradeoffs. Gathering and organizing information relevant to the decision is creating a *decision landscape*. As the decision landscape is shaped, the decision context should transform to a clearer and more workable focus.

3.1 The decision landscape

The decision landscape is a characterization of issues surrounding a potential decision, such as the scale, science underpinnings, decision-makers and affected stakeholders (Rehr et al. 2012). The first step in describing the decision landscape is to frame the *decision context*, which is the problem, issue, or reason for making a decision, all of which defines the scope of the information that will be needed (Gregory et al. 2012). The decision context can be narrow (*nutrient loadings from a wastewater treatment plant are too high*) or broad (*unsustainable management of watershed resources*), but the context must be relevant to the decision-making potential. For example, context for the narrow case above (*nutrient loadings*) must have some potential for nutrient management within the available options and context for the broader case (*watershed sustainability*) must have some potential for influencing socioeconomic policy. The decision context is probably easier to develop first in communication with a few key stakeholders; it may be adapted and refined throughout the ensuing process with information gained from others, but a thoughtful initial attempt will save later controversy and challenge. This initial stage can also help define who needs to be involved in the process and what role will they play. For example, a collaborative multi-stakeholder committee may be deeply involved in all the SDM steps, consulting periodically with technical experts or public representatives, and ultimately providing recommendations to a decision-maker.

The decision landscape is drawn from and constrained by the decision context; it is intended to identify and organize information relevant to the problem, values, alternatives and tradeoffs in a decision context.

Initial characterization of a decision landscape should include:

a) **Scale of the decision**: How big an area, how long a time, how many communities, will be affected?
b) **Facts and current knowledge**: What is known about relationships between pieces of the decision puzzle (i.e., effects of stressors and potential benefits of reducing them)?
c) **Current condition**: What is the status of the issue and why is a decision needed now instead of later?
d) **Unintended consequences**: What else, other than its intended purpose, will the decision affect?
e) **Decision-makers**: Who would be making the decision or components of the decision? Who would be funding the actions if decisions were made? Who authorizes the different steps of a potential action?
f) **Stakeholders**: Who will be positively affected and who will be negatively affected? How have stakeholders been engaged in the past?
g) **Legal status**: Who owns or is responsible for property that might be altered by decisions? What laws are applicable and who is responsible for enforcing them?
h) **History**: What decisions have been made in the past and how did they lead to the current situation? Are planning or visioning documents already developed that are relevant to the issue?

The decision landscape is useful only if it can be communicated to decision-makers and stakeholders. A graphic representation (e.g., **Fig. 3-1**) or flow chart of the issue to be resolved and the likely effects of different decisions on the things that people care about is very useful. Another possibility is an issue paper (or 'white paper') that describes the decision context and provides an overview of the issues affecting decision alternatives and tradeoffs. The overview can be at a basic level to satisfy most stakeholders with appendices or additional material available to technical experts and those who want greater detail. Characterization and communication of the decision landscape should be unbiased (i.e., should present information without predisposition for a particular decision outcome).

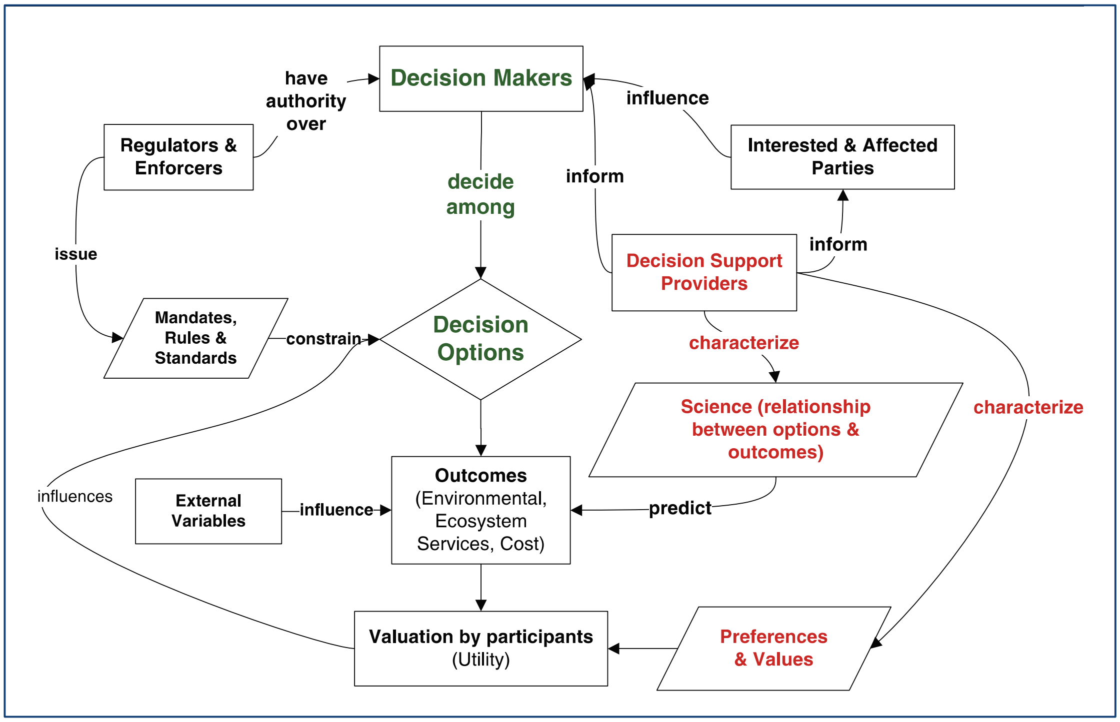

Figure 3-1. Components and key relationships in an environmental management Decision Landscape (source: Rehr et al. 2012).

The following is the process used to characterize the decision landscape for the Guánica Bay watershed in southwestern Puerto Rico. It describes the initial decision context (**Section 3.2**), a systems framework for generating a comprehensive decision landscape (**Section 3.3**), a workshop summary that led to better understanding and a 'sketch' of the decision landscape (**Section 3.4**), a summary of archival literature research to characterize the broader landscape and tradeoffs that covered a range of environmental, economic, and social outcomes (**Section 3.5**) and a re-casting of the decision context in the broader scope (**Section 3.6**). Additional historic information is provided in **Appendix A**.

This Guánica Bay watershed example illustrates a decision context that is initially limited in scope (i.e., one or two focused objectives). When a systems framework is used to examine these objectives, it leads to a comprehensive assessment of issues, a broader list of objectives, multiple decisions, and a broader group of stakeholders. Anticipating these multiple decisions and including them in the discussion can reasonably be expected to satisfy more stakeholders. Guidance to develop the decision landscape is provided in **Appendix B**.

3.2 Initial decision context for coral reef protection at Guánica Bay

Coral reefs are present along the entire southern coast of Puerto Rico and some of the most attractive reefs for snorkeling and diving occur on and around the cays near La Parguera in the municipality of Lajas, which is west and down current of Guánica Bay. Coral reefs in the areas of La Parguera and Guánica are a valued natural resource and a mainstay of the coastal recreation and tourism economy (**Fig. 3-2**).

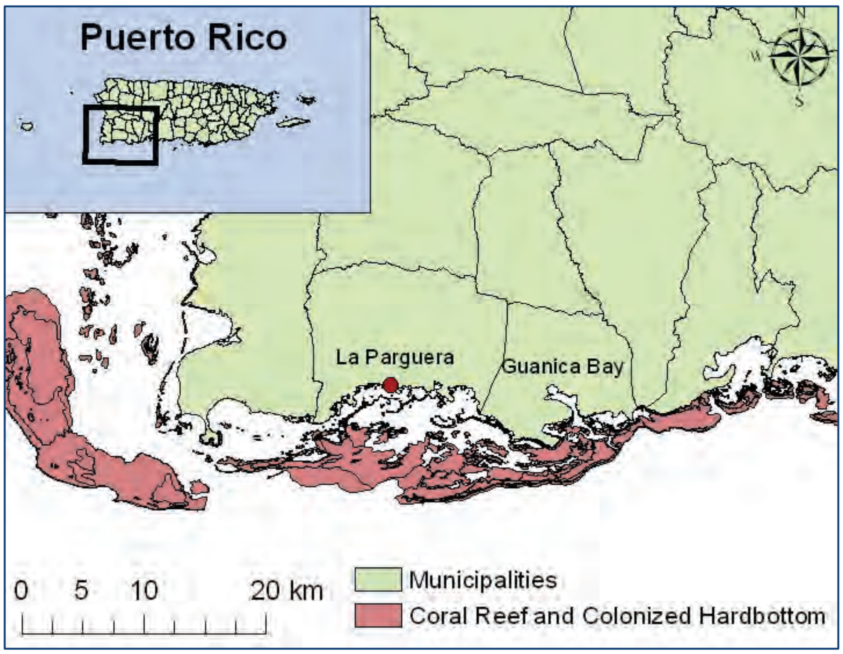

Figure 3-2. Coral reefs fringe the southwestern coast of Puerto Rico and provide coastal recreation and tourism opportunities.

Puerto Rico has used images of their pristine coral reefs and biologically diverse mountain forests to promote ecotourism (**Fig. 3-3**).

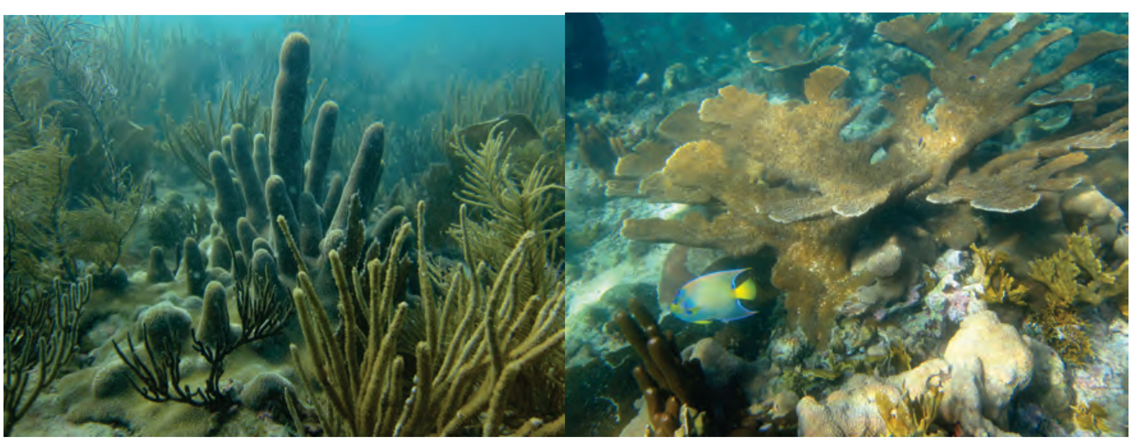

Figure 3-3. Images of coral reefs in the areas of La Parguera and Guánica illustrate their natural beauty (photo credits: Alan Humphrey, EPA and Jon McBurney, Lockheed Martin).

The Puerto Rico legislature has passed several laws to promote the ecotourism industry:

- 1998 - Law 340 that established a public policy for promoting ecotourism with the intention to create an Ecotourism Board.
- 2006 - Law 254 "Law for the Sustainable Development of Tourism in Puerto Rico", which is administrated by the Puerto Rico Tourism Company (PRTC).

In June 2013, the PRTC formed an Interagency Commission to coordinate efforts at the Commonwealth government level for optimal development and promotion of sustainable tourism, as well as ecotourism throughout the island. In the southwest, the PRTC has established a tourism route through the towns of Yauco, Utuado, Guánica, Sabana Grande, Maricao and Las Marías to highlight the natural ecologies and habitats of the region.

The presence of coral reefs has made the Guánica Bay area a priority for investigation, assessment and management.

- 1978: The Puerto Rico Coastal Zone Management Program (PRCZMP) designated eight areas as Special Protection Areas (SPA), including the Southwest, which was divided into three sectors – La Parguera, Guánica and Boquerón (DRNA et al. 2008). The PRCZMP also recommended the designation of 12 areas as natural reserves because of the quality and extent of coral reefs, including the Guánica State Forest. Guánica State Forest was added to the PRCZMP in 1988 (DRNA et al. 2008; NOAA et al. 2009).
- 1978: The Federal Court approved the first Order of Consent between EPA and PRASA for violation to the Clean Water Act (CWA) in 88 of 97 wastewater treatment plants (WWTPs) owned at the time by PRASA (91% of the WWTPs). Guánica and Lajas WWTPs were subject to the original 1978 Court Order (U.S. v. PRASA, Civil Action 78-0038 (CC) 1978)
- 1985: The U.S. District Court amended the 1978 Court Order and imposed sewer connection limitations to about 40 WWTPs. Guánica and Lajas WWTPs were subject to this ban (U.S. v. PRASA, Civil Action 78-0038 (TR), 83-0105 (TR) 1985).
- 1997: The Federal Court approved a stipulation requiring PRASA to identify WWTPs that needed Advanced Wastewater Treatment (AWT) (U.S. v. PRASA, Civil Action 78-0038 (CC) and 83-0105 (CC) 1997). Lajas WWTP was required to either be upgraded or to relocate its outfall to a larger stream with an increased assimilative capacity (Vincenty Heres & Lauria et al. 1997). The plant was upgraded to tertiary treatment.

- 1997: EPA filed a criminal case and civil suit against the Copamarina Beach Resort and its operators for discharging sanitary sewage directly into the Caribbean Sea without a National Pollutant Discharge Elimination System (NPDES) permit. In 2000 EPA and Copamarina signed a Consent Decree that required Copamarina to pay a civil penalty of $200,000 to the U.S. and permanently barred the resort from discharging any pollutants.
- 1998: Gregory Morris & Associates, Inc. conducted two studies on the impacts of restoring the historic Guánica Lagoon for the Puerto Rico Department of Natural and Environmental Resources (DNER), which was funded by EPA (GMA 1999a&b).
- 1999-2002: The National Oceanic and Atmospheric Administration's (NOAA) Puerto Rico Coral Reef Monitoring Program (PRCRMP), administered by Puerto Rico DNER, was implemented in nine reserves (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) to provide a baseline characterization of Puerto Rico's coral reefs and to monitor water quality (García-Sais et al. 2001a, 2001b, 2001c, 2001d, 2004, 2005, 2006; Hernández-Delgado 2003).
- 2002: The USCRTF identified the need for action at the local level to reduce key threats to coral reefs in the seven states and territories with significant coral reef resources (Florida, Hawai'i, American Samoa, CNMI, Guam, Puerto Rico and USVI). PR DNER formed an interagency partnership to develop the Local Action Strategy.
- 2004: NOAA's Coral Reef Conservation Program and the Center for Watershed Protection (CWP) held a capacity building workshop in San Juan that focused on the Local Action Strategies for each jurisdiction. Workshop participants decided that each jurisdiction should have a watershed of emphasis to serve as a demonstration that could be tied to effects of land-based sources of pollution on coral reefs. NOAA and CWP chose Guánica Bay Watershed because of prior coral reef work by NOAA's PRCRMP; the strong DNER leadership and stakeholder engagement at the Guánica State Forest; and former studies of the historic Guánica Lagoon (personal conversations with Jen Kozlowski and Anne Kitchell).
- 2004: The University of Puerto Rico (UPR – M), in collaboration with the Puerto Rico DNER and funded by NOAA, established the Caribbean Coral Reef Institute (CCRI) at the Magueyes Island Marine Laboratory in La Parguera, PR. CCRI has been conducting research and ecosystem assessment activities around Puerto Rico, including the coastal areas near Guánica and La Parguera.

- 2005-2007: NOAA conducted the Coral Reef Habitat Assessment for Puerto Rico at 40 Marine Protected Areas (MPAs) including the Guánica State Forest Natural Reserve and Biosphere Reserve. As part of the assessment, NOAA mapped and calculated the areal extent of the benthic habitats (NOAA 2009).
- 2006: EPA closed the 1978 Court Order and other administrative open orders issued to PRASA. The same year EPA and PRASA signed a Consent Decree that addressed PRASA's CWA violations involving discharges in violation of its NPDES permits; failure to operate and properly maintain all 61 wastewater treatment plants in Puerto Rico; and discharges of raw sewage from seven collection systems. Under the terms of the Consent Decree, PRASA paid a $1 million penalty, undertook a Supplemental Environment Project valued at $3 million, and implemented injunctive relief valued at approximately $1.7 billion. PRASA agreed to complete 145 short-term, mid-term and/or long-term capital improvement projects at its wastewater treatment plants (including construction of a new Biological Nutrient Removal [BNR] treatment plant providing tertiary treatment in Guánica) over the next 15 years.
- 2007: PRASA was able to construct a BNR module for the Guánica WWTP with a capacity of 1.25MGD.[1]
- 2008: EPA issued an administrative compliance order against Puerto Rico National Parks Company from the Caña Gorda Public Beach WWTP for discharging pollutants into the sea without an NPDES permit.[2]

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[1] The BNR didn't have enough inflow to operate because the projects for the new hookups were not completed. In 2011, PRASA decided to start operations of the BNR since part of the hookup projects have been completed. However, the BNR needed to undergo through some repairs in order to starts operations because several parts have been deteriorated due to the years that was out of service. In August 2015, the BNR finally started up.

[2] The NPDES permit was issued on 2009. On 2014, EPA sent to the PR National Parks Company (NPC) a letter to show cause for failure to comply with its permit effluent limits. The PR NPC opted to stop their discharge and to haul their effluent into PRASA Guánica WWTP.

3.2.1 Initial decision context

Across the Caribbean, coral reefs are dying from the cumulative effect of global and local factors (Hughes 1994; Jackson et al. 2001, 2012, 2014; Knowlton 2001; Morelock et al. 2001; Pandolfi et al. 2003; García-Sais et al. 2005; Pandolfi and Jackson 2006; Alvarez-Filip et al. 2009). Among the local factors are sediment, nutrient and contaminant efflux from human activities in the adjacent watershed. This is the case for Guánica Bay. Coral reefs near Guánica and La Parguera have declined, with dramatic reductions in living colonies of reef-building stony corals like the Boulder Star Coral, *Orbicella annularis (***Fig. 3-4***)*.

Figure 3-4. Reef-building stony corals formed the structure of Caribbean reefs (e.g., *Orbicella annularis* [left] and *Acropora palmata* [right]) (photo credits: left - Charlie Veron; right - Alfredo Montañez Acuña, UPR).

Bleaching events in 1981, 1987, 1990, 1998 and 2005 caused by elevated sea surface temperature have also adversely affected stony corals (Williams and Bunkley-Williams 1989, 1990; Williams et al. 1987; Goenega et al. 1989; Velazco-Domínguez et al. 2003; García-Sais et al. 2006, 2008; Miller and Lugo 2009). Disease outbreaks have increased in number, prevalence and spatial distribution (Gladfelter 1982; Weil et al. 2003, 2009; Weil and Rogers 2011; Bruckner and Bruckner 1997, 2006; Cróquer and Weil 2009; Harvell et al. 2009), causing further decline in stony coral communities.

Furthermore, other coral reef assemblages have shown signs of disease and have been affected by bleaching, including octocorals and hydrocorals (Weil et al. 2002; Weil 2004; Toledo-Hernández et al. 2007, 2009; Prada et al. 2009; Flynn and Weil 2009), crustose coralline algae (Weil 2004; Ballantine et al. 2005), zoanthids and sponges (Weil 2004; Weil et al. 2006; Weil et al 2009).

Massive fishing pressure has also adversely impacted Puerto Rico's coral reefs. Large vertebrates (e.g., the green turtle, hawksbill turtle, manatee and Caribbean monk seal) have been decimated in the central and northern Caribbean Sea, herbivores and predators were reduced to very small fishes and sea urchins (Jackson 1997).

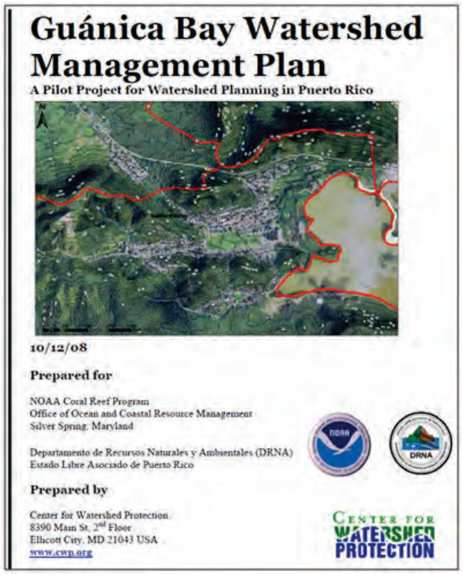
The problem (issue) is that coral reefs, which are highly valued for tourism and recreation, fisheries, shoreline protection and natural products (i.e., sources and templates for pharmaceuticals, biochemicals, and biomaterials), are declining from the effects of multiple stressors (Warne et al. 2005; CWP 2008). Some of these stressors (e.g., land-based sources of pollution) might be reduced or alleviated through changes in human activities in the watershed.

The decision-maker in the initial decision context is the USCRTF (see below). There is a reasonable presumption by the USCRTF that many, if not most, stakeholders would prefer to preserve the services delivered by healthy reefs. The SDM process should include all those alternatives (management options) that might be employed to stop or reverse the decline. The reason for making a decision now rather than later is to reverse the trend before the damage is irreparable and the valuable services provided are lost forever.

3.2.2 Decision-maker: U.S. Coral Reef Task Force

The USCRTF is responsible for assisting U.S. jurisdictions (States, Territories and Commonwealths) in protecting the coral reef ecosystem. Based on the results of the 2007 workshop and discussions with DNER and CWP, NOAA contracted the CWP to develop a WMP for the Guánica Bay Watershed (**Fig. 3-5**).

The CWP conducted interviews with natural resource managers, academics, local farmers and residents to better understand Guánica Bay and its watershed. CWP compiled the findings of the interviews with the results of a weeklong field survey, including assessment of stream channels and point sources, and visits to representative areas to evaluate restoration and conservation opportunities. The resulting report *Guánica Bay Watershed Management Plan* (CWP 2008) not only identified potential sources of pollution but proposed several actions to reduce pollution in watershed runoff, including agricultural practices, river- and stream-bank erosion and improved sewage treatment at the Guánica wastewater treatment plant. The WMP also identified actions to reduce sediment loads in reservoirs and restoration of an historic lagoon in the Lajas Valley to filter pollutants from waters entering Guánica Bay. The rationale for all proposed actions was to reduce physical, chemical and biological stressors in effluent waters with the objective of protecting resources in the watershed, including coral reefs, from land-based sources of pollution.



Proposed Management Options

- **Agricultural Practices**
- **Lagoon Restoration**
- **Reservoir Restoration & Maintenance**
- **Sewage/Waste Management**
- **Riparian Restoration**

Figure 3-5. The 2008 Guánica Bay Watershed Management Plan identified potential sources of pollution and proposed a series of management actions.

In 2009, the USCRTF initiated a Watershed Initiative to better incorporate land-based sources of pollution and socio-economic considerations of those living in the watershed into strategies for coral reef protection. During its 2009 meeting in San Juan, Puerto Rico, the USCRTF selected Guánica Bay as the location of its first multi-agency priority watershed. A driving force for the selection of Guánica Bay was the availability of the WMP (CWP 2008).

In Guánica, the USCRTF has combined the efforts of NOAA, CWP, EPA, US Department of Agriculture/Natural Resources Conservation Service (USDA/NRCS), US Fish and Wildlife Service (FWS), Puerto Rico Department of Natural and Environmental Resources (DNER), Puerto Rico Department of Agriculture (PRDA), Puerto Rico Land Authority (PRLA), US Geological Survey (USGS), University of Puerto Rico (UPR), Puerto Rico Electric Power Authority (PREPA), and Puerto Rico Aqueduct and Sewer Authority (PRASA). The consortium of agencies has therefore become a stakeholder and decision-maker in the Guánica Bay watershed.

The USCRTF watershed initiative and the WMP demonstrate *alternative-focused thinking* (i.e., seeking alternatives on a particular issue prior to formally characterizing the broader values and objectives of stakeholders). The driving force for the WMP was to guard against and reverse the effects of land-based sources of pollution in the watershed. While care was taken to incorporate the concerns of many stakeholders, particularly farmers, into the WMP, the focus was identifying and characterizing alternative actions rather than stakeholder values. In *value-focused thinking (*and SDM), the values and objectives of stakeholders, in a formal elicitation process, would have been documented before alternatives were proposed.

3.3 Systems thinking and systems diagrams

Scientists often take an analytic or reductionist approach to solving problems: splitting complex phenomena into elementary parts to better understand the individual processes (e.g., molecular biology). But modern environmental decision-making cannot be about individual processes or isolated issues. 'Systems thinking' is an approach to problem solving that is based on the belief that the component parts of a system are best understood not in isolation but in the context of relationships and interactions with one another and with other systems (von Bertalanffy 1972). The USCRTF focus in Guánica Bay is an example of a reductionist approach, applying resources to address a single issue (i.e., coral reef protection) relatively isolated from consideration of impinging factors and unintended outcomes. A systems approach considers more than one issue and broadens the decision context. While it is more costly and time consuming, the systems approach should ultimately provide better information for decision-making.

There are several core principles about how systems function (AST 2008):

- **Feedback:** performance of organizations and systems is largely determined by a web of interconnected circular (not linear) relationships;
- **Delay:** actions have both immediate and delayed consequences;
- **Unintended consequences:** today's problems are too often yesterday's solutions;
- **Awareness:** comprehending the relative benefits of the various options, as well as the underlying factors and trade-offs; and
- **Leverage:** systems will improve with a few key coordinated changes sustained over time.

A systems approach is built on the understanding that everything affected by a change is connected to something else that may also be affected. Not every effect will be important, but it is worth going through the process to make sure all possible consequences have been considered.

One framework supporting a systems approach is the DPSIR, which has been a valuable tool for organizing and communicating complex environmental issues. The DPSIR framework was developed by the European Environmental Agency (EEA 1999) and has been used by the United Nations (UNEP 2007).

The framework (**Fig. 3-6**) assumes cause-effect relationships among interacting components of social, economic, and environmental systems (Pierce 1998; Smeets and Weterings 1999). These are:

- **D**riving Forces: Socio-economic sectors that describe basic needs of human society (i.e., food, water, fuel and shelter) and secondary needs (i.e., recreation, cultural heritage and sense of place)

- **P**ressures: Driving Force-generated emissions and land use changes that affect the environment
- **S**tate: Status of the environment and ecological resources, including attributes that provide services
- **I**mpacts: Changes in delivery of ecosystem goods and services as a consequence of changes in ecological state
- **R**esponses: Societal reactions to changes in ecosystem services, values and sustainability (e.g., management actions)

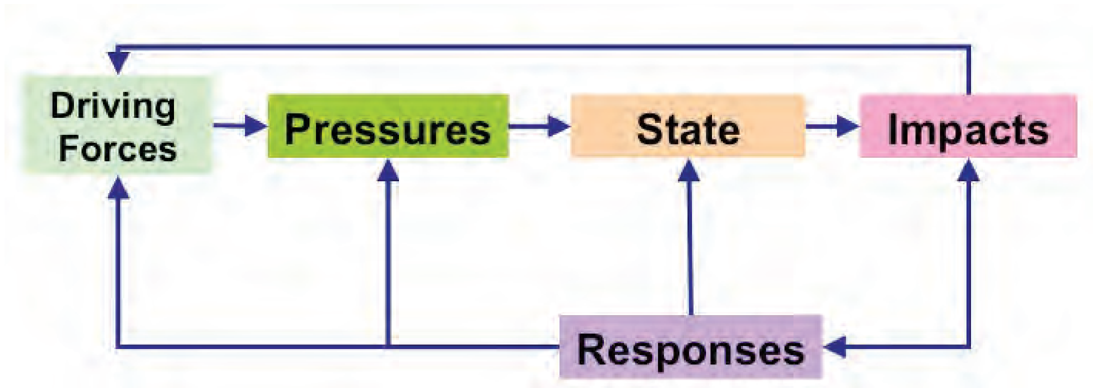


Figure 3-6. The DPSIR (Driving Forces, Pressures, State, Impacts, Responses) framework and conceptual relationships among DPSIR sectors (source: Bradley et al. 2014b).

EPA's ORD has used the DPSIR approach to generate conceptual maps for examining socioeconomic implications of coral reef management actions (Yee et al. 2011). Information gained from a decision-support workshop in Puerto Rico (described in **Section 2.4**), from two previous workshops in U.S. Virgin Islands and the Florida Keys, and from discussions with expert focus groups and literature reviews, has led EPA to develop a coral reef DPSIR conceptual map (**Fig. 3-7**) that is presented in greater detail at EPA's ReefLink web site (EPA 2014a). A DPSIR tutorial prepared by EPA is also available (EPA 2014b). EPA is also developing a DPSIR technical support document (Bradley and Yee 2015).

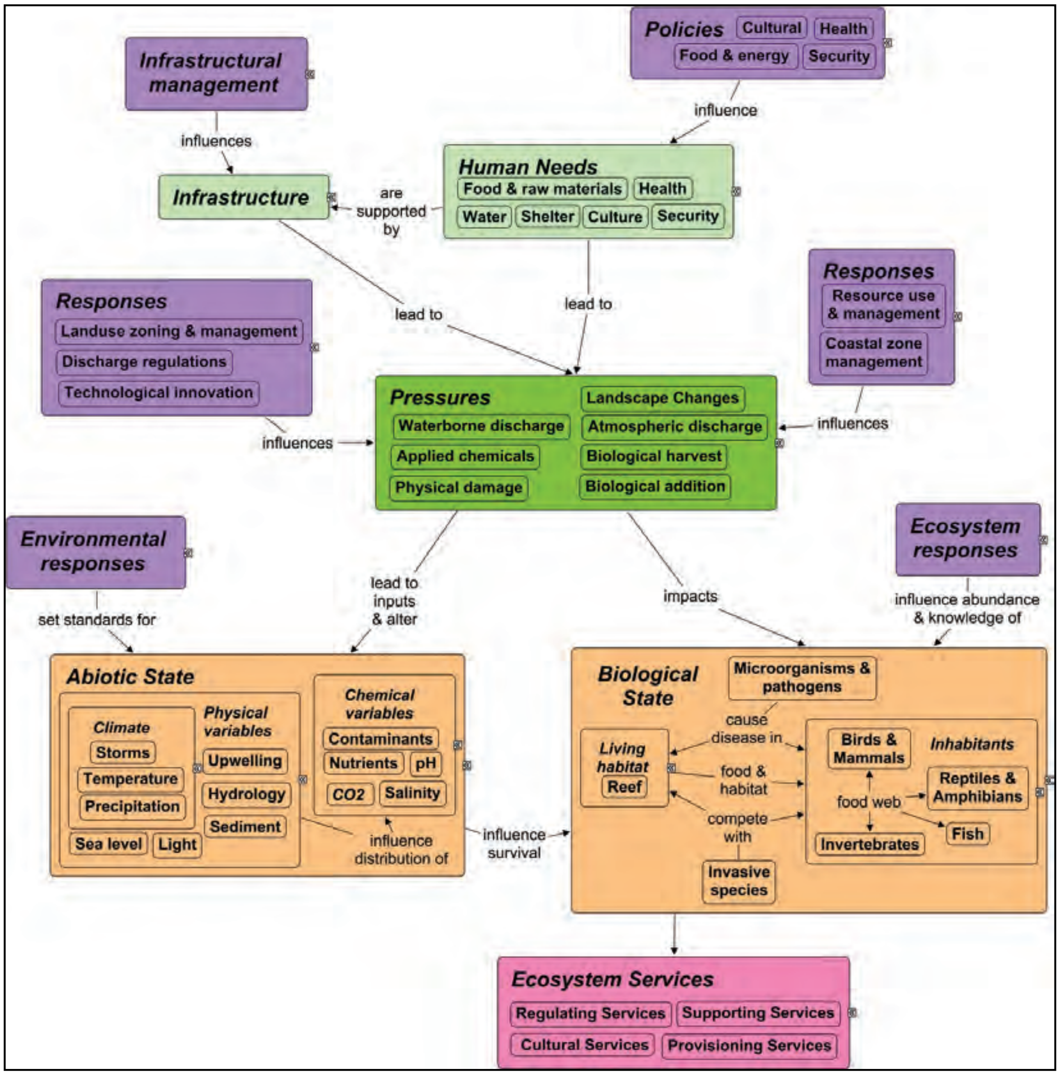


Figure 3-7. A coral reef DPSIR (Driving Forces, Pressures, State, Impacts, Responses) conceptual map developed by EPA using information from workshops held in the U.S. Virgin Islands, Puerto Rico and the Florida Keys, discussions with expert focus groups, and literature. (Note: the Driving Forces, Pressures, Impacts and Responses boxes have been collapsed. More detail is included at www.epa.gov/ged/coralreef. Boxes are color-coded to follow the scheme used in Fig. 3-6 (e.g., light green=Driving Forces; dark green=Pressures; orange=State; pink=Impacts; and purple=Responses).

3.4 Coral reef and coastal ecosystems decision-support workshop

In 2010, the U.S. EPA and the CCRI hosted a Coral Reef and Coastal Ecosystems Decision-support Workshop at La Parguera, Puerto Rico (Bradley et al. 2014b). Forty-three representatives from Federal and Commonwealth government agencies, non-governmental organizations and academic institutions, and citizens from the Guánica Bay watershed participated (**Fig. 3-8), (Appendix C**).

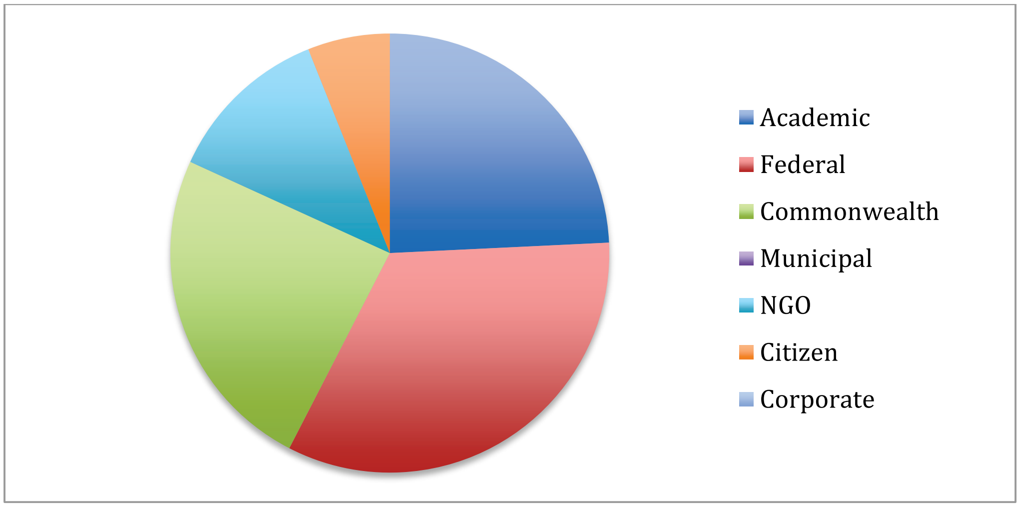


Figure 3-8. Forty-three representatives from Federal and Commonwealth government agencies, non-governmental organizations and academic institutions, and citizens from the Guánica Bay watershed participated in the 2010 Coral Reef and Coastal Ecosystems Decision-support Workshop at La Parguera, Puerto Rico.

The workshop served as an exercise in *decision-sketching* (Gregory et al. 2012) which is a means to quickly identify preliminary information on objectives and possible measures, a range of possible management actions and their consequences, and key pieces of information and their uncertainties. Sketching can help to identify what key stakeholder groups or decision-makers are needed for participation in future workshops and what kinds of information may be needed for future analysis.

The three key steps to decision sketching are (modified from Gregory et al. 2012):

1. **Framing the decision:** What is the decision? Who are the decision-makers? What is the relationship to other decisions? What is the goal?
2. **Developing the sketch:** What is the range of objectives and alternatives under consideration? What information is known and are there critical gaps? What trade-offs or uncertainties are likely to be most critical?
3. **Planning the consultation and analysis**: Given what you've learned, what tools and information are needed?

The workshop was designed to garner stakeholder and decision-maker input to develop a decision analysis framework for addressing problems related to human activities (e.g., agriculture, urbanization, sediment and nutrient loads, stormwater run-off and wetland loss) believed to be damaging to coastal resources (**Appendix D**). The workshop was invaluable for fleshing out the decision landscape (Bradley et al. 2014b).

3.4.1 Framing the decision

Three presentations were given at the outset of the workshop, each designed to help frame the decision context. These included an overview of declining coral reefs in southwestern Puerto Rico (presented by Jorge Garcia-Sais, Department of Marine Sciences, UPRM), an overview of plans by USDA/NRCS to reduce soil erosion in the watershed (presented by José Castro, USDA/NRCS), and a summary of the alternatives proposed by CWP in the WMP to protect coral reefs from further degradation (presented by Paul Sturm, Center for Watershed Protection). This information provided a common basis of understanding for the participants.

The next session was initiated with a presentation on systems thinking and the DPSIR framework. This set the stage for three facilitated breakout groups to discuss and characterize specific decision scenarios that had been outlined in the management plan; these were (Bradley et al. 2014b):

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
    - Hydroseeding of bare soil associated with roads and homes
    - Enhanced wetlands for sewage treatment
    - Pet waste cleanup ordinances in coastal cities

A facilitator and a DPSIR conceptual mapping note-taker led each breakout group to generate a concept map using the DPSIR framework as a guide. The transparency of DPSIR was an asset in this exercise—participants could easily see how different factors affected others and there were many discussions on the strengths of these relationships; moreover, many new relationships were revealed. By the end of the allotted time, the groups had developed a relatively detailed concept map for each set of alternatives (see Bradley et al. 2014b).

3.4.2 Developing the sketch

EPA merged the DPSIR concept maps from the three breakout groups, and participants were provided an opportunity to comment, revise, and make further suggestions to the developing sketch. Although participants originally completed all of the concept maps during the workshop, EPA ultimately refined the input into a single Guánica Bay concept map (**Fig. 3-9a & Fig. 3-9b**).

The importance of this step was to link the different decision alternatives into a common framework that showed the possible consequences and the likely tradeoffs. Several examples include:

- Converting mountain farms from sun-grown to shade-grown coffee would require money and time for farmers to convert to the new strains and new methods. It would however, eventually provide increased vegetative cover and habitat for wildlife.
- Restoration of the lagoon would remove it from agricultural production and could bring mosquito problems to the community of Fuig, which has grown out to the lagoon area since it was drained. However, the lagoon restoration would increase nutrient cycling, trap sediments and provide new tourism and recreational opportunities (i.e., boating, fishing and bird-watching).
- There are benefits of reducing sediment efflux not only to coral reef condition but also to stream habitats and preventing agricultural soil loss. Additionally, sediments are filling the reservoirs and reducing the availability of drinking water and irrigation water.

The integrated concept maps also illustrated how several different actions could have an effect on a single endpoint, and how one action could have an effect on several endpoints.

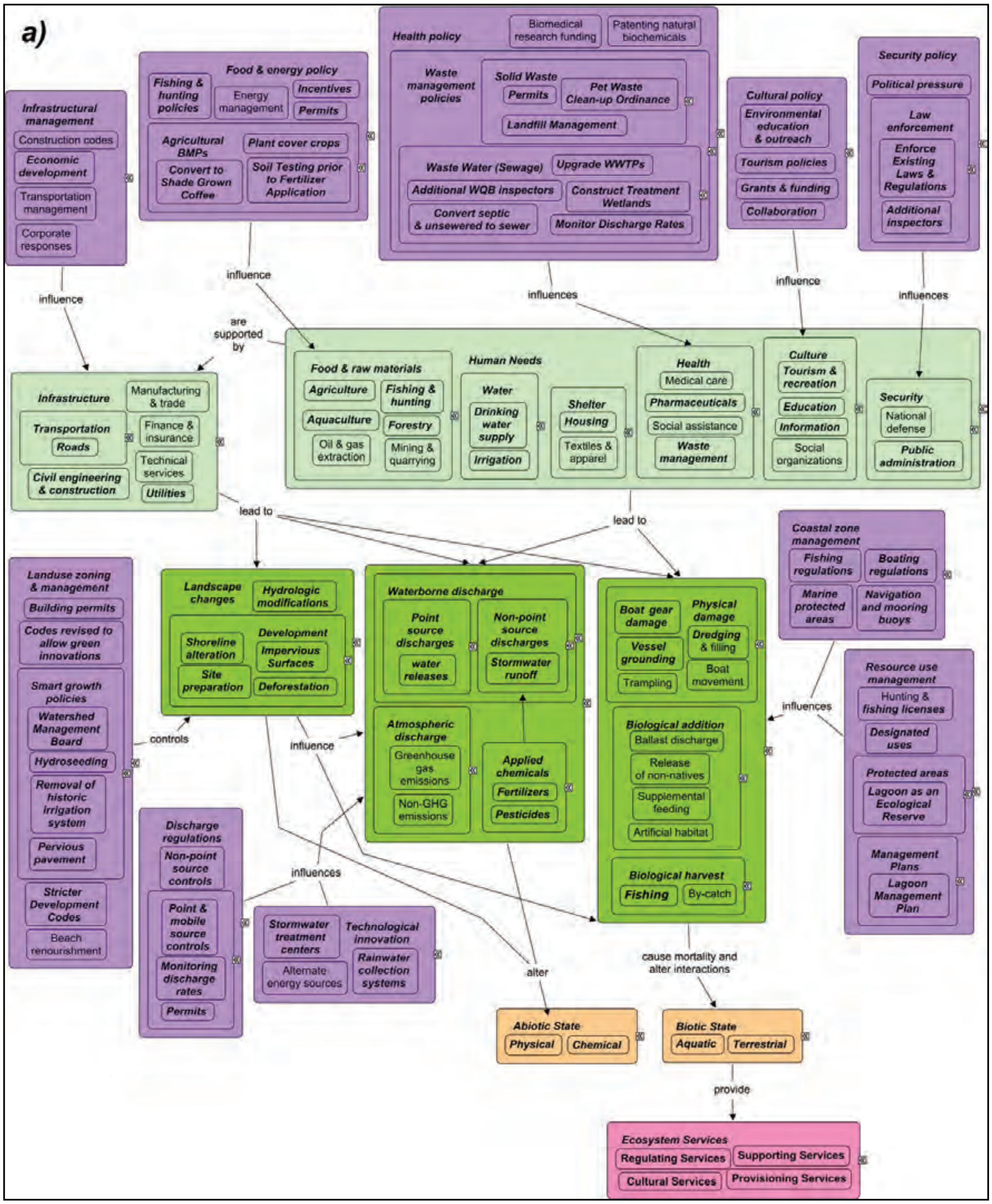


Figure 3-9a. **Guánica-specific DPSIR (Driving Forces, Pressures, State, Impacts, Responses) concept map developed by EPA based upon information from the Decision-support Workshop, showing details for Driving Forces, Pressures, and Responses to each proposed decision alternative** (source Bradley et al. 2014b). Boxes are color-coded to follow the scheme used in **Fig. 3-6** (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. 3-9b**.

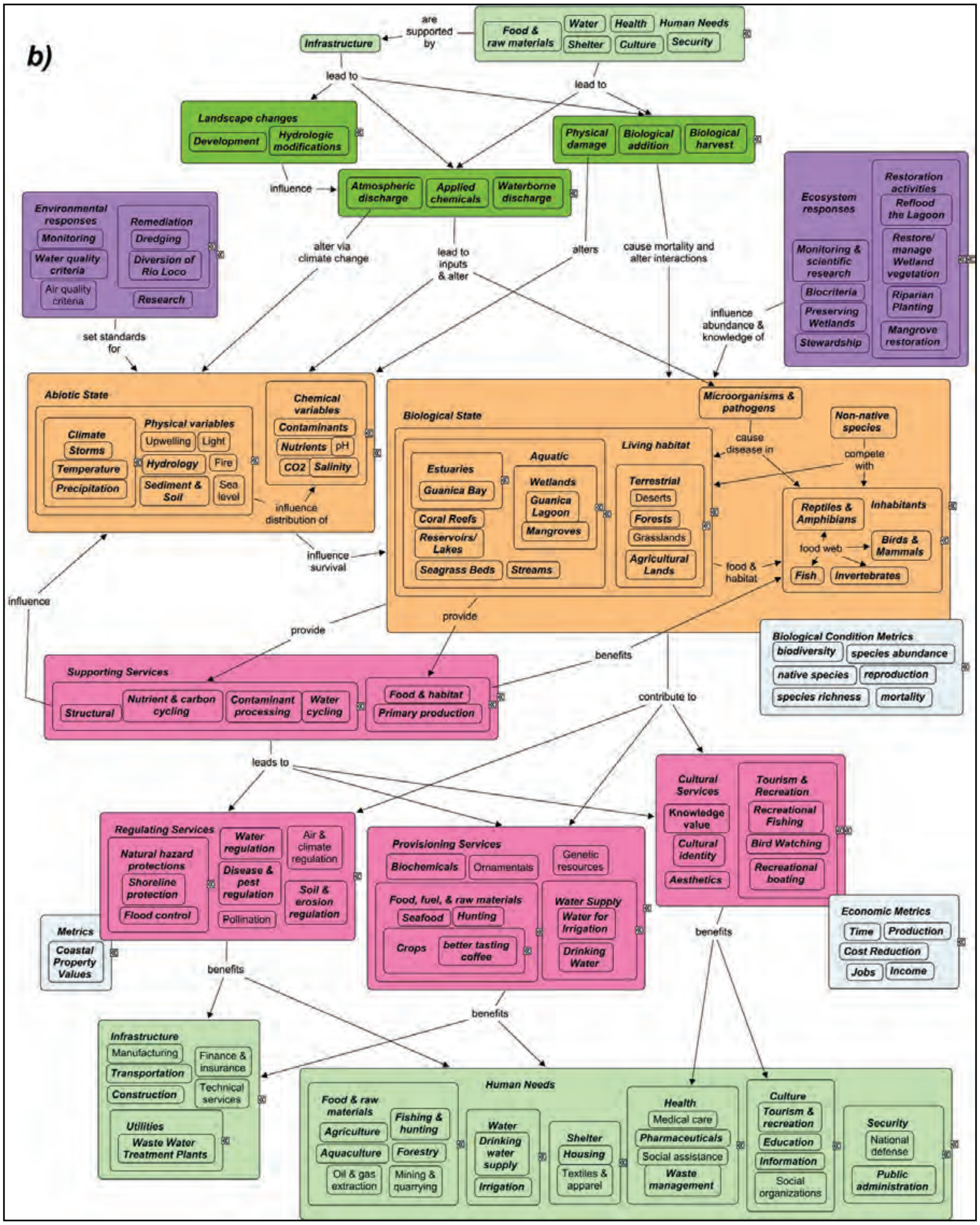


Figure 3-9b. Guánica-specific DPSIR (Driving Forces, Pressures, State, Impacts, Responses) concept map developed by EPA based upon information from the Decision-support Workshop, showing details for State, Impact, and benefits to Driving Forces (source Bradley et al. 2014b). Boxes are color-coded to follow the scheme used in **Fig. 3-6** (e.g., light green=Driving Forces; dark green=Pressures; orange=State; pink=Impacts; and purple=Responses). Grey boxes identify some possible performance measures identified by the group. The nodes presented here link with those in **Fig. 3-9a**.

3.4.3 Planning the consultation and analysis

Information gathered in the early steps of decision sketching is used to inform the information needs for the decision landscape. While considering the conceptual maps they had developed, workshop participants provided information that was later organized into a preliminary list of objectives (**Table 3-1**).

Table 3-1. Preliminary objectives list created through workshop discussions during the 2010 Decision-support Workshop (source: Bradley et al. 2014b).

Objective	Sub-objective
Land-use planning	- Environmentally sensitive development - Soil conservation and farm land quality
Water quality	- Bay (water 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	

Also discussed were measurable attributes for these objectives that could be used to gauge their performance. Workshop participants created preliminary lists of management options (Table 3-2) and information gaps requiring further research (Table 3-3).

Table 3-2. Management options developed by participants during the 2010 Decision-support Workshop

Water Management

- Restoration of Guánica Bay
- Develop a total maximum daily load (TMDL) for the Rio Loco
- Establish non-point source monitoring stations in the Guánica Bay Watershed
- Monitor additional beaches for water quality
- Vessel grounding program
- Additional mooring buoys
- Enforce use of mooring buoys
- Additional channel markers
- Improved navigational charts to reflect water depth, coral reefs and other sensitive resources
- Enforcement of the Clean Water Act
- 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

Terrestrial Management

- Reforestation
- Forest management plans
- Forest Legacy Program
- Community Forest and Open Space Conservation Program
- Land use management plan to guide future development
- Beach cleaning program
- Riparian restoration throughout the Guánica Bay watershed
- Enforce the requirement for runoff controls and other Best Management Practices at construction sites

Waste Management

- Construct wastewater treatment wetlands
- Enforcement of wastewater treatment systems
- Enforcement of residential on-site septic systems

Social/Political

- Education and outreach
- Process to manage stakeholder conflicts
- Education program to address the cultural component of some management practices
- Education and outreach on mosquito control
- Enforce existing regulations and laws
- More resources for law enforcement
- Research planning process

Table 3-3. Information gaps and research studies suggested by participants at the 2010 Decision-support Workshop (source: Bradley et al. 2014b).

Issue	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 (hydrology model) • Monitoring sediment & nitrogen in Rio Loco
Pollutant Fate	• Stream sediment studies • Marine stable isotope studies
Coral Reef Impacts	• 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 impacts • Tracking temporal trends in uses and impacts

Information from the workshop strongly influenced the decision sketch. Information was gained from stakeholders that characterized many concerns, identified several additional alternatives related to the initial decision context (protecting coral reefs) and laid a path for describing broader, more comprehensive goals for the watershed.

Participants at the Decision-support Workshop elevated several important factors for developing a complete decision landscape:

- Communities in the Guánica Bay watershed are linked by a complex hydrologic system that brings pollutants, in the form of sediment and nutrients, from agricultural economies to the coastal waters that support fishing economies. Sediment and nutrients originate in mountain ridges (coffee farming) and valley farms (vegetables and pastureland) and are transported by a man-made construct of dams, reservoirs, tunnels and canals. Both the infrastructure and agricultural practices influence the quality and quantity of water moving downstream. Moreover, municipal development in the foothills (Yauco) and coastal region (Guánica and La Parguera) has affected water uses and water quality.
- While it is generally understood that sediment and nutrient efflux from Guánica Bay can adversely affect coral reef condition, it is not known how much local activities are contributing to reef decline nor what level of local management actions will be required to reverse the trend.
- Alternatives proposed by the WMP (CWP 2008) were consistent with the USCRTF goal of reducing sediment efflux into Guánica Bay, but except for monetary costs, other potential tradeoffs were not described.
- The positive effects of reducing sediment in the watershed reach far beyond protection of coral reefs. Positive effects include (among others) reduced soil loss from farms, reduced sedimentation in reservoirs, improved stream and river water quality, improved fish and bird habitat and greater tourism and recreation potential.
- It was not always clear where the authority lay to permit, delay or deny an action. Also, there are actions that Federal and Commonwealth agencies can take without consulting local stakeholders. An integrated decision-making framework for the watershed could circumvent some of these inconsistencies and avoid future confusion.
- These factors were instrumental in guiding the next step of developing a decision landscape—archival research on past decisions and policies. To understand where we stand now, we have to see where we've been.

3.5 Archival research

Archival research is a type of primary research that involves locating, evaluating, and systematically interpreting and analyzing information from original archival records (Corti 2004; Schmidt 2011). Interpretation and analysis of past decisions requires a historical context. Consequently, EPA's archival research included a broad search for historical information on Puerto Rico and particularly for policies that affected communities in southwestern Puerto Rico. Based upon information gleaned from the 2010 workshop and further discussions with several Federal, Commonwealth and local decision-makers, the archival research was initially focused on 1) the construction of hydrologic infrastructure (hydroelectric plants, dams; sanitary sewer systems, municipal stormwater systems; irrigation and drinking water) and 2) agriculture (sugar cane , shade-grown and sun-grown coffee), draining the historic Guánica Lagoon, and the establishment of the Lajas Valley agricultural reserve.

Reviews of historical information provided a means to further focus archival research on specific decisions related to land and water use. Ultimately, the most relevant historical decision that emerged was the construction of a massive reservoir and irrigation system in the 1950s to supply water for agriculture irrigation. To interpret this event requires some recognition of the history and economy of Puerto Rico, which is summarized below. (Additional historical background is provided in **Appendix A**.) Existing perceptions of past decisions and the decision-making process were then elicited from stakeholders during a workshop held in 2012 (see **Section 4.2**). The information gathered during the archival research has been used throughout the research project.

3.5.1 Geographical setting: Guánica Bay

Guánica Bay is a narrow body of water south of the town of Guánica in southwestern Puerto Rico (**Fig. 3-10**). The Bay has a narrow opening (about ¼ mile [440 m] across), which is less than 2 miles (3 km) from the mouth of the Rio Loco. There are low, rugged hills on both sides of the Bay and three areas—Guánica downtown, Ensenada ward and La Pieza sector—on its shores. The hills on each side of the mouth of the Bay comprise the Guánica Dry Forest, a United Nations Biosphere Reserve since 1981 (Miller and Lugo 2009). Coral reefs occur outside the mouth of the Bay as they do across most of southern Puerto Rico (García-Sais et al. 2005). To the west of Guánica is a coastal plain, (Lajas Valley) and La Parguera, a coastal town that is a tourism destination for divers, boaters and fishers. Northeast of Guánica lies the city of Yauco.

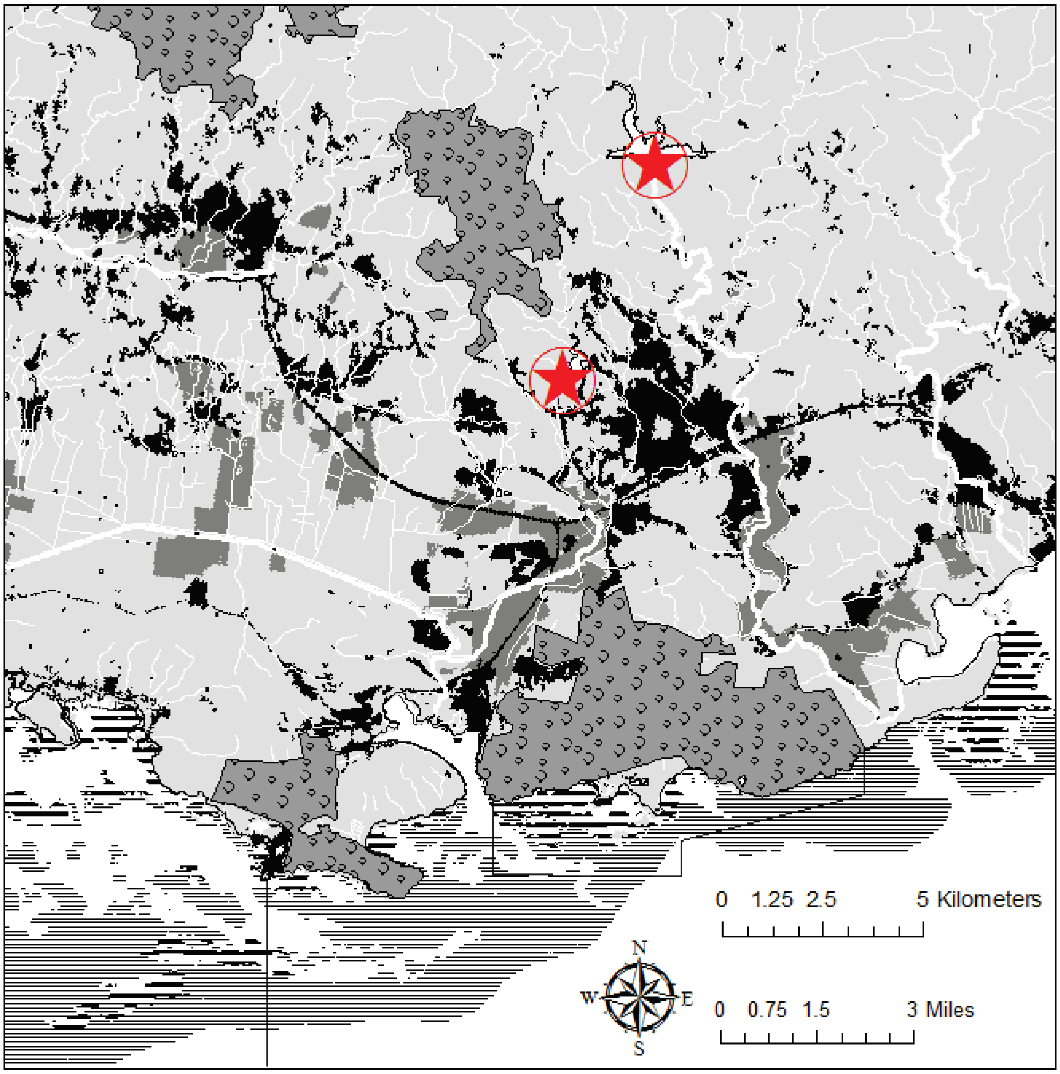


Figure 3-10. **Key urban and natural areas of the Guánica Bay Watershed** (adapted from Carriger et al. 2013). Black shading = developed areas, medium grey shading=cultivated crops & pasture, spotted grey shading=terrestrial protected areas, offshore hatched shading=seagrass, coral, and rubble benthic habitats, stars=locations of Loco and Luchetti dams. Credit for map layers: The hydrography layers came from the USGS National Hydrography dataset (Simley and Carswell Jr. 2009) (downloaded from http://nhd.usgs.gov/); and land cover came from the 2001 National Land Cover Database (Homer et al. 2004) (downloaded from http://www.mrlc.gov/). Additional map layers were downloaded from Florida International University's Map Imagery User Service, which included Kendall et al. (2001) and Keel (2005).

3.5.2 Historical perspective

Guánica Bay and Puerto Rico have a rich history. Taíno Indians inhabited the island when Christopher Columbus landed in 1493 and Juan Ponce de León established a Spanish settlement at (what is now) Guánica in 1508. During this time, the economy of Puerto Rico, and that of the Guánica Bay area, was shaped by gold mining and subsistence farming of tobacco, coffee and sugar cane, relying on slave labor. While slaves were present in Puerto Rico for nearly four centuries, it was not until the large-scale development of the sugar industry that slaves were imported in mass numbers (Bowman 2002): in 1765 there were only about 5,000 slaves in the colony; by 1830 there were more than 30,000 slaves. In 1873 slavery was abolished, however, their contributions and heritage are reflected in Puerto Rico's art, music, cuisine, and religious beliefs.

Tobacco became the dominant product in the mid-1600s (Carrión 1983). The amount of coffee grown in Puerto Rico was insignificant until 1736 and blossomed by the mid-1800s with the immigration of Corsican coffee growers to the Yauco region.

But after nearly 400 years of Spanish rule, many Puerto Ricans desired autonomy. In 1897 Puerto Rico was granted constitutional autonomy and representation in the Spanish parliament. But this limited autonomy was short-lived. In February 1898, over 16,000 U.S. soldiers landed at Guánica Bay as an offensive in the Spanish-American War. By August, Spain had ceded Puerto Rico to the American forces (**Fig. 3-11**).

Figure 3-11. Depiction of U.S. troops landing at Guánica in 1898 by artist Howard Chandler Christy (source: Wikipedia 2014).

Under U.S. influence, Puerto Rico quickly underwent many changes, often to the benefit of U.S. economic interests rather than the well-being of Puerto Ricans. It was not until 1917 that the U.S. Congress passed the Jones Act granting U.S. citizenship for all Puerto Ricans and provided unrestricted entry to the U.S. mainland. Two months later Congress passed the Selective Service Act, which brought nearly 20,000 young Puerto Ricans into U.S. military service during World War I.

Heavy U.S. investment in sugar cane began to pay off by the 1920's when sugar became the main export crop of Puerto Rico. For Puerto Ricans, however, sugar cane provided a static monoculture economy that employed most of the population at extremely low wages. By 1938, per capita income for Puerto Ricans had not risen above $100 a year.

An important aspect of this historical context (see greater detail in **Appendix A**) is that U.S. sugar interests owned most of the land, controlled the economy and sold over 90% of the sugar produced to the U.S. market. When the U.S. Department of Agriculture eventually eliminated sugar subsidies the industry waned. Because much of the land that fell out of production was still in U.S. ownership, Puerto Rico was forced to import most of its food from U.S. markets. Prices were held artificially high by U.S. tariffs, so the island became more and more indebted and dependent. The land monopoly was not broken until 1941, when the Land Reform Act limited ownership to 500 acres. By this time, however, there were few Puerto Ricans who could afford to buy land.

3.5.3 Operation Bootstrap: Industrialized agriculture and manufacturing

The term *bootstrap* refers to a leather loop used to pull a boot on and is commonly used to mean an ability to help oneself without the aid of others. The U.S. Congress determined that Puerto Rico would be less dependent and more able to fend for itself in the world economy if it had a modern industrial infrastructure. The Industrial Incentives Act of 1947, commonly called "Operation Bootstrap", was intended to replace the failing sugar economy by incentivizing industrialization in agriculture and manufacturing. At this time Puerto Rico was one of the poorest islands in the Caribbean with a high population density (600 per square mile) that had not (and could not, it was believed) subsist as an agrarian system (Davis 1948).

The result of Operation Bootstrap was to shift Puerto Rican labor from agriculture to manufacturing and tourism. Manufacturing that occurred on the island shifted from labor-intensive (e.g., apparel, tobacco) to capital-intensive industries, particularly pharmaceuticals, chemicals, machinery and electronics (**Fig. 3-12**). It wasn't the intent of Operation Bootstrap to eliminate the agrarian economy. Some economists emphasized manufacturing while others had argued for a balanced approach that included manufacturing and 'industrial' agriculture, using modern agriculture technologies and water delivery systems for irrigation.

Figure 3-12. Operation Bootstrap shifted Puerto Rican labor from agriculture to manufacturing and tourism. On the left, Governor Luis Muñoz Marín is laying the first stone for the Puerto Rican Can Company as part of Operation Bootstrap (1962). On the right, women are working in a textile factory (source: Wikipedia 2014).

The resulting strategy was drawn from capitalistic, free enterprise models of production, which included economic incentives to hold down labor wages, train the labor force in new technologies, and create an infrastructure (roads, water systems, airports) to support a strong export-based economy. If the government provided the infrastructure, the private sector would provide the production, distribution and transportation of goods. The program consisted of three inter-related components: Market-oriented export manufacturing, export-based natural resource industries (agriculture) and labor reform. Although modeled specifically for Puerto Rico, this was similar to economic plans of other Caribbean nations.

The U.S. consequently infused millions of dollars to build factories for industries that would benefit from the large labor pool and low wages. Under the Industrial Incentives Act, goods could enter the U.S. without tariff and profits were not taxed. By 1950, there were over 80 large industrial plants in Puerto Rico and the rural agricultural society was transformed into an industrial working class (Wells 1969). However, funding was also made available for industrialized agriculture, including a massive dam construction project for southwestern Puerto Rico.

3.5.4 Puerto Rico, a Free Associated State (Commonwealth)

In 1950, the Governor of Puerto Rico, Luis Muñoz Marin, successfully requested that the U.S. Congress declare Puerto Rico a Free Associated State (Commonwealth). This agreement preserved strong ties to the U.S. but allowed Puerto Rico its own constitution, legislature and elections. The Governor's political party (Populares) won the first true election (1952) by an overwhelming majority despite concerns the party was too close, and too often acquiesced, to U.S. interests.

In 1954, the U.S. Congress revoked the Puerto Rico exemption for the Federal Labor Standards Act, forcing wages for needlework and manufacturing dramatically higher and causing many factory employers to leave the island. Poor economic conditions and few opportunities drove large numbers of Puerto Ricans to emigrate to the U.S., mostly to New York City. There was such a huge emigration that even with a high birth rate the population of Puerto Rico declined. A new boom in manufacturing was engineered through the 1976 Federal Tax Reform offering tax exemptions to U.S. corporations. Nonetheless, unemployment sometimes reached 20% during this period and Puerto Rico remained heavily subsidized. The tax exemptions were curtailed in 1996 and over 16,500 manufacturing jobs were lost within a few short years (Miller and Lugo 2009).

Puerto Rico passed an "Agricultural Reserve Law" in 1999 in attempt to reverse the trend of declining agriculture. Lands used for agriculture in Puerto Rico declined during the 20th century from 2 million to only 500,000 acres. Many farmers abandoned their farms and these had reverted back to forest (Gellis et al. 1999). The law was intended to protect land for agricultural use by requiring farmers who received irrigation water to keep acreage in production. In most places, including Lajas Valley, the law has failed due to the Puerto Rico government's inability to collect the penalty of $50 per acre not in production.

3.5.5 Guánica Bay and southwestern Puerto Rico

Towns and communities around Guánica Bay, although culturally and geographically isolated from San Juan and the U.S. political agenda, were not unchanged by the events of the 20th century. Ensenada, on the west coast of the Bay, was home to *Central Guánica*, at one time the largest sugar processing plant in the world (**Fig. 3-13**). The central remained in operation, despite a declining sugar industry, until 1982. Across the Bay, a fertilizer plant, Ochoa Fertilizer Co. (**Fig. 3-14**), which is still in existence, was built in 1948 with storage silos and a pier for shipping. People living in the area worked as laborers in the sugar cane fields or mountain coffee farms. Unlike sugar production, Puerto Ricans owned many of the coffee farms. These were generally small farms on steep mountain slopes north of Yauco. Others in the area lived by subsistence artisanal fishing or by small fruit and vegetable farms scattered throughout Lajas Valley.

Likewise, the historical events shaped the attitudes of the people living in the area. Many were delighted that the U.S. invasion in 1898 removed elite Spanish farm managers (*hacendados*) who had rigorously maintained a system of agricultural serfdom and kept rural Puerto Ricans in perpetual servitude. They were also excited about the concept of U.S. democracy and the right to free elections. Unfortunately, voting was limited to male landholders until the 1950s and the economic outlook never really changed. For some, especially for members of the Nationalist Party headquartered in nearby Ponce, the U.S. was viewed as an unwanted oppressor with no right to rule a sovereign island state. Even

Puerto Rican leaders in San Juan were viewed suspiciously for their apparent compliance with and adherence to U.S. policy.

Figure 3-13. Central Guánica, a major sugar cane processing plant (top photo) was on the west shore of Guánica Bay (photo credit: Herbert A. French, 1947).

Figure 3-14. Ochoa Fertilizer Company, Inc. was on the east shore of Guánica Bay (photo credit: Yongping Yuan, EPA, ORD).

3.5.6 The Southwest Puerto Rico Project and the Lajas Valley Irrigation System

A component of Operation Bootstrap was to industrialize agriculture along the southern coast of Puerto Rico by providing irrigation and cheap hydroelectric energy for pumping water onto fields. As early as 1908, the South Coast Irrigation Service was formed to maximize farming potential, but under its aegis only small irrigation projects were completed. In 1915 the first reservoir was built at Carite (southeast Puerto Rico), which fostered sugar cane production and provided hydroelectric power for water pumps. Similar plans had been prepared for the southwest by the Puerto Rico "*Utilization of the Water Resources*" department, but these never matured, usually for lack of funding.

In 1941, the department was changed to a public-private entity (Puerto Rico Water Resources Authority) and, with better funding, planned and implemented the Southwest Puerto Rico Project (SWP) and the Lajas Valley Irrigation System (LVIS), a series of five dams and an extensive irrigation canal and drainage system (**Fig. 3-15**). The intent of these projects, at an anticipated cost of $32 million (1950 dollars), was to improve sugar cane production in the southwest coastal plain and provide inexpensive hydroelectric power for farmers to pump irrigation water. The dams were completed from 1951-1956 and the irrigation system, including drainage of a large lagoon (Guánica Lagoon, northwest of the Bay), was completed by 1961.

The SWP and LVIS were both complementary and contradictory to Operation Bootstrap. Electrifying rural areas was a step toward industrialization, but jobs were moving from the fields to the factories, leaving fewer laborers for sugar cane harvesting. Agricultural employment for Puerto Rico declined from over 200,000 to only 120,000 between 1950–1960. Sugar cane was still harvested by machetes and required cheap, plentiful labor. By the mid 1960's the growth of the sugar cane industry across most of Puerto Rico had all but stopped. The soil had become depleted of nutrients and stalks yielded only about ½ the sugar yielded in 1950. However, in Lajas Valley sugar cane production increased until about 1972 and the Central Guánica stayed in operation until 1982. The newly irrigated, fertile lands sustained sugar cane production during this period, but were ultimately unable to save it as the underpinning of an agricultural economy.

3.5.7 The rise of sun-grown coffee production

With sugar production in decline, coffee production was elevated in importance. Coffee cultivation had existed in the mountains of Puerto Rico since the mid-1700s and was its most lucrative export by the end of the 19th century (Wilson 1899). However, hurricanes and storm events continually decimated coffee farms to the extent that the government of Puerto Rico was forced to step in with protective taxes, inflated farm prices, crop insurance and even direct payments to farmers. Often these incentives benefited larger farms over smaller.

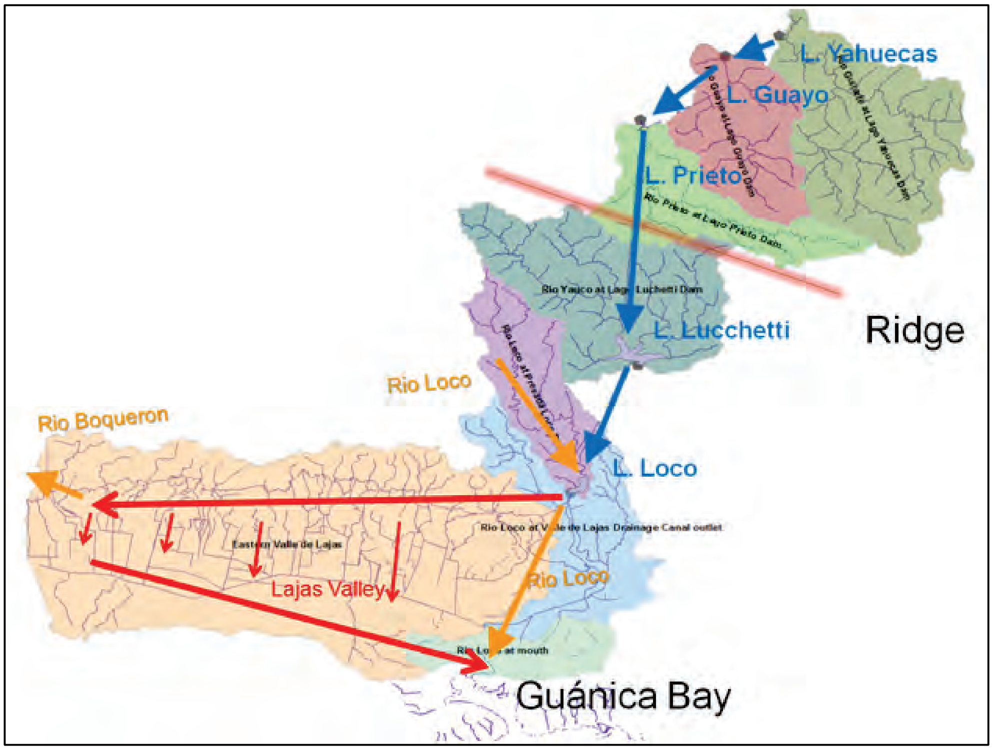


Figure 3-15. The Southwest Puerto Rico Project (blue arrows) consisted of five dams, three of which reversed watershed flow from north to south (adapted from Bousquin et al. 2014). The Lajas Valley Irrigation System (red arrows) consisted of a long canal that diverted water from Lago Loco across the Lajas Valley for irrigation, with a return ditch for drainage into Guánica Bay. The natural flow of Rio Loco and Rio Boquerón is shown (gold arrows).

In an effort to increase coffee production, Puerto Rico's Agricultural Experiment Station advocated a strategy to increase coffee yield by eliminating shade trees (canopy) and raising sun-tolerant coffee varieties in full sunlight (Vicente-Chandler et al. 1968). 'Sun-grown' coffee was not immediately adopted, despite government encouragement and incentives, until the 1980s (Borkhataria et al. 2011). Part of the reason was that the transition required not only elimination of the canopy, but also destruction of shade-coffee trees and replanting with sun-tolerant varieties (**Fig. 3-16**). For small farmers, time out of production causes a major lapse in cash flow. Consequently, widespread conversion to sun-grown coffee did not occur until the latter half of the 1980s.

3.5.8 Erosion and sediment distribution

Little by little, in the mountain ridges surrounding the five reservoirs of the SWP, the land-use transition began to take effect. Here, as elsewhere in Puerto Rico, sun-grown coffee cultivation began to replace shade-grown. This resulted in reduced biodiversity (from loss of canopy habitat) and increased soil erosion from the steep, and now poorly

Figure 3-16. Mountain farm near Yauco, Puerto Rico, cleared to plant sun-grown coffee (photo credit: Ross Lunetta, EPA, ORD)**.**

vegetated, slopes. Soil began to wash from hillsides into streams and ultimately into the reservoirs and irrigation canals.

But, coffee farming practices are not the only land-use activity that generates sediment in the Guánica watershed. Water delivery systems have altered the path of streams, riparian zones have been stripped of vegetation and municipal areas have grown. Although sedimentation is always a concern for reservoir longevity, the rate of sediment strapping and accumulation in Puerto Rico reservoirs has quickened dramatically. Today, the reservoirs of the SWP, only 60 years old, have about ½ their original water storage capacity (Soler-López 2002).

Continuing sedimentation threatens the ability to meet future water needs, which include irrigation, hydro-electric power generation, drinking water, wastewater diluent, downstream aquatic ecosystems and in-stream and in-reservoir recreational activities. Sediment accumulation in reservoirs also reduces the capacity to protect downstream communities from floods during severe rain events.

The increased sediment loads in the SWP reservoirs and aqueducts has led to increased sediment deposition in Guánica Bay (Bousquin et al. 2014). Increasing sediment deposits over the last several decades have changed the bathymetry of the Bay (Miguel Canales Jr. personal communication) and, after rain events, plumes of sediment can be seen dispersing from Guánica Bay into the nearby coastal zone and travelling west on prevailing currents toward La Parguera (**Fig. 3-17**). The occurrence of sediment plumes in coastal zones harboring valued coral reef ecosystems led to a concern that corals were experiencing inhospitable conditions caused by land use practices and instigated the USCRTF Guánica Bay Watershed Initiative.

Figure 3-17. Water and sediment leaving Guánica Bay enter the coastal zone and are swept to the west (see sediment trail) towards La Parguera by prevailing ocean currents (photo credit: NOAA).

3.5.9 Analysis - economic independence and self-determination

The EPA analysis of the literature located during the archival research determined that Operation Bootstrap and the development and implementation of plans for the SWP and LVIS were key decisions that have influenced the Guánica Bay Watershed. Operation Bootstrap was also the subject of analysis by Gordon K. Lewis (1963), who observed both the decision process and its aftermath. Lewis documented the efforts of the Spanish and the U.S. military governments to alleviate poverty and support economic growth in Puerto Rico through a series of failed attempts to develop agricultural exports, notably sugar, coffee and tobacco. The strategy was to generate an export-oriented economy (like postwar Japan) through industrialization of both manufacturing and agriculture (similar to Latin American models, but designed specifically for Puerto Rico). However, there was political resistance because an island like Puerto Rico was perceived to emulate a more ‘natural’ existence and should depend on subsistence economy rather than an ‘artificial’ manufacturing economy.

In his analysis, Lewis (1963) presents evidence that Operation Bootstrap was economically beneficial but, in balance, the benefits favored the landowners and investors rather than the workers. This in fact perpetuated, rather than remedied, the cycle of poverty for most Puerto Ricans. Lewis also concluded that plans for economic development were too closely linked to the U.S. economy. The industries that benefitted from the Industrial Incentives Act were U.S. companies that relocated to Puerto Rico to take advantage of the low wages, low environmental regulation and tariff and tax reductions. The beneficiaries were more the U.S. companies and less the Puerto Rican communities.

An anonymous author (1949), highly knowledgeable of Operation Bootstrap and likely one of its early strategists, presented some different perspectives. This author also described the plan as a strategy to reduce poverty through subsidies (tax incentives), land reform and labor reform. The challenges were finances, attitude and programmatic structure. To run the program, new agencies were formed with staffs of newly trained technical experts. Success of the program was, according to this author, tied to the abilities of these public managers to achieve a level of cooperation with private interests. But an additional concern was the ‘whims’ of the U.S. Congress in manipulating trade markets. There was a fear that changing economic policies could only deepen the “precarious condition” of Puerto Rican dependency on the U.S.

Archival evidence thus indicates that the most significant issue affecting the watershed of Guánica Bay was at its core a dedicated effort to reduce poverty and foster economic independence across Puerto Rico. Unfortunately this purpose did not materialize and today the U.S. taxpayers still heavily subsidize Puerto Rico. The unsuccessful attempts in agriculture and manufacturing have spurred greater interest in the tourism and recreation sectors of the Puerto Rican economy. The enactment of Law in 254 in 1998 in an attempt to form an Ecotourism Board is evidence of a continued desire to be economically independent. The promise for ecotourism relies on pristine, natural coral reefs, tropical forests and other natural resources.

The SWP and LVIS permanently altered the hydrology of the Guánica Bay watershed for the promise of economic development. But the failure of Operation Bootstrap to bring prosperity to Puerto Rico has resulted in the inability to maintain the infrastructure built for that very purpose. Maintaining the SWP and flow of water through the LVIS for agriculture and other uses is still important to stakeholders, but has become increasingly difficult with limited funds for reducing or removing sediment that is filling the reservoirs and canals. The conundrum that they now face is that of competing economic sectors. Higher yield sun-grown coffee farms in the mountain ridges, through soil loss, are threatening the delivery of water to struggling farms in Lajas Valley; and the farms in both the mountains and the valley, through sediment and nutrient pollution, are threatening the existence of coral reefs and the fishing and tourism opportunities they provide.

Another important factor that emerged from EPA's archival research is the lack of self-determination for Puerto Ricans. With both Spanish and U.S. rule, external political bodies have made major decisions about the island's economy and social structure. Puerto Ricans, certainly until the period of Governor Muñoz Marin, have been given little influence over their own affairs. Predictably, imposed policies were more economically beneficial to the external parties than to Puerto Rico. As a consequence, the motives of any external entity making decisions for Puerto Rico are viewed with some suspicion.

3.6 Summary

Through the efforts of the USCRTF and the Guánica Bay WMP (CWP 2008), a narrow emphasis for protecting coral reefs was expanded to incorporate a broader set of issues in the watershed. This provided an opportunity to hold a Decision Workshop (2010) for further characterizing and organizing the multiple issues under consideration. The workshop provided preliminary guidance on concerns, values, management alternatives, and potential performance measures (Carriger et al. 2013; Bradley et al. 2014b). Additionally, archival research was conducted to better understand the social and economic history of the Guánica region. This research brought to light the drive of Puerto Ricans to achieve economic independence and the unintended consequences of that effort—an altered hydrology of the Guánica watershed and an infrastructure that is increasingly difficult to maintain.

From the process, a better understanding of the broader decision context has emerged. Decisions in the Guánica Bay watershed have been couched in tradeoffs among ridge agriculture, valley agriculture, tourism and fisheries. Because of these different economic interests, stakeholders from different sectors have different values to consider in making decisions. While coral reef protection and watershed pollution are important issues, they are now being considered more clearly in the context of other stakeholder values and concerns.

Chapter 4. Define Objectives and Develop Alternatives

4.1 Introduction

While the entire SDM process is collaborative, two aspects of the process—defining objectives and developing alternatives—are developed through direct interactions with stakeholders and decision-makers. Objectives reflect the values of stakeholders (what is important) and alternatives are means to achieve them (Keeney 1992). In environmental management, we are often interested in values at a societal level, which would include the consideration of values related to individuals, organizations, and society as a whole. Stakeholders are asked to think about values on each of those levels in a deliberative process (Gregory et al. 2012).

4.1.1 Defining objectives

Objectives are statements of what is valued by stakeholders under a certain context (Keeney 1992). When informally making decisions, people often do not have a clearly defined or recognized set of objectives. While many decision-makers say they have clear objectives, what they really have is a messy mix of means and ends, targets, policies and vision statements, most of which are not useful for decision-making (Gregory et al. 2012). When decision-makers are developing policies and implementing decisions for a watershed, stakeholder objectives likewise may not have been fully considered or understood (Gregory and Keeney 1994).

> While many decision-makers say they have clear objectives, what they really have is a messy mix of means and ends, targets, policies and vision statements, most of which are not useful for decision-making (Gregory et al. 2012).

Objectives in decision-making have a very specific purpose. They focus decision-makers on what matters in terms of outcomes and become the evaluation criteria for identifying and evaluating alternatives (Gregory et al. 2012). The process of thinking through and writing down objectives helps decision-makers to make more informed decisions.

Objectives are usually described as something that matters (e.g., availability of quality habitat for important species, or quantity of sediment loads into Guánica Bay) and a verb indicating the preferred direction of change (e.g., maximize or minimize) (Mollaghasemi and Pet-Edwards 1997; Dunning et al. 2000; McDaniels 2000; Keeney 2007; Gregory et al. 2012). One example might be to "*Maximize the availability of quality habitat for a fish species*". Another example might be to "*Minimize the sediment loading into Guánica Bay*".

The item of value is the key part of the usefulness of objectives in reflecting values. The direction of preference further specifies whether the item of value should be achieved or avoided. Objectives are context specific: they are defined for the decision at hand, not for universal usage.

Formal decision analysis includes tools to properly elicit 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). Together, the decision-makers and stakeholders develop a set of objectives that everyone agrees will be used to evaluate alternatives.

Objectives have a direction of preference and an item of value.

- Maximize the availability of quality habitat for a fish species.
- Minimize the sediment loading into Guánica Bay.

Elicitation of objectives from workshop attendees was through development of DPSIR concept maps as described in **Section 3.4** and covered in detail in Bradley et al. 2014b. Once elicited, stakeholder objectives can be organized into an objectives hierarchy (OH), which is a formalized method to identify, describe, and structure the key objectives stemming from the decision context (Gregory and Keeney 2002). OH is a structured representation of the values of stakeholders (**Fig. 4-1**) and is useful for understanding the trade-offs in decision-making. This formal structure allows us to view any alternative in context of a broader objective to which it contributes, and also to more the specific objectives that contribute to it.

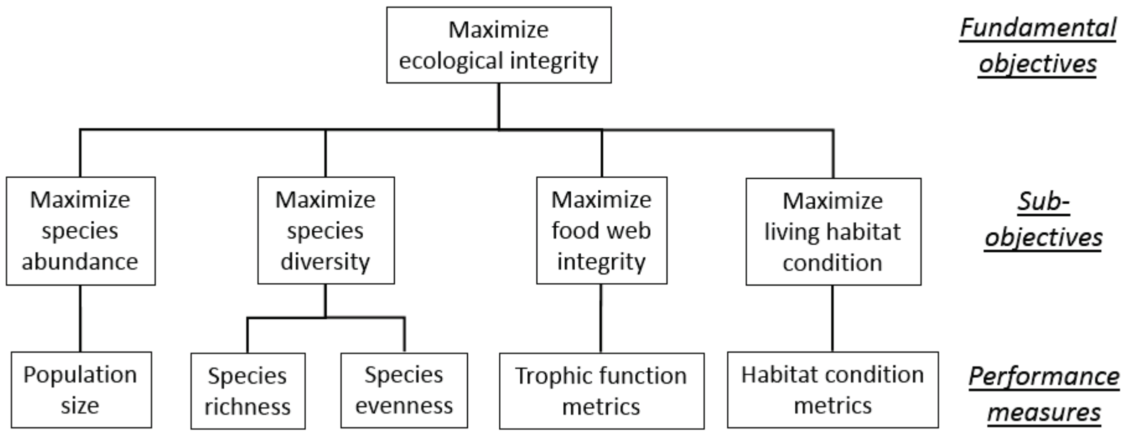


Figure 4-1. Example objectives hierarchy (OH) for one of the proposed fundamental objectives for the Guánica Bay Watershed (source: Carriger et al. 2013).

Objectives in the upper levels of the hierarchy reflect broad or inclusive values–the fundamental objectives. A fundamental objective is usually determined when the answer to "*why is this important*" is *"…just because"*…. meaning that it is simply something that humans need or want. "*Maximize ecological integrity", "maximize human health",* and *"minimize management costs"* are good examples of broad, encompassing fundamental objectives.

Evaluation measures, attributes that can be used to evaluate performance toward higher-level objectives, are at the bottom of the OH (Keeney 1992). Effective attributes are characterized by their measurability, understandability, and operability. The objectives and their corresponding attributes form a common vision for what is valued (objectives) and what will be assessed (attributes). The transparency of this approach helps to avoid future confusion and disagreement. At first, the OH is normally very broad, and is further refined over time.

Good objectives are:

- Fundamental
- Complete
- Concise
- Sensitive
- Understandable
- Independent (Gregory et al. 2012)

Progress towards these objectives is indicated by progress towards narrower, more specific objectives (means objectives). Means objectives answer, *"How do I achieve this?" or "What are the means to achieve this?"*.

"*Process objectives"* are different than fundamental and means objectives because they focus on improving the decision process. They don't describe what should be done, but rather how it should be done (Keeney 1992). An example of a process objective might be "*utilize credible scientific data"* when appraising decisions. The process objectives help achieve both fundamental and means objectives.

Key types of objectives:

- Fundamental objectives are the outcomes or ends you really care about, no matter how they are achieved.
- Means objectives refer to particular ways of achieving the fundamental objectives.
- Process objectives describe *how* something should be done.

A "*means-ends*" network can more fully specify the relationship between fundamental, means and process objectives and help elucidate which objectives are fundamental and which are means (**Fig. 4-2**). The fundamental objectives are the end concerns while the means objectives are important for achieving them. As noted, the ends objectives are the fundamental objectives: They reflect concerns that are important for their own reasons and not because they contribute to something that is more valuable (Keeney 1992). The recognition of these types of means-ends relationships is very useful because it reinforces linkages and establishes a path for the alternatives to achieve the objectives. The relative positions for different objectives along the means-ends path can usually be guided by asking, *"Why is this important?"* when moving towards the end objectives and *"How do I achieve this*?" when moving away from the fundamental objectives. The means furthest away from the fundamental objectives in this path will imply potential management actions.

For example, the information gathered during the 2010 Decision-Makers Workshop was examined, analyzed, and consolidated by EPA to generate a preliminary OH and further refined into a means-end network for the watershed management plan (**Fig. 4-2)**, (Carriger et al. 2013). The approach for developing the objectives relied on existing sources such as the 2010 workshop products (e.g., DPSIRs) created by the participants with the existing watershed management plan and policy or management documents relevant to the problem area. The fundamental objectives were organized with an objectives hierarchy and means objectives for achieving these fundamental objectives were identified for both the watershed and marine regions.

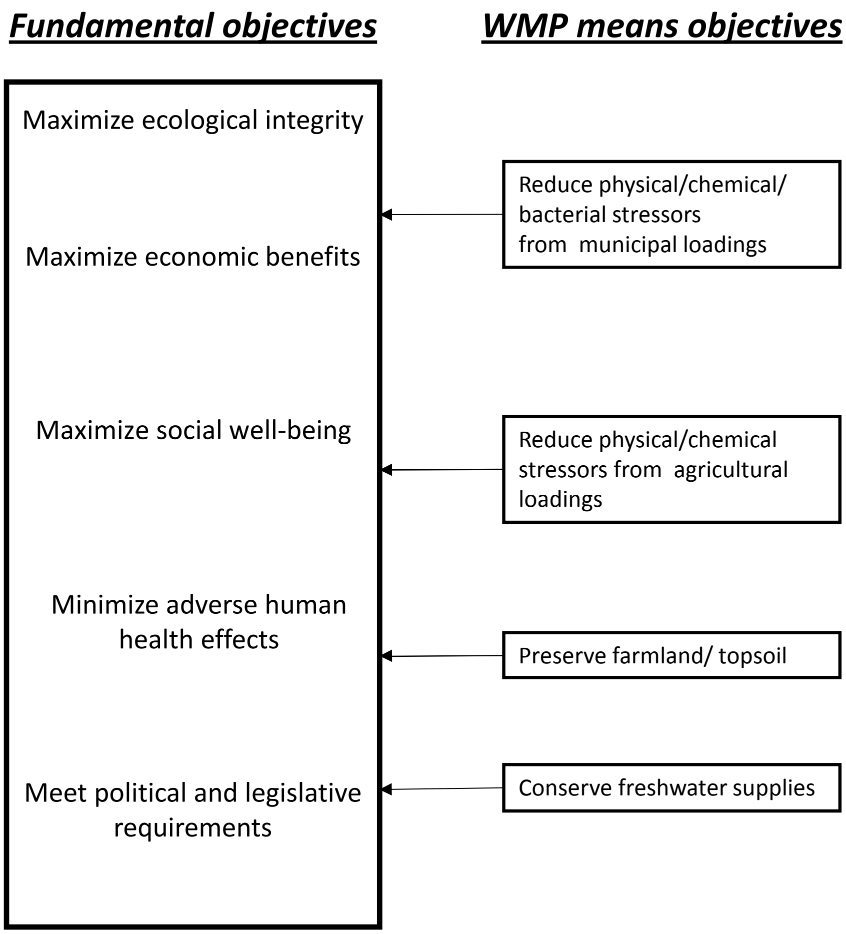


Figure 4-2. Means-end network for the Guánica Bay watershed based on expected effects of recommended actions from the Watershed Management Plan (CWP 2008) on fundamental objectives proposed in Carriger et al. 2013.

Key ideas:

- A fundamental objective is an end that you are trying to achieve
- A means objective is a way of achieving an end or fundamental objective
- A process objective is a way of improving the decision process itself
- Evaluation measures are attributes that can be used to evaluate performance toward higher-level objectives
- Focusing on objectives helps find creative solutions to problems
- Objectives only need to state the thing that matters, and what direction you'd like it to move in (i.e., increase or decrease)

There are many valuable aspects to an objectives hierarchy (Keeney 1992, 2007); one is that it represents a common vision—most stakeholders will agree on objectives high in the hierarchy even if not specific approaches for reaching an objective. The OH can be checked with stakeholders for consistency to ensure their values are being properly represented. Another is that objectives low in the hierarchy usually present opportunities for measuring performance. As with DPSIR, the transparency of an objectives hierarchy also helps to avoid future confusion and miscommunication.

4.1.2 Developing decision alternatives

Decision alternatives describe the different avenues that might be taken to achieve a particular objective. As emphasized in **Chapter 2**, decision alternatives should be considered only after objectives are understood. Seeking stakeholder input to identify and define decision alternatives can be valuable 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.

Decision alternatives can be examined for a variety of factors. Each decision alternative 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. The scale (how big a project is or might become), the number and level of decision-makers required, the funding, and the acceptability within the community all affect the complexity of a decision. Effectiveness partially requires factual information; this may require a best estimate of which alternative or combination of alternatives is more likely to achieve the objective. If alternatives are not achieving the objectives, it could imply that they should be reformulated.

Most decisions will affect more than one objective. For example, establishing a marine protected area will serve to maximize the long-term health of fisheries, but depending on the restrictions imposed, could maximize or minimize tourism, recreation and scientific learning. It may also detract from economic opportunities because of interrupted shipping lanes or reduced short-term fish catch.

Key points about decision alternatives:

- Decision alternatives describe the different avenues that might be taken to achieve a particular objective.
- Each decision alternative should be evaluated for complexity, effectiveness for the proposed objective, and potential consequences to other objectives.
- Most alternatives will affect more than one objective.

Objectives and decision alternatives were elicited at workshops in the Guánica Bay watershed. One workshop reviewed decision-making processes used in the watershed to characterize process objectives. The other was a Public Values Forum, which used the WMP as a backdrop for discussion of what is important in the watershed and how can it be achieved. Both workshops are described below.

4.2 Decision-making workshop

EPA convened a decision-making workshop in Guánica, Puerto Rico, on August 16 and 17, 2012. The purpose of the workshop was to examine and understand how decision-makers and natural resource users engage in the management of non-market resources (land, water quality, agriculture, fishing, urban redevelopment and tourism) in the Guánica Bay watershed. A particular emphasis at the workshop was the interaction between decision-makers and stakeholders during the decision-making process. Intrinsic to this approach is a concept that stakeholders and decision-makers invest in preservation and conservation of ecosystems because of the non-market benefits provided. This differs from market values that lead to, for example, food and fuel products extracted from an ecosystem.

Market and non-market goods and services:

- Some environmental goods and services, such as fish and seaweed, are traded in markets, thus their market value can be directly observed.
- Conversely, a non-market good or service is something that is not bought or sold directly. Therefore, a non-market good does not have an observable monetary value. Examples of this include beach visits, wildlife viewing, or snorkeling at a coral reef.

Qualitative research methods are widely used in the social sciences to investigate human behavior. In this study, EPA used *participant observation* research methods and open-ended questions administered in a workshop setting. Participant observation is the method in which the researcher participates with the research subjects. For example, in this case, the researcher (Gerardo Gambirazzio) participated in the workshop sessions and passively observed the dynamics among the participants. In addition, he spent two days working with fishermen and two days with small-farm coffee growers.

Observations of local fishermen included documenting their daily activities, noting their expenses, work schedules, and use of equipment, and also included discussions concerning their work, fishing methods, routes, and markets. Observations of small-farm coffee growers included the location of farms, the type of coffee, their production, capacity, and losses from an infestation of coffee bean borers ("Broca"). Also discussed were management practices of small coffee growers, as well as the economic, social, environmental and political pressures that are perceived by the farmers as threatening the survival of coffee growing enterprises.

The purpose of the research design was threefold: 1) collect information across various time periods and on different issues that have impacted the Guánica region; 2) better understand the physical, environmental, political and geographical boundaries of the region as they pertain to decision-making; and 3) better understand how users of natural resources and managers of those resources work toward sustainability within these social, political and economic boundaries. Data collected by these methods were used to interpret the role of decision-makers over time and on different types of resource management issues. Insight was also gained on how structures for decision-making are formed (decision-making bodies) and how they result in management plans for the users and stakeholders of natural resources in Guánica Bay.

The EPA researcher, Gerardo Gambirazzio, was also the facilitator for the workshop, which was conducted in Spanish to facilitate discussions with and among the stakeholders. The workshop was structured around two complementary parts:

a. Investigate how decision-makers were structured, or not, along a chain or hierarchy, and identify who they were and what they did or did not do (Day 1)
b. Investigate how local users and managers used non-market natural resources and the challenges they faced (Day 2; **Appendix E**).

Fifteen people attended the workshop (**Fig. 4-3**), including farmers, fishermen, and representatives of local and Commonwealth government agencies and Non-Governmental Organizations (**Appendix F**).

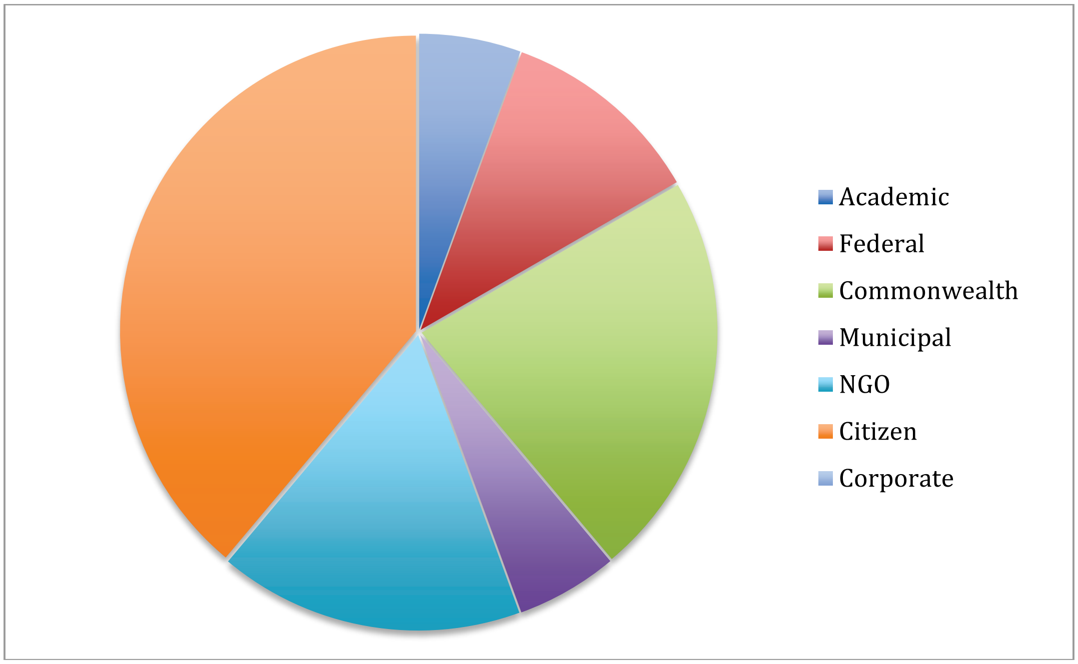


Figure 4-3. Workshop participants included farmers, fishermen, and representatives of local and Commonwealth government agencies and non-government organizations.

4.2.1 Decision issues in Guánica Bay watershed

Non-market resources are the environmental goods and services (e.g., clean air and water, and healthy fish and wildlife populations) that are not traded in markets. Workshop participants discussed the ways in which non-market natural resources, and activities using non-market natural resources, are managed and regulated at various levels of government. Partly because of who was present at the workshop, the discussions tended to focus on agriculture and fishing.

Decision-making structure. Workshop participants agreed that there is a confusing network of agency bodies at Federal, Commonwealth and local levels that are assigned to regulate natural resources and promote conservation practices. It was argued that agencies are stove-piped and rarely share data or collaborate on decisions with one another. The fishermen, for example, raised the issue that federal agencies (e.g., NOAA) and Commonwealth agencies (Puerto Rico DNER and Puerto Rico Department of Agriculture) regulate fishing. Puerto Rico Department of Agriculture also regulates agriculture, and participants felt the Department of Agriculture supports farming practices without considering consequences to coastal resources that are critical to fishermen.

Decisions concerning large projects have a disproportionate influence on environmental resources and non-market values. According to participants, these are conceived and planned at the Federal and Commonwealth levels, almost always excluding local stakeholders. Examples noted were the Lajas Valley Project, the draining of Guánica Lagoon, the wind project at Guánica Forest, and siting of polluting industrial plants along Guánica Bay. This has resulted in a sense of disenfranchisement and lack of local control.

It was suggested that a strategic plan should be developed to determine which land should be kept in a natural state and which land should be developed. Locally developed plans however, are not integrated into the Federal/Commonwealth decision-making process, which has traditionally exploited market-value resources and consequently transformed the natural landscape. For example, the Land Use Management Plan for the town of Guánica reflected viable ongoing economic activities in Guánica (fishing, tourism, and recreation), emphasizing revitalization of the waterfront as a tourism destination. But the Federal/Commonwealth government issued permits to allow construction and operation of a fertilizer plant on the shores of Guánica Bay (i.e., Ochoa Fertilizer Plant, see **Fig. 3-6**), which ultimately, according to some participants, contributed to degradation of the Bay and destruction of the town's economy.

It was emphasized that local citizens must demand more accountability from their leaders. For example, the Puerto Rico Department of Agriculture promotes and incentivizes the cultivation of coffee. However, Puerto Rico imports large quantities of coffee—a practice that is ruining small coffee farms. The companies that import coffee are reaping benefits from imported coffee, and do not foster policies that support locally grown coffee.

Training and outreach. A separate discussion during the workshop centered on training for stakeholders on the use of natural resources. Managers stated that they provide training on certain practices and on new regulations such as soil uses and other farming techniques. However, fishermen said that they receive no training on best practices or on new regulations. The fishermen, who were all commercial fishermen, felt that recreational and subsistence fishermen were depleting the resource through unsustainable fishing practices and adversely affecting the commercial industry. From this discussion it was concluded training and education needs may be greatest for recreational and subsistence fishermen.

There are many agencies providing training and outreach, ranging from Commonwealth agencies such as DNER, to universities such as the University of Puerto Rico Extension Program located in Yauco, and to Federal agencies such as EPA, NOAA, USDA/NRCS and the US Army Corps of Engineers. According to the participants, these agencies do not appear to work together to plan and coordinate training and outreach activities.

Priorities for natural resource management. Participants were asked to discuss their priorities for the Guánica watershed. They engaged in a lively and sometimes heated exchange of ideas. From this discussion, a set of priorities and associated objectives was developed (**Table 4-1**).

Table 4-1. Priorities for natural resource management and associated objectives developed by participants at the 2012 Decision Workshop.

Priority	Associated Objective
Provide economic and technical assistance to farmers, Form coffee cooperatives	A healthy coffee-growing region (economically and ecologically) – the "Napa" of Puerto Rico
Establish a set of sustainability rules	Guánica becomes a sustainable community
Manage natural resources as a "common" (including establishing a marine reserve) modeled after the island's first ecotourism project at the Punta Santiago Nature Reserve in Humacao, Puerto Rico	The Guánica Bay watershed area becomes an ecotourism destination
Develop cultural tourism (i.e., the sugar industry and Sierra Bermeja mountains, south of Lajas Valley, which has 95 million-year-old serpentine rocks, considered the most ancient rocks of the Caribbean plate, and 88 archeological sites)	The Guánica Bay watershed area becomes a cultural destination
Increase enforcement of environmental laws • Theft/destruction of lobster pots • Recreational fishing licenses and limits • Prohibited fishing practices (use of chlorine) • Education for the DNER Rangers	Sustainable marine resources

Environmental research. It is important to understand how and why government and other researchers conduct research, and how they obtain and share information with the community regarding the use of natural resources. An exercise was used to elicit information on this topic.

Fishermen said that the researchers from the University of Puerto Rico are common in the area of fisheries and fisheries management. A resource manager commented that researchers from universities and agencies conduct research in the Guánica Dry Forest, but the results are seldom shared with the community. Most of the participants agreed that research projects conducted in Guánica watershed, whether on fishing, agriculture or urban issues have been single-focus projects, isolated from other social, economic, environmental, and political processes at work in the watershed.

Transparency and access. Another exercise elicited opinions on access to decision-makers and transparency in the decision-making process. One participant noted that the problem wasn't so much transparency, but rather manipulation of information and issues by decision-makers (agencies) toward a preconceived end. In general, participants were unaware which issues decision-makers are addressing and why they chose those issues over others. This led to a discussion on the lack of communication between natural resource users and Federal and Commonwealth agency managers. This detachment leads to adverse political and economic effects to the community, the environmental landscape of the mountains, the town, the Bay, and the coral reefs.

Fishermen spoke at length about the lack of understanding by Federal and Commonwealth decision-makers about the economics of their business. Commercial fisheries in the Guánica Bay watershed are mainly artisanal, occurring mainly in coastal habitats or on the insular shelf. The main fishing gears used are: hand lines, fish traps (for reef fish), wooden cage lobster traps, gill nets and trammel nets, horizontal and vertical long lines, trawling, gathering by hand (e.g., queen conch), and using scuba-diving equipment with spear guns. Specific concerns were:

- *Competition among fishers is brutal*. For example, lobsters are a very profitable catch and some fishermen cut the lines to others' lobster pots. There is no enforcement of laws that prohibit this. Also, fishermen have to retrieve their cut pots by scuba diving, often in dangerous conditions.
- *The market for locally caught fish is very limited*. There are six companies in Puerto Rico that control the fishing industry. The artisanal fishermen catch fish to feed their families but also sell part of their catch, which puts them in direct competition with commercial fishermen.
- *Commercial fishermen must comply with fishery regulations*. Regulations prohibit catching certain fishes some months of the year and DNER Rangers are responsible for enforcing the fisheries regulations. Recreational and artisanal fishermen must also comply with fishery regulations, but there is no enforcement. According to DNER they have established a permit system to regulate the recreational fishermen but it is not yet implemented.
- *Lack of conscientious behavior*. The recreational fishermen see less benefit in conserving coral reefs relative to commercial fishermen. For example, some recreational or artisanal fishermen use chlorine when they fish, which also kills reef building corals and other biological habitat.

Coffee growers, who indicated they are facing a desperate economic situation, voiced a different set of concerns.

- *Patronage and favoritism*. The term "*apadrinamiento*" (godfather) describes government officials who select certain farmers to receive benefits and incentives.
- *Subsidization of large farms over small*. Government farm incentive programs commonly support large farms and neglect small farms. In some cases, the government covers 100% of the farming costs for some large farms (i.e., provides the coffee plants, guarantees the crop sales). This means that large farms have minimal risks, don't have to expand and don't have to use farming practices (e.g., sun-grown coffee) that destroy the landscape and create erosion. This is similar to when sugar was the dominant crop and the U.S. Government subsidized large corporate farms.
- *Small family-owned and operated farms are disappearing*. The small growers have to take more risky actions to make a profit, including actions that are damaging to the environment (e.g., clearing tree canopy and exposing the soil). Funding should be made available and accessible to small family-owned farmers and small entrepreneurs.
- *There is a severe shortage of coffee pickers*.

The participants all agreed that local stakeholders feel disenfranchised. People making the decisions do not include resource users in the decision-making process. Likewise, there is little community engagement about decisions being made, and stakeholder objectives and ideas are rarely considered. Participants highlighted certain aspects related to disenfranchisement:

- There is a need for a methodology or structure to manage the natural resources that includes resource users. As an example, some participants felt that more stakeholder involvement was needed in managing the Guánica Dry Forest Reserve.
- Federal agencies are detached from the stakeholders, since they are too far away from the Guánica Bay watershed. There is a feeling of lack of control on the part of local managers since they do not make the actual decisions. There is often confusion about who is in charge and who truly is making the decisions. Sometimes local managers don't agree with the decisions that have been made by Federal managers.

- Local communities are sometimes not even aware of decisions that have been made. According to workshop participants, a U.S. company had constructed a platform (about 300’ X 150’) to receive natural gas at the Puerto Rico Electric Power Authority (PREPA) facility. Once the platform was obsolete, the U.S. company was required to dispose of it. They hired a fisherman to find a suitable location to dump it offshore so it could not be found. According to participants, the U.S. company sank it two miles offshore of the town of Salinas. No enforcement actions were taken against the company or PREPA.
- Puerto Rico agencies are highly politicized.
- Decisions are not always consonant with the scientific studies.
- When stakeholders are asked to participate in decisions, their opinions and recommendations are subsequently not considered.

Concerns about transparency and access are summarized in **Table 4-2**.

Table 4-2. Transparency and access concerns raised by participants at the 2012 Decision Workshop.

Fishermen	Coffee Growers	Shared
Competition among fishers is brutal	Patronage and favoritism	Local stakeholders feel disenfranchised
The market for locally caught fish is very limited	Subsidization of large farms over small	Lack of communication between natural resource users and Federal and Commonwealth agency managers
Commercial fishermen must comply with fishery regulations	Small family-owned and operated farms are disappearing	Local communities are sometimes not aware of decisions that have been made
No enforcement for recreational and artisanal fishers	There is a severe shortage of coffee pickers	
Lack of conscientious behavior		

4.2.2 Non-market values of ecosystem resources

Natural resource goods and services, such as clean air and water, and healthy fish and wildlife populations, are not traded in markets. Their economic value (e.g., what people are willing to pay for them) is therefore not revealed in market prices. Non-market valuation methods provide a way to assign dollar values to them. Without these estimates, natural resource goods and services may be implicitly undervalued, and decisions regarding their use and stewardship may not accurately reflect their true value to society. The second day of the workshop was devoted to characterizing non-market ecosystem values for the participants.

Natural resource management and conservation. An exercise was completed that asked participants to identify natural resources that are neglected or face challenges. The discussions identified several potential investment opportunities:

- *Collection, storage and distribution of water and future availability (security) of water*. There are water shortages, especially during the summer, and these are becoming more acute. One issue is the old irrigation system infrastructure. Sedimentation and inadequate outlets has reduced the flow capacity of conveyances.
- *Neighborhood blight*. Parts of the town of Guánica look very run down. This creates a negative impression of the town and potentially curbs tourism. The Guánica municipal government does not invest in improvement projects that would maintain quality housing or aesthetic attractions. Restoration of the town urban center would benefit tourism.
- *Agricultural lands must be rescued*. Some agricultural lands have been or are being used for municipal development.

Economic development. As part of another exercise, participants identified and discussed the economic sectors they would like to see developed in Guánica Bay and the actions they recommend to achieve economic sustainability. Highlighted in the discussions were agriculture, fishing, ecotourism, forests and recycling, as noted below and summarized in **Table 4-3** (pg. 66).

Agriculture. The participants felt strongly that agriculture must be viewed as long-term investment in Puerto Rico. According to former P.R. Department of Agriculture Secretary Javier Rivera, Puerto Rico imports 85% of its food. Puerto Rico should establish local food production that is fully sustainable and diversified. Participants felt that there should be a marriage between food security and conservation of the land.

Some of the challenges include:

- The large supermarket chains import food from low-cost global exporters and from the U.S. mainland. Local farmers cannot compete. Even the Department of Education School Lunch Program buys their goods from importers[3]. Additionally, there are farmers who grow for the export markets when they should supply the local market first.

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[3] On July 24, 2013, the governor of Puerto Rico announced his commitment that for the upcoming school year the food served in the school lunch program would be comprised of 50% locally grown food. Some critics have argued that this commitment was not met. Reference: El Vocero de Puerto Rico 2013). http://www.vocero.com/no-es-hecho-en-puerto-rico-menu-de-comedores-escolares/

- Many farms do not support independent livelihoods for their owners. Many farmers receive more income from food stamps than from farming and this further reduces the desire of small farmers to produce.
- Multi-crops should be encouraged. Insurance companies will only insure sun-grown coffee when it is grown with other crops. Farms must be insured in order to receive government incentives.
- Studies should be conducted to understand consumer preferences and to more successfully market locally grown products to Puerto Ricans.
- Farmers must develop an entrepreneurial mindset. For example, some farms could establish residential programs for aspiring farmers to learn and practice the technical and business skills needed to run a small-scale farm. This has worked in other places, and could work in Puerto Rico.
- Puerto Rico should develop a branding strategy for shade-grown Puerto Rican coffee. This would include a field inspection and certification process.

Fishing. Commercial fisheries in the Guánica Bay watershed are small-scale and occur mainly in coastal habitats or on the insular shelf. Participants identified a wide range of challenges where additional resources could benefit commercial fishing:

- Small-scale fishermen have no information to develop their businesses.
- In Salinas the fishermen created their own co-op to better manage the resource as a group.
- Fishermen are blamed for over-fishing, but they believe it is pollution from the farms that has adversely impacted the fish populations.
- Local fishermen sell their fish right away. They call people on the phone and then drive around the city delivering the fish.
- The small commercial fishermen want to stay small, but want to make a living wage.
- If overfishing is really an issue, the small fishermen blame the six large companies.
- The small fishermen feel that Puerto Rico should develop a fish industry in international waters. Japanese are fishing near Puerto Rico in international waters.
- The government should support the aquaculture industry.
- There should be more fish stocks protected and managed by the government.

Ecotourism. Workshop participants felt that ecotourism should be developed in the Guánica Bay watershed. This would serve to educate visitors about natural resources, would provide funds for ecological conservation, and would benefit the economic development and political empowerment of the local communities with tourism dollars. Discussion points related to ecotourism included:

- The government should provide some subsidies to support development of ecotourism.
- A restored Guánica Lagoon could provide refugia and nursery areas for birds and fishes, and support an ecotourism industry (kayaking, bird watching). It could become a central part of the community. The participants were baffled by delays in the restoration of the lagoon; they felt that it was either political or that a small group of people who didn't live in the watershed were delaying the restoration.

Forests. Local wood carvers require wood but are limited by regulations restricting use of wood from the Guánica Dry Forest. This restriction was used as an example that the Commonwealth (DNER) does not include or consider stakeholder needs in Dry Forest management.

Recycling. Participants had a short discussion on the lack of recycling in the Guánica Bay watershed area. They felt that an emphasis should be placed on reducing, reusing and recycling materials. It was pointed out that recycling was not currently economically feasible and therefore the government should subsidize it. They also felt that an education program was needed.

- In 2010, EPA formed the Puerto Rico Recycling Partnership (PRRP) to promote materials source reduction, clean composting, reuse, and recycling through a working partnership including government (at all levels), non-profit organizations, citizens, environmental groups, and the private sector.
- Three communities (Guaynabo, Rincon and Vieques) were chosen as pilot communities. Things learned from the pilot communities will be valuable to other communities throughout Puerto Rico facing similar socio-economic-environmental challenges.

Table 4-3. Economic sectors and challenges to economic sustainability, as identified by participants during the 2012 Decision Workshop.

Sector	Challenges
Agriculture	The large supermarket chains import food from low-cost global exporters and the U.S. mainland. Local farmers cannot compete.
	Many farms do not support independent livelihoods for their owners.
	Farms must be insured in order to receive government incentives and insurance companies require farmers to grow multiple crops.
	Farmers do not understand the Puerto Rican consumer's preferences.
	Farmers must develop an entrepreneurial mindset.
	Puerto Rico should develop a branding strategy for shade-grown Puerto Rican coffee.
Fishing	Small-scale fishermen lack information to develop their businesses.
	When fishermen form co-ops they can better manage the resource as a group.
	Fishermen are blamed for over-fishing, but they believe it is pollution from the farms that has adversely impacted the fish populations.
	Puerto Rico should develop a fish industry in international waters.
	Government should support aquaculture.
	More fish stocks should be protected and managed by the government.
Ecotourism	Government should provide subsidies to support development of ecotourism.
	A restored Guánica Lagoon would provide refugia and nursery areas for birds and fishes, and support an ecotourism industry.
Forest Crafts	Local wood carvers require wood but are limited by regulations restricting use of wood from the Guánica Dry Forest.
Recycling	Government should place an emphasis should on reducing, reusing and recycling materials.
	Recycling is not currently economically feasible and the government should subsidize it.
	An education program is needed.

4.2.3 Summary

The Decision-Making Workshop led to a better understanding and characterization of past decisions in the watershed and challenges for social, environmental and economic balance. In particular, participants stressed the lack of local involvement and influence in decisions being made (usually at the Federal and Commonwealth level), and felt that this had led to a series of uninformed decisions that were often contradictory to local needs and local vision.

The workshop also led to a better understanding of new and old challenges for important economic sectors, particularly small-scale commercial fishing and coffee farming. These challenges have been aggravated by policies and decisions within the watershed (e.g., poor enforcement of fishery regulations) and outside the watershed (e.g., coffee import tariffs).

The workshop was also very informative concerning non-market values for natural resources. It became clear through the discussions that non-market value was elusive for most users of resources. Conservation of natural resources was a high priority because of long-term needs for extraction economies, not for the non-market values. The fishermen, who must sail miles further into the ocean to search for $50 worth of fish to break even at market, are upset about degradation of the coral reef ecosystem, not because it is an aesthetic loss or a loss of potential tourism dollars, but because it is essential habitat for fish. For coffee-growers, the political and economic imperatives to farm sun-grown coffee cause erosion of sediment that ends up in the rivers and on the Bay.

4.3 Public Values Forum

EPA convened a Public Values Forum in January of 2013 to engage Guánica Bay watershed community members and decision-makers in a workshop setting to better understand and define what is important for restoration of the Guánica Bay watershed and associated coastal/marine regions. Drs. Robin Gregory and Julian Gonzalez (Value Scope Research, Vancouver, Canada), two recognized and neutral facilitators experienced with working with diverse groups in cross-cultural settings, facilitated the workshop in both English and Spanish and summarized its results (Gregory and Gonzalez 2013).

EPA structured the workshop around activities and discussions that helped to characterize valuable aspects of the watershed, to identify availability of and needs for science and technical information to improve decision-making, and to demonstrate structured decision-making tools that could benefit future watershed management planning and implementation. The Public Values Forum was built on past work conducted by EPA in the region with stakeholders and decision-makers, including information from prior workshops (see **Sections 3.4 and 4.2**) and archival research on the socio-economic development of the region (see **Section 3.5**).

A broad group of stakeholders participated in the Forum, representing many interests in the watershed and coastal zone (**Fig. 4-4**; **Appendix G**). Prior to the Forum, EPA, Value Scope Research, colleagues from other governmental agencies, and non-government organizations (NGO) collaboratively generated a list of stakeholder categories to identify potential participants (**Table 4-4**). The thirteen categories were drawn from existing information about previous meetings, workshops and planning documents, and were deemed sufficient to ensure broad stakeholder representation based on the available knowledge about the region, and on information collected earlier on the context, and agreement with outside decision-makers. An invitation list was developed so that 2-3 stakeholders were initially invited from each category.

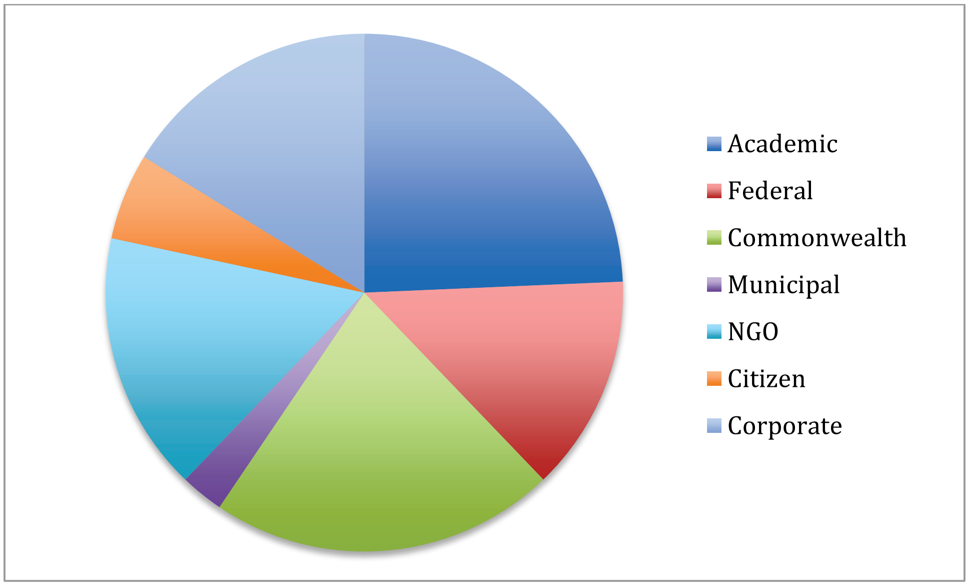


Figure 4-4. Public Values Forum participants included academics; representatives of government agencies, non-government organizations and businesses, and citizens.

Several invited participants provided names for potential additions to further fill the categories. Nonetheless, some categories (particularly fishing, recreation, and government- municipality) were not completely filled. For example, municipality officials were lacking because new local governments had just been installed after elections.

Table 4-4. Categories used for targeting stakeholders for the Guánica Bay watershed Public Values Forum.

- Community leaders/neighbors
- Environment- coastal/marine
- Environment- forest
- Environment- watershed
- Farming- upper watershed
- Farming- Lajas Valley
- Fishing
- Government- municipality
- Government- Puerto Rico
- Government- US
- Public health
- Recreation (other than fishing)
- Tourism

The first morning of the workshop offered several opening presentations that established an initial context and a common base of information for the Forum. These included two presentations from EPA, one on research in the watershed (Dr. William Fisher) and one on regulatory responsibilities and agency goals (Ms. Evelyn Huertas). Roberto Viqueira Ríos, the Guánica Bay Watershed Coordinator and director of the NGO '*Protectores de Cuencas*', provided an overview and status update for the Guánica Bay Watershed Management Plan (CWP 2008). Dr. Richard Appeldoorn, a University of Puerto Rico marine scientist and Director of the Caribbean Coral Reef Institute, described the coastal ecosystems and the human activities in the watershed that threaten their condition. Dr. Manual Valdés-Pizzini, a sociologist and Director of the Interdisciplinary Center for Coastal Studies Social Sciences Department at the University of Puerto Rico, gave a presentation on the socioeconomic setting and history of the watershed and coastal zone. The facilitators (Drs. Robin Gregory and Julian Gonzalez) then provided an overview of the Forum goals and framework.

The workshop reconvened after lunch with a discussion of the topics and information that were presented in the morning. Participants asked questions of presenters on several topics including the watershed and coral reef restoration effort, varying contributions of different stressors to coral reef degradation, uncertainty surrounding the sources and effects of stressors (particularly sediment and nutrients), potential impacts of resuspended sediments, and information sources.

One discussion topic revolved around sediment deposition in Guánica Bay and the coral reefs. It was agreed that the highest sediment transport occurs after major rainfall events, but the primary source of sediment was disputed. Some felt the sediment arose from the Rio Loco watershed and others from the diversion of water from Lago Loco through Lajas Valley for agriculture irrigation. There was insufficient scientific evidence to resolve the issue, so Dr. Gregory explained that procedures were available to bring together scientists who had contrasting factual evidence. Technical issues can be clarified and evaluated in a formal process to clarify uncertainties and data gaps.

One participant felt that there had been too much emphasis on coral reefs, which initiated a discussion of other valued resources, including beaches and fisheries. This discussion led to identification of values beyond coral reef protection and highlighted other social and economic issues. For example, one concern was the inability of PREPA to remove sediment that continually collects in the irrigation canals and drainage ditches in Lajas Valley. Also, the potential loss of farmland was discussed in response to a proposal to restore the historic Guánica Lagoon for sediment and nutrient filtration.

The facilitators then led a discussion on how workshops could be used to identify both the values and some of the factual information needs for good decision-making. The focus of a Public Values Forum was on understanding and incorporating stakeholder values into the decision process. Emphasized during this discussion was the difference between factual (knowledge-based) claims and value information. Values are what people care about (Keeney 1992) whereas fact-based claims are descriptive characterizations of states of the world (Failing et al. 2007). For decision-making purposes, the factual claims often describe past, current, or future impacts from decisions, and their uncertainties, based on scientific or local knowledge. Values represent what is important (to be achieved or avoided) in a decision context and are the reason why decisions are made. For example, "eco-tourism opportunities would bring more visitors to the watershed" is a factual claim while "I hope the income level of residents increases" is a values-based statement. Whatever the source, knowledge-based claims can be held to standards of veracity and relevance while values held by individuals would not be tested for legitimacy (Failing et al. 2007). The need to identify values *before* proposing alternatives was stressed. Clarifying data needs and gaps is essential for exploring alternatives, but the decisions should be optimally designed to fulfill stakeholder values.

The workshop participants began to identify and organize the key values and factual elements to support further management decisions in the Guánica Bay watershed. Based on their interests and expertise, the participants self-selected into one of four breakout groups: ecology land, aquatic ecology, economy, or social issues, to discuss what they felt was important in the watershed (**Fig. 4-5**).

Figure 4-5. Day 1 breakout groups for establishing an initial list of values in the social category (foreground) and economics category (background) at the Public Values Forum held for the Guánica Bay watershed in Puerto Rico (photo credit: John Carriger, ORISE Fellow).

Each breakout group developed and presented an initial list of objectives reflecting their values for the watershed and coastal regions, which the facilitators reviewed and compiled into a combined list of objectives that included all of the objectives identified in each of the breakout groups. The combined list of objectives was reviewed the following morning of day 2 (**Table 4-5**). 'Process' objectives were taken from each group and compiled to highlight the objectives regarding improvements to the decision-making process in the region. Many of these mirrored process concerns in the previous workshop. Objectives with question marks indicate topics that were not fully defined or resolved as to meaning during the workshop.

Table 4-5. Initial objectives generated from four breakout groups in the first day of the Public Values Forum (adapted from Gregory and Gonzalez 2013).

Ecology - land

- Meet future water demands (Agriculture + Development)
- Restore and conserve habitat for important species
- Improve monitoring and feedback of current actions
- Reduce contamination from agriculture effluent
- Reduce stormwater runoff
    - Ecological best-management practices
    - Outreach and incentives
- Reduce soil loss (maintain productivity of land)
    - Through best management practices in agriculture
- Reduce uncertainty about outcomes of management actions
- Understand relative contribution of sediment origins (two watersheds)
- Preserve forest habitats
- Protect endangered and threatened wildlife species

Ecology - aquatic

- Restore lagoon natural processes (filtration of nutrients and sediments)
- Restore shallow water coral reefs
    - Reduce nutrient loads flowing into the ocean
    - Enhance fish biomass and abundance
- Improve monitoring and feedback of current management actions
- Reduce human contamination
    - Endocrine mimics (cosmetics, birth control)
    - Runoff from roads (Hydrocarbons)
    - Sewage pathogens
- Reduce uncertainty about outcomes of management actions
- Protect endangered and threatened marine species
- Protect mangrove habitats
- Protect marine habitats for migratory birds

Economy

- Demonstrate economic value of ecosystem services
- Estimate net benefits of best management practices
- Protect infrastructure of Southwest Puerto Rico Project
    - Dredging reservoirs
    - Maintaining tunnels
- Promote community economic benefits
- Improve employment opportunities
    - Publish job opportunities
    - Training and workshops for unemployed
    - Undertake human capital analysis
- Increase sustainable economic development
    - Promote eco-tourism
    - Maintain/increase swimming beaches
    - Promote opportunities for value-added employment and revenue

Table 4-5. (continued)

- Increase the agricultural activities and agricultural productivity within Lajas Valley Agricultural Reserve and upper Guánica Bay (Loco and Luchetti) watersheds
    - Establish fair prices for products (increase revenue to local producers)
    - Develop value-added products
    - Preserve agricultural farmland
    - Increase revenue for secondary industries supporting agriculture
- Restore commercial and sport fisheries
    - Increase fish catch
    - Create marine protected areas
- Increase renewable energy production
    - Hydroelectric power generation
    - Alternatives (solar, wind, geothermal)

Social

- Promote quality of life for people in Guánica Bay watershed
- Maintain small-scale farming opportunities and way of life
- Reinforce cultural heritage and traditional livelihoods
    - Lagoon fishing
    - Artisans
- Improve well-being and human health:
    - Water quality
    - Air quality (asthma – haze from Saharan winds)
    - Food security
    - Safety and health of agriculture workers
- Improve recreation opportunities
- Meet legal & political requirements
- Promote education
    - Formal and informal (visual)
    - Promote pro-environmental attitudes
    - Change behaviors
- Maintain sufficient potable water for citizens (quantity + quality)
- Expand spiritual and aesthetic opportunities
    - Commune with nature

Process

- Better program integration across different levels of government
- Better communication across agencies
- Better communication among agencies, citizens and Non-profit organizations
    - Provide consistent information to citizens
    - Improve access of information for citizens
- Demonstrate respect for all citizens (environmental justice)
- Enhance opportunities for meaningful public participation
    - Land use planning and zoning
    - Improve responsiveness of agencies to citizens' concerns.
    - Provide a clear follow up to concerns
- Improve fairness in resource management and decision processes
    - Participation (Inclusivity?)
    - Enforcement (appropriate level of government)
- Establish clear criteria for zoning (land use planning)

During the presentations of objectives, each breakout group was also asked to identify individuals or interest groups that should be, but were not represented at the Forum. Participants identified the Puerto Rico Department of Health, local community leaders, teachers, employees from public works departments, Puerto Rico Planning Board, Caribbean Landscape Conservation Cooperative, Puerto Rico Land Use Plan developers, U.S. Army Corps of Engineers, neighborhoods, fishers (commercial and recreational), farmers, recreational groups like surfing and diving associations, environmental health interests, US. Department of Agriculture including the NRCS, Puerto Rico Land Authority, the municipalities (workers, mayors and local politicians), Puerto Rico Department of Agriculture, land owners, and economic co-operatives.

It was explained by the facilitators that the objectives identified by the participants (**Table 4-5**) were merely a starting point to be further explored in more detail on the next day. There was discussion about how some of the objectives would take considerable work and coordination to achieve, while others (e.g., the 'low-hanging fruit') were relatively easy to implement and might be first considerations for action. Before closing, the facilitators described the importance of attaining multiple values in a course of action and finding optimal paths to achieve the values. Designing actions that achieve multiple values will create greater positive benefits.

On the second day, the consolidated objectives list (**Table 4-5**) that the participants had developed on the previous day was presented, and participants identified things that were missing or misinterpreted. Participants also discussed how to specify (detail) concerns reflected in the objectives. Facilitators asked questions that helped expand some of the objectives to consider broader impacts (e.g., water needs) or help to define the objectives (e.g., empowerment).

Initial performance measures were created for each objective (**Table 4-6**), which provided additional focus for the objective and led to potentially useful metrics for evaluating management actions. Participants introduced potential new management actions and for each action they characterized the timing, costs, and level of confidence. Not shown in **Table 4-6** is the benefit timing (e.g., immediate [<1 year], short-term [1-3 years], medium-term [3-10 years], and long-term [10+ years]), designated for each action by the workshop groups. Confidence was also indicated (low, medium or high) for the likelihood that the action could be implemented and the objective achieved. Possible regulatory or political reasons the action might or might not be implemented were discussed. Participants were told not to list actions already underway or recommended in the 2008 WMP.

Table 4-6. Initial priority management actions from different breakout groups shown with potential performance measures and the values served (adapted from Gregory and Gonzalez 2013).

Area	Values	Performance Measures	Actions
Economic	Protect agricultural land (fully utilize potential?)	• Reduce % fallow land • Diversify crops • Promote BMP • $/Ha of production (by type of crop) • Salinity of soil • $ Farm production loss due to land under water	• Implement development plans (?) • Ensure continuity of plans • Implement BMP incentives plan • Ensure no net loss of agricultural land • Avoid practices that increase soil salinity • Improve mechanism for water drainage (clean channels to increase water flow)
	Ensure availability of good quality water supply (for agriculture?)	• Percentage of full capacity for reservoir • $ Avoiding costs for building new water infrastructure • Percentage of catchment area with vegetated cover (?)	• Dredge sediment from water reservoirs • Schedule maintenance of water reservoirs • Reforest catchment areas
	Create more job opportunities	• Number indirect and direct jobs created • Average $ level of pay • $ Value added in local industry	• Prioritize hiring needs • Assess private business investment opportunities • Develop re-training plans for workers
Aquatic ecology	Improve water quality (in rivers and ocean?)	• Turbidity • Solids in suspension • Nutrients • Coliforms	• Restore lagoon • Monitor water quality before, during and after lagoon restoration • Educate community about (?) • Convert Guánica WWTP to tertiary • Restore marshes ability to filter sediments (?) • Consistent enforcement of regulations
	Foster healthy native aquatic community	• Size • Diversity • Health	• Create and improve habitat (where?)
	Improve quality of life related to water resources use	• Aesthetics: reduce visible waste • Reduce turbidity of water • Number of people involved in ecological improvements of the watershed • Ha (cuerdas) forested • Number of recreation activities • Number of recreationists	• Reforestation • Eliminate invasive aquatic species • Conserve soil • Program to educate citizens and industry on reduction and recycling of waste • Educate population about importance of lagoon and marsh ecological services

Table 4-6 (continued)

Area	Values	Performance Measures	Actions
Land ecology	Restore fauna and habitat	• Index of species biodiversity • Kilometers of ecological corridors • Ha habitat suitable for trust species	• Convert sun grown to shade grown coffee • Establish riparian buffers • Reforestation • Forest enhancement • Restore Guánica lagoon • Land acquisition for conservation purposes • Promote enhanced habitat for trust species • Consistent enforcement of regulations • Continue implementation of 2008 GBWMP
	Conserve soil productivity	• Percentage reduction in erosion • Crop production in tons per ha	• Promote sustainable agricultural practices • Promote best management practices • Continue hydro-seeding • Create state and private land management plans
	Reduce point and non-point source of contamination in watershed	• Sediments and nutrient levels mg/L/M^2 • Concentration of hydrocarbons	• Identify point sources of pollution • Create green infrastructure to treat runoff waters
Social	Promote education	• Environmental attitude survey • Number of community members acting in projects	• Promote pro-environmental attitudes via formal and informal education • Implement adopt a beach program • Promote capacity building in schools and communities
	Improve health	• Percentage people connected to PR Aqueduct and Sewer Authority (PRASA) • Census statistics	• Increase participation in PRASA • Conduct epidemiological studies on key health issues • Survey of home owners to determine status of septic tanks
	Promote sustainable communities	• Number demonstration projects • Number of community based enterprises • Number of community networks • Number of conferences and seminars in communities	• Conduct capacity building workshops • Create community coalitions • Provide citizens access to information • Create opportunities for enhanced public involvement • Promote efficiency through better inter-agency communication

Dr. Brian Dyson (EPA) introduced a decision analysis tool under development by EPA. DASEES (Decision Analysis for a Sustainable Environment, Economy and Society) is a web-based tool to organize the many values and diverse factual information that might be needed for a complex environmental management decision. One component of DASEES is a social network analysis (SNA) tool. Participants had been asked on the first day of the Forum to identify the different people and groups that they worked with on watershed environmental issue and this information was captured in an SNA. Dr. Tom Stockton (Neptune, Inc.) demonstrated the tool and the results of the informal survey. Discussion ensued on the utility of these types of tools to improve communication within and among community organizations (**Fig. 4-6**). Participants asked about the availability of software for SNA, and EPA subsequently forwarded an SNA freeware package to all the Forum participants.

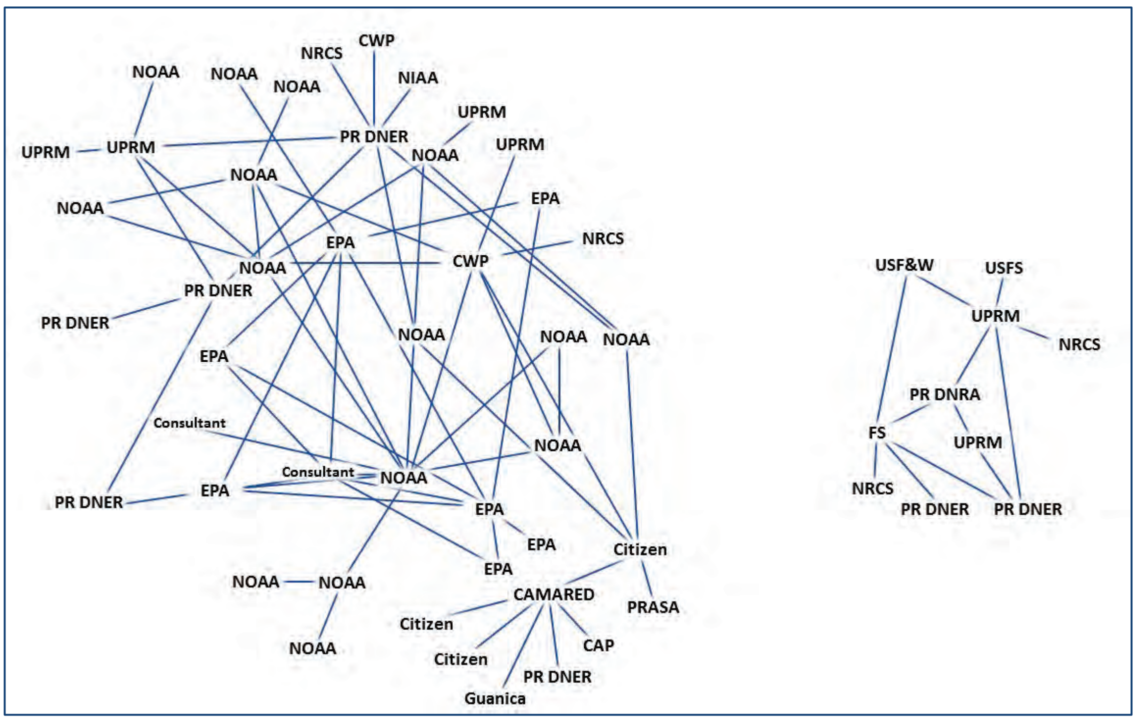


Figure 4-6. Social Network Analysis (SNA) of workshop participants at the Public Values Forum (source: Tom Stockton, Neptune and Company, Inc.). Participants are identified by the organization they represent. Lines represent communication between stakeholders. The workshop analysis showed a small group of stakeholders had isolated communication. This type of analysis can help resolve such issues at the beginning of SDM.

The facilitators described additional tools, including the development of a consequence table, to display the likely effects of different alternatives on multiple objectives.
A consequence table is extremely helpful for interpreting impact assessments and typically contains a matrix of potential effects of alternatives on performance measures for objectives in each cell (Gregory et al. 2012). Its use can augment different phases of a decision-making process, including generating new alternatives, identifying missing or

insufficient objectives and performance measures, eliminating dominated alternatives, identifying information sources for the impacts of alternatives on objectives, trade-off analysis, and appraising the impacts of objectives on alternatives from the best available information. The consequence table demonstrated at the Forum was primarily used to show how one might initially appraise the impacts of alternatives on objectives and creatively derive new alternatives.

For demonstration purposes, an example consequence table was generated interactively (**Table 4-7**). Although the matrix was not populated, participants could see how different alternatives could be rated for effects on multiple objectives in the watershed.

Table 4-7. **Illustrative consequence table developed interactively for Guánica Lagoon restoration, showing objectives in rows and possible management alternatives in columns** (adapted from Gregory and Gonzalez 2013 to reflect correct acreage).

		Alt. 1	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**
Values or Concerns	**Criterion & desired direction**	**Current status**	**Full lagoon restoration (1200 acres)**	**Partial lagoon restoration (900 acres per GME 2011)**	**Adaptive & precautionary plan restoration**	**Other plan (yet to be developed)**
Economics						
Environment - land						
Environment - water						
Social & cultural						
Information uncertainty						
Public participation						
Governance and process						

On the final day of the workshop, new breakout groups were formed, and the list of actions developed on the first two days was narrowed into a focused list of high priority actions. The goal was to have a set of key, high-priority actions to pass along to decision-makers, since it would be too costly to implement every action with the limited resources that were available. Each breakout group selected ten management actions from the list that they felt were the highest priority.

Participants used anonymous electronic voting to prioritize the management actions selected by each group that would best achieve valued outcomes. The voting equipment included hand-held transponders that recorded the responses of individuals. Prior to voting on the decision alternatives, participants used the transponders to record certain personal information, such as whether they had read the 2008 Guánica Bay WMP (CWP 2008) or whether they lived within the watershed. Reporting for the voting results could then account for these relevant characteristics of the voting demographic.

For example, the highest priority for participants with limited knowledge of current watershed initiatives was educational programs to promote sustainability (from among alternatives of the Economics work group), whereas those who claimed a lot of knowledge preferred development and implementation of management plans for marine areas (**Fig. 4-7**). As another example, participants preferred best management and conservation practices (from among the alternatives of the Social work group) regardless of whether they had read the 2008 WMP (**Fig. 4-8**).

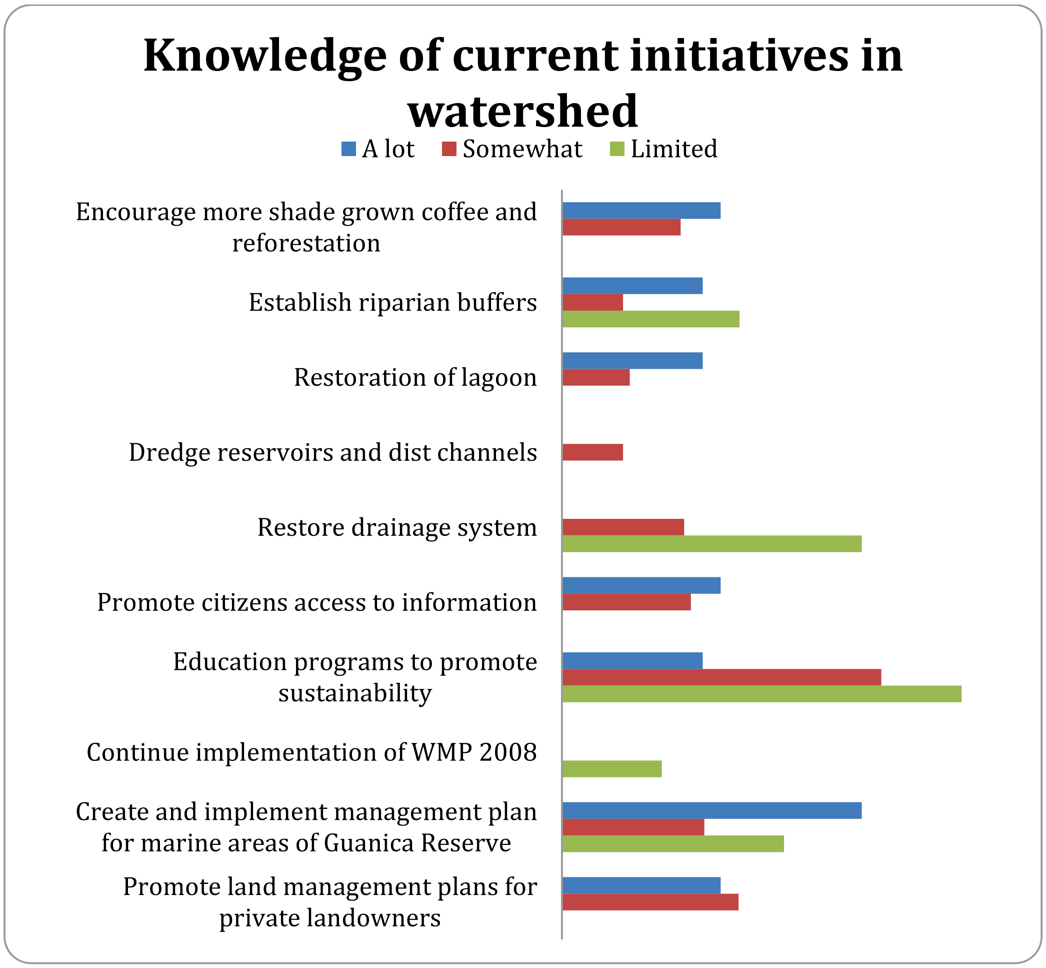


Figure 4-7. Prioritization results for the actions identified by the Economics workgroup for restoring the Guánica Bay watershed and coastal zone, differentiated by knowledge of current initiatives in the watershed (adapted from Gregory and Gonzalez 2013).

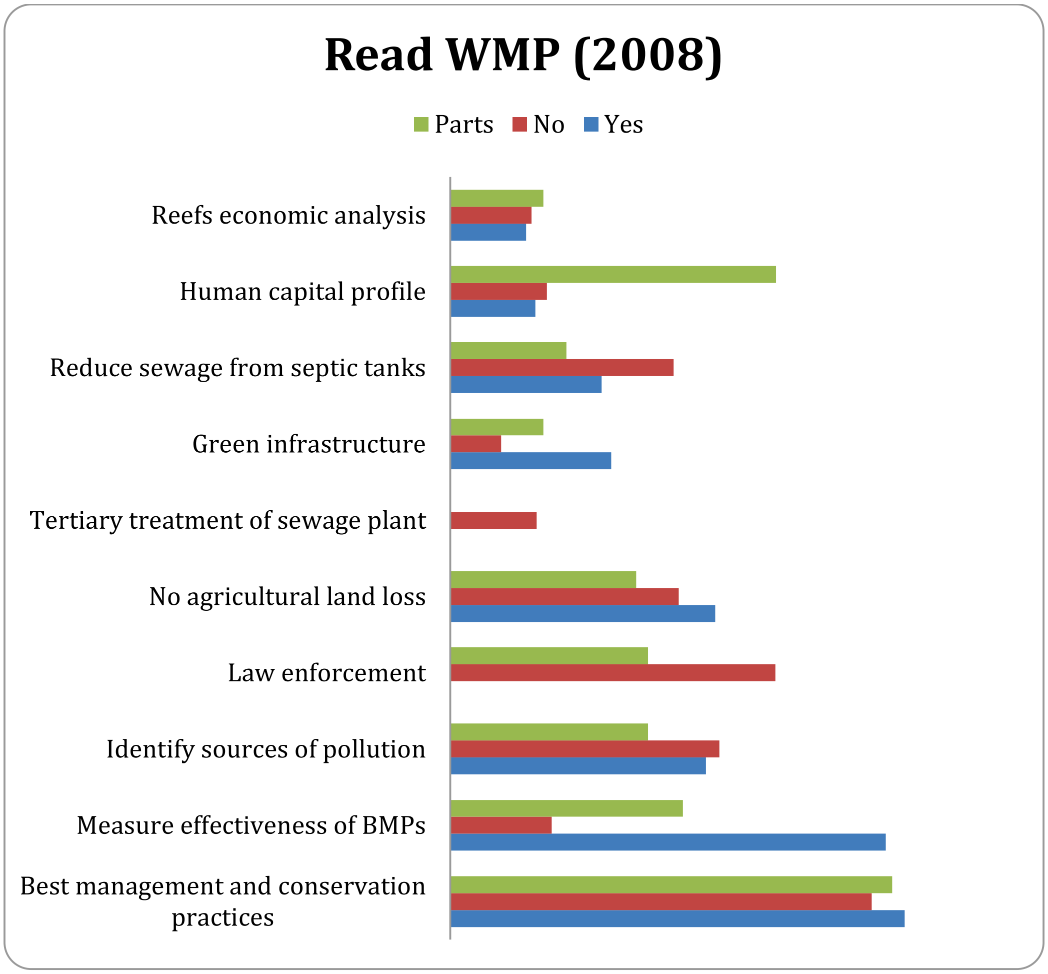


Figure 4-8. Prioritization results for the actions identified by the Social workgroup for restoring the Guánica Bay watershed and coastal zone, differentiated by knowledge of the 2008 watershed management plan (CWP 2008) (adapted from Gregory and Gonzalez 2013).

Once the results were presented, additional discussions focused on which alternatives would be less controversial and less costly to implement (low hanging fruit) and could have high and immediate impact on objectives. Each group then identified priority actions (**Table 4-8**).

The results (**Table 4-8**) are clearly informative for any decision-maker in the watershed. Although there were stakeholder categories that were not represented, the list of priorities illustrates a broad concern for many different issues interlaced throughout the watershed and across various stakeholder groups. Most of the priority actions support not only protection of coral reefs but also other watershed objectives such as agriculture, fishing, human health, law enforcement, water availability and environmental education. The broad concerns represented do not necessarily narrow the options for a decision maker but provide ample evidence of issues to consider for any alternative. Further discussion among stakeholders and development of consequence tables could strengthen or eliminate some of the alternatives listed.

Table 4-8. Priority actions identified by each of the four work groups in the Public Values Forum (source: Gregory and Gonzalez 2013). These are not listed in priority order.

Land Ecology	Aquatic Ecology	Economics	Social
1. Research opportunities	1. Promote shade grown coffee	1. Encourage more shade-grown coffee and reforestation	1. Best management and conservation practices
2. Improve river quality	2. Reforestation and buffer zone	2. Establish riparian buffers	2. Measure effective-ness of BMPs
3. Educate people near the river	3. Promote BMPs (soil, water, sea)	3. Restore the lagoon	3. Identify sources of pollution
4. Monitor water quality	4. Monitor water quality in the watershed	4. Dredge reservoirs and distribution channels	4. Law enforcement
5. Diversify economic opportunities	5. Education and investigation about drainage system in Lajas Valley	5. Restore drainage system	5. No agricultural land loss
6. Improve infrastructure	6. Educate public and industry in reduction and recycling of waste	6. Promote citizens access to information	6. Tertiary treatment of sewage (to reduce nutrient loadings to Guánica Bay)
7. Restore ecosystems	7. Education and enforcement of water laws	7. Education programs to promote sustainability	7. Green infrastructure
8. Recreation opportunities in the watershed		8. Continue implementing actions in the WMP	8. Reduce sewage from septic tanks
9. Agricultural incentives		9. Create and implement a management plan for marine areas of the Guánica Reserve	9. Human capital profile
10. Co-management of protected areas in watershed		10. Promote land management plans for private landowners	10. Reefs economic analysis

4.3.1 Summary

Overall, the workshop approach was beneficial to the management process of the Guánica Bay watershed and to the programmatic aspects of EPA's sustainability research. Public Values Forum participants included key decision-makers, NGO leaders with strong interest in restoring the watershed, academics, farmers and recognized business leaders. The Forum introduced tools and frameworks that helped to generate greater insights for decision-making and could be used by participants for their own decision-making processes. Learning about SDM and working through examples inspired many of those in attendance, some of whom have a significant role in the restoration and management of the watershed. In addition, bringing together the different stakeholders provided greater insight into the watershed and coastal/marine governance process and diverse values that need to be considered in EPA initiatives in the Guánica Bay watershed region. The Forum created within the participants a better understanding of value-focused thinking (Keeney 1992) and its potential for improving management of the Guánica Bay watershed.

The importance of understanding stakeholder values is receiving greater recognition in conservation and environmental management programs. Historically, many environmental initiatives have not placed a priority on incorporating values into territorial and federal government policies, often resulting in sub-optimal communication and fragmented management (Aguilar-Perera et al. 2006). In this Public Values Forum, the need for broader representation of stakeholders beyond those in attendance, including greater representation from residential interests, was explicitly and iteratively emphasized as a means to achieve a more complete understanding and clarification of values in the watershed.

The Public Values Forum helped clarify some areas of disagreement regarding the WMP, in particular the restoration of Guánica Lagoon, and provided additional ideas on how they might be resolved. The facilitators stressed the importance of separating facts from values when disagreements occurred and this was instrumental in creating positive discussion and insight regarding the lagoon. Some disagreements are based on values while others are based on facts, or the predicted outcomes from decisions. Depending on the degree and type of factual- or values-based disagreements, different settings and information would be required to lend greater insight into the problem. Since this was a Public Values Forum, there was a greater focus on what is important (values), but a future workshop focused on scientific issues was also discussed as a means to resolve some of the scientific disagreements.

Guidance for developing a public values forum is provided in **Appendix H**.

4.4 Summary of the workshops

A robust participatory process of information sharing and stakeholder engagement should be requisite for environmental management and sustainability strategies to inform decision development and implementation, and to foster public engagement and support. 'Sustainability' necessitates a consideration of broad and multi-disciplinary issues (Valdés-Pizzini 2001; Munda 2008). Environmental management ultimately benefits from consideration of factors such as socioeconomic and cultural behaviors and perceptions, communication between governments and local communities, and strong participation by community members (Aguilar-Perera et al. 2006). The two EPA workshops described in this Chapter (Decision-Making Workshop and Public Values Forum) engaged stakeholders in structured discussions about their vision and concerns for the watershed and their perception of how decisions are made.

The Decision-Making Workshop elucidated many stakeholder concerns about how decisions have been made in the past. Participants emphasized the lack of local involvement or influence in decisions and the apparent lack of communication or agreement among government agencies. They believed that these process issues resulted in both contradictory policies and decisions that did not benefit local needs. The outcomes have affected economic (e.g., fishing and coffee farming) as well as social (e.g., lack of initiative) values.

The overall outcome of the Decision-Making Workshop was that the participants achieved a better understanding of past decisions in the watershed and the challenges for social, environmental and economic balance. In particular, participants stressed the lack of local involvement and influence in decisions being made (usually at the Federal and Commonwealth level), and felt that this had led to a series of uninformed decisions that were often contradictory to local needs and local vision. The workshop also led to a better understanding of new and old challenges for important economic sectors, particularly small-scale commercial fishing and coffee farming. These challenges are aggravated by policies and decisions within the watershed (e.g., poor enforcement of fishery regulations) and outside the watershed (e.g., coffee import tariffs).

The Public Values Forum illustrated the broad range of objectives that stakeholders have for the watershed, including coral reefs, agriculture, fishing, human health, law enforcement, water availability, environmental education and more. Participants gained an appreciation for the effects that any given decision might have on the multiple objectives and a better understanding of the need for valuation and tradeoff analysis. Groundwork was laid in the workshop for recognizing the difference between value-focused thinking (why) and alternative-focused thinking (how).

Objectives identified during the Public Values Forum (**Table 4-5**) showed a lot of similarity to concerns mentioned during the initial 2010 Decision Sketching Workshop (**Table 3-1**), the 2012 Decision-Making workshop (**Table 4-1**), and in preliminary inferences from management documents (Carriger et al. 2013). The platinum standard for determining objectives is to elicit them directly from stakeholders and decision-makers (Parnell et al. 1998), but even preliminary assessments or inferences from written reports or during decision sketching exercises can be valuable in identifying information needs and developing creative alternatives. Development of objectives is an iterative process, and early assessments can also be useful in identifying critical stakeholders who may need to be invited to subsequent workshops where objectives are further refined.

Stakeholders in both workshops identified several critical decision issues:

1) Local stakeholders have had little influence in decisions being made in the watershed. Moreover they were too often not even informed of decisions and initiatives (Gregory and Gonzalez 2013). This has led to distrust and apathy.
2) Economic independence is a goal. The lack of a self-supporting economy was evident in discussions concerning fisheries, eco-tourism and agriculture in Lajas Valley.
3) Incentives to bolster the sugar industry resulted in an unbalanced, monolithic economy that ultimately struggled without incentives. This left Puerto Rico with few economic alternatives when sugar production collapsed.
4) Rather than viewing environmental conservation as a tradeoff with economic purposes, most stakeholders recognized that stable ecosystems are necessary for future economic viability.
5) Inadequate water availability is a liability for future economic and municipal growth. The inability to prevent soil loss and sedimentation into reservoirs and irrigation canals has adversely affected water quality and quantity. Existing agricultural and municipal water needs may not be met in the near future.
6) Enforcement of regulations and provision of incentives is unfair to some economic sectors. Lack of enforcement of environmental regulations for recreational and subsistence fishers has hurt commercial fishers. Coffee growing incentives target large farms over small, reducing the chance for small farms to prosper. Unequal application of laws and opportunities generate resentment and stifle economic success.
7) Environmental education is needed for farmers, fishers, and other citizens. Training in best management practices for farmers and fishers was widely supported as was better education opportunities for people living along the rivers and around Guánica Bay. Knowledge is power.
8) Ecotourism is potentially a viable economic driving force. Development of the bay, coral reefs and coastal zone, the Guánica State Forest, historic buildings and monuments, mountain coffee farms, and forest biodiversity were all identified as potential attractions for tourists.
9) Communication is lacking between stakeholders and government agencies and among stakeholder groups. Communication with agencies could reinforce trust in decision-making and improve decisions; communication among groups would strengthen the community voice.

Chapter 5. Estimate Consequences and Evaluate Tradeoffs

5.1 Estimating consequences

Chapter 4 illustrated how structuring objectives and their corresponding performance measurements help to concisely define "what matters" about a decision and drive the search for creative alternatives (Gregory et al. 2012). The next step in the decision process is to estimate the consequences of different alternatives on each of the multiple objectives identified by stakeholders (see **Table 4-5**) using performance measures as indicators. Information about consequences comes from three main sources:

1) **Structural modeling**: Consequences may be evaluated qualitatively through group deliberations using influence diagrams or graphical models that link decisions to objectives through changes in intermediate variables (Marcot et al. 2012). For many decisions, a qualitative assessment of likely outcomes is sufficient.
2) **Targeted studies and predictive modeling**: Influence diagrams are often turned into predictive quantitative models based on empirical data. Some tools for conducting quantitative analysis of consequences include probabilistic networks and simulation models.
3) **Expert judgments**: Where empirical data are unavailable, analysts may rely on expert judgments to reduce uncertainties in predicting consequences.

The goal of each approach is ultimately the same: to estimate the consequences of each alternative on the performance measures.

In the following sections, we describe how EPA has been using a combination of these approaches to identify where information is needed to qualitatively link decisions to objectives (**Section 5.2**), conduct scientific investigations and expert panels to reduce uncertainties (**Section 5.3**), and develop tools to conduct quantitative analyses of consequences (**Section 5.4**). In **Section 5.5**, we describe how the scientific information in a consequence table (see **Table 4-7**) can be used to conduct a tradeoff analysis.

5.2 Identifying information needs

Because each decision alternative will likely affect more than one of the objectives, estimating consequences should incorporate systems thinking to guide information collection and scientific investigation. Before the Guánica Bay workshops, EPA developed graphical models to link decisions to stakeholder-valued outcomes, and identify key linkages where scientific information may be needed (see **Fig. 3-8**). The scheme was based on the results of expert focus groups formed to discuss each of the five DPSIR sectors (see **Section 3.3**). The focus groups organized coral reef information into the five categories (EPA 2014a) and provided EPA with insights to the types of science questions that should be considered for each sector.

When applied to a decision context, such as protecting coral reefs, some questions seem obvious. For example, it may seem quite obvious that sediment from farming is contributing to the degradation of reefs and that reef degradation will affect fishing and tourism opportunities. But the proposed decisions will refine the questions. For example, how much difference will shifting coffee cultivation from sun-grown to shade grown practices make on sediment loads, coral reef condition, and fishing and tourism opportunities? Other questions arise from the additional objectives raised by stakeholders. For example, sediment trapping in reservoirs has diminished the sediment runoff to the coastal zone; how does the loss of water storage capacity affect the availability of domestic water sources in an island with small watershed areas? When examined in a systems framework, each decision alternative will generate a robust set of potential consequences and knowledge gaps for science investigation (**Table 5-1**).

The principal importance of the Driving Force sector in a DPSIR framework is to characterize how human activities are driven by socioeconomic needs as well as how some socioeconomic needs are fulfilled by the goods and services provided by environmental resources, such as coral reefs. The Driving Forces are highly interdependent (e.g., coral reefs attract tourism and fishing, activities that can degrade coral reefs). For research related to the Guánica Bay example, it was important to identify the types, intensity and interactions of Driving Forces in the watershed and to identify the types and levels of human activities (Pressures) generated by each Driving Force.

Table 5-1. Issues in a DPSIR-based framework, sample research questions from stakeholder discussions (see Table 3-3), and targeted EPA research activities.

Overarching Issues	Sample Research Questions	EPA Research Activities
Influence of socio-economic Driving Forces (D) on human activities (P)	What are the sources of nutrient and sediment loading?	Hydrologic modeling (Yuan et al. 2013; Hu et al. 2015)
	What are the sources of contaminants?	Citizen-volunteer and professional monitoring to identify fecal sources of contamination in southwestern Puerto Rico (Rodriguez et al. 2014)
Influence of human activities (P) on the state (S) of the environment	What are the priority stressors affecting reef health?	A coral reef example of science-based multi-stakeholder deliberation (Rehr et al. 2014)
	What are the effects of watershed-derived stressors on reefs?	Responses of coral reef fauna to human influence (Oliver et al. 2014)
	How do we define reef condition along a stressor gradient?	Biological integrity of coral reefs (Bradley et al. 2014a)
State (S) of ecosystems required for sustainable delivery of ecosystem services (I)	What is the state of coral reefs?	Reef assessments in 2010, 2011 based on methods from a Field Manual for Coral Reef Assessments (Santavy et al. 2012)
	What are the attributes of ecosystems that contribute to ecosystem services?	Quantifying coral reef ecosystem services (Principe et al. 2012)
Effects of changes in ecosystem state (S) on what stakeholders value (I), including ecosystem services	How do we link changes in reef condition to changes in ecosystem services?	Comparison of methods for quantifying reef ecosystem services (Yee et al. 2014b)
	How do we link changes in land cover to changes in ecosystem services?	Linking ecosystem services supply to stakeholder values in Guánica Bay Watershed, Puerto Rico (Smith et al., In Review)
	What is the economic value of reef ecosystem services?	Economic valuation of Puerto Rican Reefs (ongoing)
Consequences of decision alternatives (R) on what stakeholders value (I)	What are the potential effects of pollutant loadings on reef ecosystem services?	A coral reef example of building consensus in environmental decision-making (Rehr et al. 2014)
	What are the effects of decision options on water resources?	Estimating effects of management options on water storage capacity of Lago Lucchetti (Bousquin et al. 2014)
	What are the effects of sediment reduction on coral reef ecosystem services?	Linking management of sediment runoff to coral reef ecosystem services using Envision (ongoing)

Research under the Pressure sector should seek to determine the influence of human activities on changing stressors in the ecosystem. This requires characterizing the types and levels of human activity that generate sediment, contaminants, nutrients and other pollutants, and how much they generate. For the Guánica Bay project, this included measuring terrestrial sediment in the coastal zone and estimating changes in sediment reaching the coastal zone as a consequence of various management alternatives, including conversion of coffee farming to shade-grown cultivation and dredging reservoirs in the watershed.

Research under the State sector should be directed at measuring the state (condition) and persistence of the ecosystem, and linking changes in state with changes in delivery of ecosystem goods and services. For the Guánica Bay project, this included reef assessments using fish, stony coral, sponge and gorgonian indicators that characterized the potential for delivery of ecosystem services. It also included expert deliberation to characterize the levels of condition (or thresholds) necessary to support persistence and sustainable delivery of ecosystem services. It is important to recall that water quality stressors (*e.g.*, sediment, nutrients, contaminants) are generated by human activities (Pressures) but once generated become a condition of the reef—and therefore the effects of water quality are investigated under the State sector of DPSIR. To this end, laboratory studies were conducted to characterize the effects of various sediment types and loads on various coral reef species.

The Impact sector links ecological condition with potential delivery of ecosystem goods and services. Research in this sector should generate defensible relationships between the condition of the ecosystem and the potential delivery of ecosystem goods and services, and how the delivery and value of goods and services changes as ecosystem condition changes. In the Guánica Bay case, this included development of different approaches to estimate goods and services from ecosystem condition and linking changes in condition to changes in goods and services. It also included ongoing research into the market and nonmarket value of coral reefs to the ecotourism economy.

The different research efforts that initiated from this system approach are summarized in **Table 5-1**. In **Section 5.3**, we highlight some of these efforts.

5.3 Scientific investigations to reduce uncertainties

EPA is using targeted studies, predictive modeling, and expert group deliberations to gather the information needed to link management actions to consequences for ecological, economic, and human health endpoints. Although EPA research was initially focused on protection of coral reefs, efforts ultimately migrated to a more holistic consideration of management consequences to objectives throughout the watershed. This section provides examples of past and ongoing EPA research efforts focused on reducing uncertainty across the DPSIR framework.

5.3.1 Coral reef condition

The Guánica Bay Watershed Management Plan (CWP 2008) proposed several actions to reduce anthropogenic stressors from the watershed in order to protect coral reef habitats. Stakeholders at the Public Values Forum recognized a key uncertainty in this approach was the state, or condition, of the reefs outside Guánica Bay. There are two important components to this uncertainty—measurement and interpretation of measurements.

The measurement component had been a focus of previous EPA research, which included development of indicators and field survey designs that were defensible for Clean Water Act reporting (Fisher 2007; Fore et al. 2009; Bradley et al. 2010) A critical issue in indicator selection is sensitivity to human disturbance—indicators that cannot distinguish human-induced from natural change cannot be used for regulatory protection under the Clean Water Act. EPA developed and tested several stony coral indicators (Fisher et al. 2008), and has applied these validated, human-responsive indicators in probabilistic survey designs in both the U.S. Virgin Islands (Fisher et al. 2014) (**Fig. 5-1**) and southern Puerto Rico. The two Puerto Rico surveys, performed in 2010 and 2011, also included measurements of reef fish, sponges, gorgonians and other macro-invertebrates (Santavy et al. 2012), although indicators from these measurements have not yet been validated for sensitivity to human disturbance.

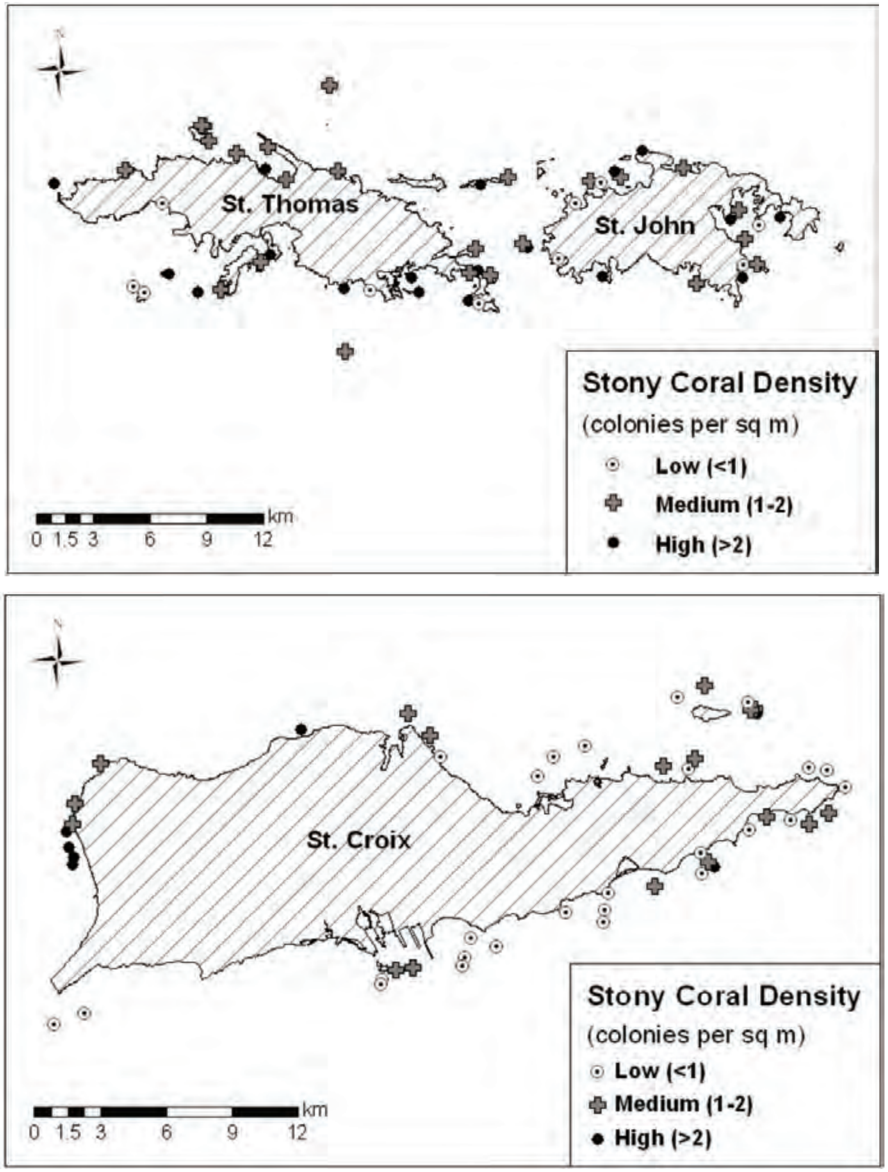


Figure 5-1. Display of stony coral density results from reef assessment surveys completed at St. Thomas and St. John (top) and St. Croix (bottom) in the U.S. Virgin Islands (source: Fisher et al. 2014).

The interpretation component of reef condition seeks to identify from the assessment data what constitutes a good, fair, or poor reef. This is being addressed by EPA as a part of a larger effort to develop a conceptual model describing how biological attributes of coral reefs change along a gradient of increasing anthropogenic stress. This model, generically called the Biological Condition Gradient (BCG) (**Fig. 5-2**), is used to show how biological attributes of aquatic ecosystems (i.e., biological condition) might change along a gradient of increasing anthropogenic stress (e.g., physical, chemical and biological impacts) (Davies and Jackson 2006). The y-axis of this conceptual model ranks biological condition and the x-axis ranks levels of anthropogenic stress.

Development of a Coral Reef BCG is a multistep process. EPA assembled a panel of US Caribbean experts with expertise in coral reef ecology and management, including knowledge of stony corals, reef fishes, sponges, gorgonians, algae, and seagrasses. In August 2012, EPA held a coral reef expert workshop in La Parguera, Puerto Rico (Bradley et al. 2014a). The goals of the workshop were to identify qualitative and quantitative reef attributes that determine coral reef condition and recommend initial categorical condition rankings for the y-axis of a coral reef BCG.

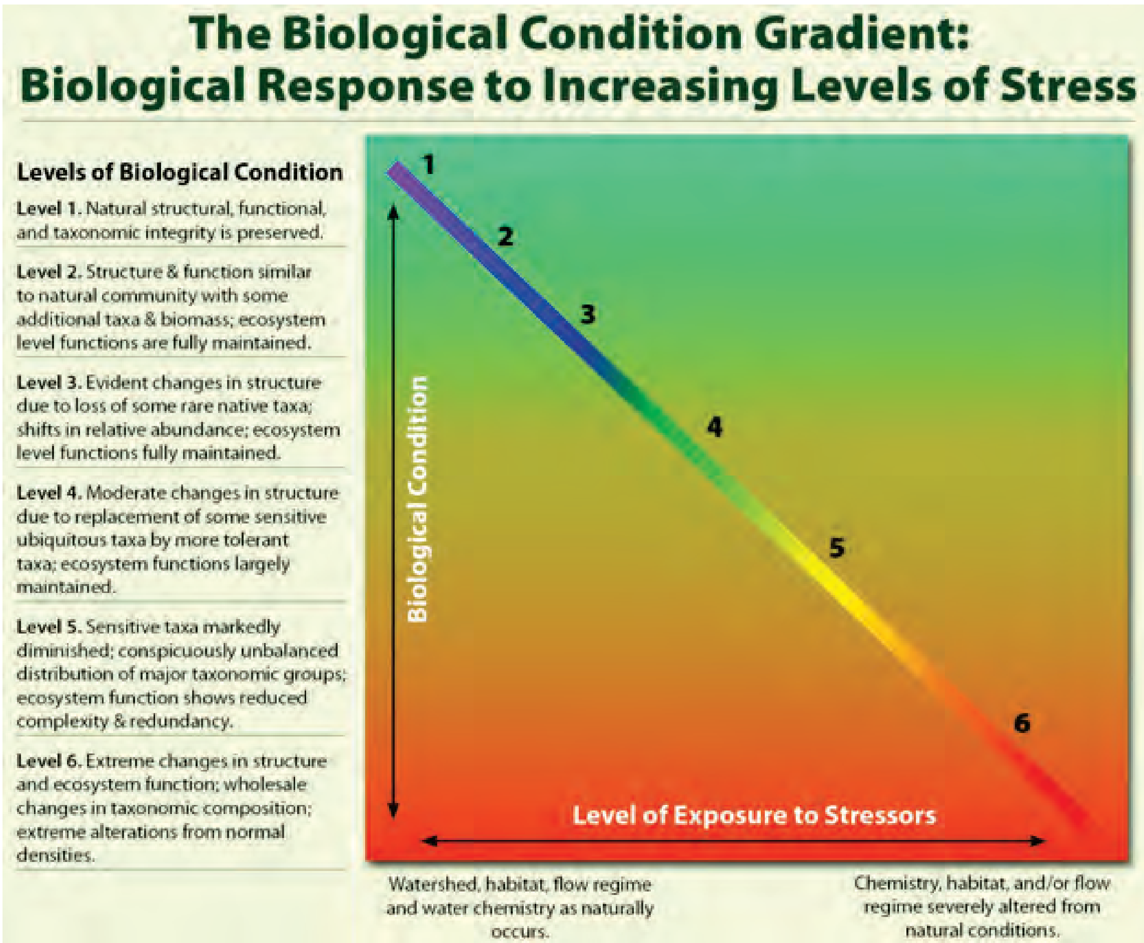


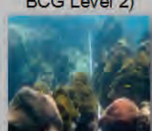
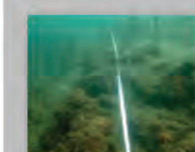
Figure 5-2. Generalized Biological Condition Gradient (BCG) (adapted from Davies and Jackson 2006).

As a first step, participants were asked to evaluate and rank coral reef condition from photographs and videos collected during EPA's 2010 and 2011 coral reef assessment surveys in shallow waters (<12 m deep) of southern Puerto Rico (**Fig. 5-3**). Participants examined the visual media, rated the condition of the coral reefs at example locations (considering stony corals, reef fish, sponges, gorgonians, turbidity, etc.) and provided rationale for their ratings. Descriptions of good and bad characteristics relative to ecological condition were captured during facilitated discussions.

Figure 5-3. Photos from EPA coral reef stations reflect a range of coral reef conditions, from good (left), to intermediate quality (middle), to severely degraded (right) (source: Bradley et al. 2014a).

A preliminary narrative BCG, using only the photos and videos, was assembled for shallow-water linear reefs of southwestern Puerto Rico. The experts were able to identify four distinct levels of condition: very good–excellent; good; fair; and poor (**Table 5-2**).

Table 5-2. Coral reef attributes of a very good to excellent site and a poor site (Bradley et al. 2014).

Condition Level!	Corals!	Fish!
VERY GOOD to EXCELLENT (Approximate BCG Level 2) 	Hi species diversity including rare, large old colonies with high tissue coverage (*Montastraea*); balanced population structure (old and middle-aged colonies, recruits); *Acropora* thickets present, Low prevalence disease, tumors, mostly live tissue on colonies!	Populations have balanced species abundance, sizes and trophic interactions!
POOR (Approximate BCG Level 6) 	Absence of colonies, those present are small, only highly tolerant species, little or no tissue. High incidence disease on small colonies of corals, sponges, and gorgonians, if present, low or no tissue coverage	No large fish, few tolerant species, lack of multiple trophic levels

A second workshop was held April 8-10, 2014, at the Forest Service headquarters in El Yunque National Forest. Twenty-five experts attended the second workshop, including 19 who had attended the first workshop. The experts broke into two groups–sessile assemblages (e.g. stony corals) and mobile assemblages (e.g., fish). During a facilitated discussion the experts assigned each species to an attribute ranking (1-6) based on its sensitivity or tolerance to different environmental stressors (**Table 5-3**). The species lists provided to the experts included those species observed during the 2010 and 2011 EPA surveys in Puerto Rico. The experts used the literature and their best professional judgment to make these assignments.

Table 5-3. Fish species assigned to attribute 2–highly sensitive or specialist taxa.

BCG Attribute	# Samples	Common Name	Scientific Name
2	87	Blue Tang	*Acanthurus coeruleus*
2	1	Redspotted Hawkfish	*Amblycirrhitus pinos*
2	4	Black Margate	*Anisotremus surinamensis*
2	12	Trumpet Fish	*Aulostomus maculatus*
2	2	Orangespotted Filefish	*Cantherhines pullus*
2	1	Reef Butterflyfish	*Chaetodon sedentarius*
2	2	Blue Chromis	*Chromis cyanea*
2	8	Brown Chromis	*Chromis multilineata*
2	1	Creole Wrasse	*Clepticus parrae*
2	4	Cleaner Goby	*Elacatinus genie*
2	1	Neon Goby	*Elacatinus oceanops*
2	2	Fairy Baselet	*Gramma loreto*
2	4	Smallmouth Grunt	*Haemulon chrysargyreum*
2	1	Glasseye Snapper	*Heteropriacanthus cruentatus*
2	1	Queen Angelfish	*Holacanthus ciliaris*
2	6	Saddled Blenny	*Malacoctenus triangulatus*
2	5	Black Durgon	*Melichthys niger*
2	1	Rainbow Parrotfish	*Scarus guacamaia*
2	2	Cero	*Scomberomorus regalis*
2	18	Harlequin Bass	*Serranus tigrinus*

During a second facilitated discussion, each expert considered the biological condition, species presence or absence and the species' attributes, and assigned a BCG level for several sampling sites from the EPA Puerto Rico reef assessment surveys. The facilitator documented critical information for the decision, any confounding or conflicting information and how this was resolved. The experts' scores were tallied and averaged into a final level assignment for each sampling station. Preliminary decision narrative rules were developed for each level, and following the workshop, statistical analysis of the data was applied to those rules to develop thresholds for each defined level. A web-based data portal to organize and share all the available coral reef ecosystem data from Puerto Rico and the U.S. Virgin Islands, STORET (EPA 2015) facilitated the work of the experts. The data portal has been initially populated with data from NOAA's Biogeography Branch and EPA's Coral Reef Assessment Program.

Ultimately, the attributes and thresholds will be organized into a conceptual, narrative model that describes how biological attributes of coral reefs change along a gradient of increasing anthropogenic (human-generated) stress. This requires, of course, that the levels of stress are also ranked along the x-axis of the coral reef BCG and linked to the human activities (pressures) that generate them. By providing an explicit characterization of how biological attributes respond to human disturbances, decision-makers will be able to determine current condition and the desired condition. Once a BCG is established, managers can set easily communicated, quantitative goals for achieving those conditions by linking the condition to stressor levels and stressor levels to human activity in the watershed.

5.3.2 Ecosystem goods and services production

During both the Decision-Making Workshop and Public Values Forum (**Chapter 4**), participants identified a concern for social and economic losses related to the decline of coral reef and other natural ecosystems. Too often, environmental assessments focus only on ecological endpoints and fail to consider the social and economic values of stakeholders (Arvai and Gregory 2003). A key to bridging ecological and socio-economic concerns is the concept of ecosystem goods and services (EGS) (Wainger and Boyd 2009). Ecosystems provide goods and services to humans, including provisioning of food, fuel, and fresh air and water, regulation of climate and flooding, and cultural value through recreational and aesthetic opportunities (MEA 2005) (**Table 5-4**). Supporting services describe the healthy functioning of ecosystems that is necessary for providing the other services.

Table 5-4. Categories and examples of ecosystem goods and services (derived from Layke 2009).

Regulatory Services Benefits obtained from ecosystem's control of natural processes	**Provisioning Services** Goods or products obtained from ecosystems
Air quality regulation	*Food resources – Crops, fisheries, wild food*
Climate regulation	*Biological raw materials – Timber, fiber, sand, animal skins*
Water regulation	*Biomass fuel*
Erosion regulation	*Freshwater*
Water purification and waste treatment	*Genetic resources*
Disease & pest regulation	*Biochemicals & pharmaceuticals*
Soil quality regulation	
Pollination	
Natural hazard regulation	

Table 5-4. (continued)

Supporting Services Natural processes that maintain other ecosystem services *Nutrient cycling* *Primary production* *Water cycling*	**Cultural Services** Nonmaterial benefits obtained from ecosystems *Recreation and ecotourism* *Aesthetic and spiritual values*

A list of stakeholder objectives developed at the Public Values Forum (**Table 4-3**) identified several objectives that could use ecosystem services as means for achieving the objective or performance measures (**Table 5-5**). Given the necessary data and information, changes and tradeoffs across these ecosystem services could then be evaluated under different decision scenarios.

Table 5-5. Identification of ecosystem goods and services that align with stakeholder objectives identified in the Guánica Public Values Forum.

Workshop Objectives	Corresponding Ecosystem Services
Ecology land	
Meet future water demands	Water quality and quantity regulation
Restore/conserve habitat for important species	Aesthetic/cultural/intrinsic value of habitat
Reduce contamination from agriculture effluent	Contaminant regulation
Reduce stormwater runoff	Stormwater retention
Reduce soil loss (maintain productivity of land)	Sediment and nutrient retention
Preserve forest habitats	Aesthetic/cultural/intrinsic value of forest habitat
Protect endangered and threatened wildlife species	Cultural/intrinsic value of threatened wildlife
Ecology aquatic	
Restore lagoon natural processes	Water quality regulation
Restore shallow water coral reefs	Aesthetic/cultural/intrinsic value of reefs
Reduce nutrient loads flowing into the ocean	Nutrient retention
Enhance fish biomass and abundance	Aesthetic/cultural/intrinsic value of fish
Protect endangered and threatened marine species	Cultural/intrinsic value of threatened wildlife
Protect mangrove habitats	Aesthetic/cultural/intrinsic value of mangroves
Protect marine habitat for migratory bird	Aesthetic/cultural/intrinsic value of marine birds
Economy	
Increase sustainable economic development	
Promote eco-tourism	Ecotourism opportunities (charismatic species)
Maintain swimming/beaches opportunities	Recreational opportunities (water quality)
Lajas Valley and upper Guánica Bay	
Preserve agricultural farmland	Crop production, nutrient retention
Restore commercial and sport fisheries	
Increase fish catch	Fisheries production
Creation marine protected areas	Aesthetic/cultural/intrinsic value of reefs
Increase renewable energy production	
Hydroelectric power generation	Hydropower production
Alternatives (solar, wind, geothermal)	Alternative energy production

Table 5-5. (continued)

Workshop Objectives	Corresponding Ecosystem Services
Social	
Maintain small scale farming opportunities	Crop production, nutrient retention
Reinforce cultural heritage/traditional livelihoods	
Lagoon fishing and Artisans	Recreational and Artisanal fishing opportunities
Improve well-being and human health:	
Water quality	Water quality regulation
Air quality (asthma)	Air quality regulation
Food security	Crop production, nutrient retention
Improve recreation opportunities	Recreational opportunities
Maintain sufficient potable water for citizens	Water quality and quantity
Expand spiritual and aesthetic opportunities	
Commune with nature	Aesthetic and cultural value of nature

Two types of functional relationships are required to translate changes in ecosystem state into human benefits: ecological production functions (EPF) and ecosystem services valuation functions (EVF) (Wainger and Boyd 2009; Compton et al. 2011). EPFs quantify the relationships between metrics of ecosystem condition and the supply of ecosystem goods and services. The realized value of these goods and services will depend on human demand for them. EVFs relate characteristics of society, such as demand, accessibility, or substitutability, to derive value for ecosystem services (Compton et al. 2011). Together, EPFs and EVFs can translate the value of ecosystems to human well-being (**Fig. 5-4**).

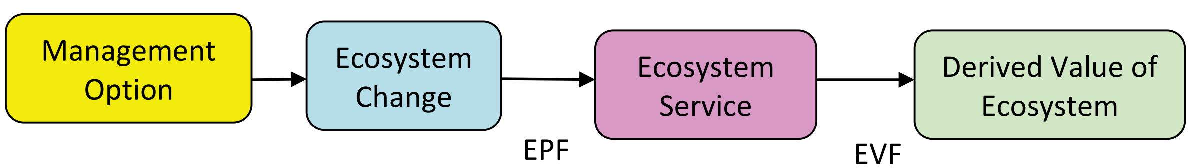


Figure 5-4. Structure to trace changes in ecosystem services values based on a management option (adapted from Wainger and Boyd 2009). EPF = ecological production functions; EVF=ecosystem services valuation functions.

EPA recently reviewed methods for generating EPFs for coral reef ecosystem services, that is, linking biophysical attributes of reef condition, such as coral cover, structural complexity, or fish biomass, to provisioning of ecosystem goods and services (**Table 5-6**, derived from Principe et al. 2012; Yee et al. 2014b). Many of the biological and ecological attributes that are being used to characterize biological integrity for the Biological Condition Gradient have relevance to ecosystem services, including habitat structure and complexity, ecosystem function, and ecosystem connectivity. In fact, EPA methods to assess coral reefs include measurements that contribute to calculation of both condition indicators and ecosystem services indicators (Fisher 2007; Santavy et al. 2012).

Coral reefs contribute to several different EGS, including shoreline protection, tourism and recreation, commercial fishing, pharmaceutical discovery potential, and existence value (ecological integrity). The contribution of reefs to shoreline protection has been modeled in a number of ways, including indices of coastal protection across different types of habitat (Burke et al. 2008; Mumby et al. 2008; Tallis et al. 2013) and biophysical process models (Gourlay and Colleter 2005; Sheppard et al. 2005; Kunkel et al. 2006; Madin et al. 2006). Information on tourism and recreational opportunities has been derived from surveys of recreational reef visitors conducted in valuation studies (Leeworthy and Wiley 1996, 1997, 2003; Wielgus et al. 2003; Leeworthy and Bowker 1997; Leeworthy and Vanasse 1999; Johns et al. 2001; Bishop et al. 2011), and through field observations of reef condition at popular dive sites (Pendleton 1994; Williams and Polunin 2002; Leeworthy et al. 2004; Leujak and Ormond 2007; Uyarra et al. 2009).

Table 5-6. Quantitative methods for linking reef ecosystem attributes to production of ecosystem services (adapted from Yee et al. 2014).

Ecosystem Service Metric	Reef Ecosystem Attributes	Method	Source
Ecosystem Integrity			
Simplified Integrated Reef Health Index	Macroalgae cover, coral cover, commercial fish biomass, herbivorous fish biomass	Index	Healthy Reefs Initiative 2010
State of the Reef Index	Macroalgae cover, coral cover, fish abundance, coral richness, fish richness	Index	van Beukering and Cesar 2004
Shoreline Protection			
Relative wave energy dissipation	Relative cover of benthic habitat types	Index	Mumby et al. 2008
Coral Reef Protection Index	Reef type, reef continuity, reef distance to shore	Index	Burke et al. 2008
Percent wave height attenuation due to presence of reef; Percent wave energy attenuation due to presence of reef	Offshore wave height and period, reef depth, reef width, reef distance to shore, reef surface friction (variability in coral colony heights; relative cover of benthic habitat types)	Differential equations	Sheppard et al. 2005; Lowe et al. 2005
Decrease in beach erosion	Wave height attenuation due to reef	Ratio	Wielgus et al. 2010
Decrease in wave run-up	Beach slope, shoreline porosity, wave height attenuation due to reef	Ratio	FEMA 2007
Recreational Opportunities and Tourism			
Relative ease of access, relative sand generation, relative opportunity for snorkeling, opportunity for sighting of charismatic species (*E. striatus*)	Relative cover of benthic habitat types	Index	Mumby et al. 2008
Relative value of a dive	Coral abundance, fish abundance, coral richness, fish richness, visibility	Choice model	Wielgus et al. 2003
Dive site favorability	Sand cover, coral cover, coral richness, fish richness, schools of fish, reef structural complexity	Preference survey	Uyarra et al. 2009
Visitation to dive sites	Coral cover, reef distance to shore, topographic complexity	Regression model	Pendleton 1994

Table 5-6. (continued)

Ecosystem Service Metric	Reef Ecosystem Attributes	Method	Source
Fisheries Production			
Relative value of finfish; relative production of curios and jewelry	Relative cover of benthic habitat types	Index	Mumby et al. 2008
Habitat value for fish production	Connectivity between mangrove and coral	Geospatial algorithm	Mumby 2006
Key commercial fish biomass	Snapper and grouper biomass	Metric	Healthy Reefs Initiative 2010
Commercial fish biomass	Benthic habitat cover	Differential equations	Ault et al. 2005
Natural Products Production			
Potential for bio-prospecting discovery	Macroalgae cover, coral Cover, fish abundance, coral richness, fish richness	Index	van Beukering and Cesar 2004
Pharmaceutical product potential	Relative cover of benthic habitat types; sponge richness	Index	Mumby et al. 2008

Methods for quantifying production of commercially important fish species have included characterizing reef habitat (Mumby et al. 2008) and, in particular, connectivity between reefs and mangroves (Mumby 2006). In lieu of fish habitat assessments, fish production is often assessed more directly through monitoring and modeling of commercially important fish species populations over time (Ault et al. 2005; McField and Kramer 2007; Paddack et al. 2009). Although there are no established protocols for estimating pharmaceutical potential from reef attributes (Principe et al. 2012), natural product potential has been linked to the presence of certain faunal groups, such as sponges, or high-density sessile organisms and habitats (Mumby et al. 2008) as well as metrics of reef integrity (van Beukering and Cesar 2004). Metrics of reef integrity combine indicators of reef health to quantify healthy reef structure and function (McField and Kramer 2007).

In addition to coral reefs, stakeholders identified concern for other natural resources in their watershed. Several methods are available for translating terrestrial ecosystem condition into ecosystem service production (**Table 5-7**). In many cases, biophysical indicators of ecosystem services production are used to represent final ecosystem goods and services (e.g. rates of carbon sequestration to represent atmospheric regulation).

Table 5-7. List of key terrestrial ecosystem services for the Guánica watershed and production function methods for linking them to changes in environmental condition.

Ecosystem Service Metric	Ecosystem Attributes	Method	Source
Atmospheric pollution removal	Tree canopy coverage; landuse/landcover	Biophysical model	Russell et al. 2013
Atmospheric regulation	Rates of carbon sequestration; landuse/landcover	Metric	Russell et al. 2013; Smith 2007
Water regulation	Rates of denitrification; landuse/landcover	Metric	Russell et al. 2013
Hydropower production	Soil depth; precipitation; landuse/landcover	Biophysical model	Tallis et al. 2013
Nutrient retention	Soil depth; precipitation; landuse/landcover	Biophysical model	Tallis et al. 2013
Sediment retention	Soil erodibility; slope; precipitation; landuse/landcover	Biophysical model	Tallis et al. 2013
Fisheries production	Benthic habitat cover; Commercial fish biomass	Index	Mumby et al. 2008
Ecotourism	Charismatic species; habitat suitability models; landuse/landcover;	Habitat suitability models	Gould et al. 2008
Recreational opportunities	Location and length of beaches	Metric	Smith et al. in review
Crop production	Rates of crop production; landuse/landcover	Metric	USDA 2009

EPA is applying the EPF methods to estimate existing or baseline ecosystem services provisioning in the Guánica watershed (Smith et al. in review). The production functions will also be applied to evaluate how changes in landuse and landcover and benthic habitat under alternative management options affect stakeholder objectives related to provisioning of ecosystem services (**Table 5-4**). Similar studies for St. Croix, U.S. Virgin Islands have resulted in maps that predict production of reef ecosystem services (**Fig. 5-5**; Yee et al. 2014b).

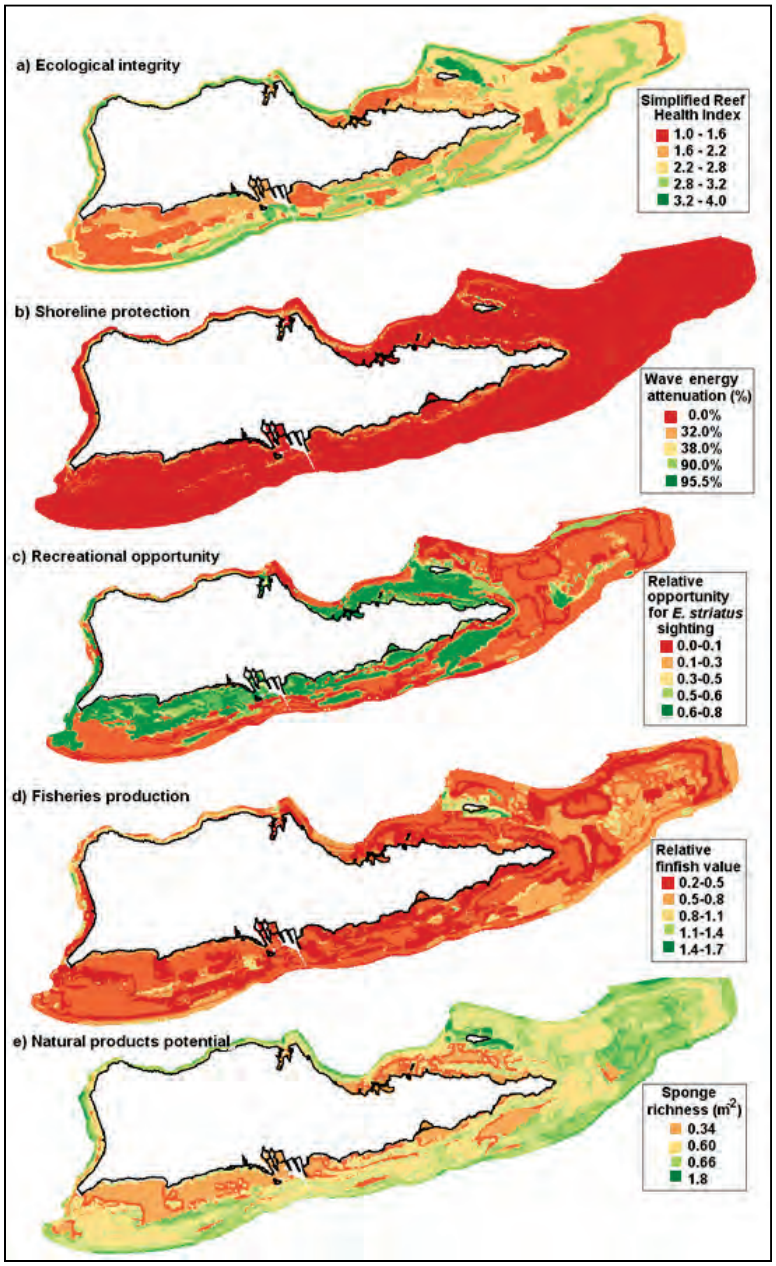


Figure 5-5. Maps of predicted reef ecosystem service production around St. Croix, U.S. Virgin Islands (source: Yee et al. 2014b). See Table 5-6 for details of each metric.

5.3.3 Social and economic benefits of coral reefs

At the Public Values Forum, stakeholders explicitly identified the economic value of environmental resources as an objective that might be useful for decision-making, and specifically an economic analysis of coral reefs as a priority action (**Chapter 4**, **Fig. 4-6**). Several derived ecosystem services benefits were identified that could be used as performance measures of economic objectives (**Table 5-8**). While ecosystem services production functions (EPF) estimate the potential production of ecosystem services, the actual derived benefits depend on additional factors such as demand, accessibility, and substitutability.

Table 5-8. Identification of performance measures related to valuation of ecosystem goods and services that align with stakeholder objectives identified in the Public Values Forum. Metrics on the right do not necessarily align directly with objectives on the left.

Workshop Objectives	Derived Ecosystem Services Benefits
Economy	Economic value of natural hazard protection
Demonstrate economic value of ecosystem services	Economic impact of recreation by residents and visitors
Promote community economic benefits	
Increase sustainable economic development	Resident and visitor use rates
Promote eco-tourism	Cultural value of ecosystems
Restore commercial and sport fisheries	Economic value of commercial fishing

Due to their open-access nature and benefits to the public good, coral reefs have often been undervalued in decision-making (Brander et al. 2009). The economic values of some services (e.g., commercial fishing) are established in markets, while others have nonmarket values for local, state/regional and national/international segments of the population (**Table 5-9**; Principe et al. 2012). Stakeholders in the Decision-Making Workshop (**Section 4.2**) recognized the importance of ecosystem conservation as a means for sustainable extraction of goods (market value and economic reasons) and less so for non-market values; and participants at the Decision Workshop spent a day characterizing non-market ecosystem values. Participants at both workshops expressed the desire for an ecotourism economy, indicating an appreciation for nonmarket values if they are tied to economic opportunity.

Table 5-9. Economic benefits provided by coral reefs (sources: Principe et al. 2012; Beaumont et al. 2008; Burke et al. 2008; Cesar 2002; Cesar and Chong 2005; David et al. 2007; Ghermandi et al. 2009; Moberg and Folke 1999; Naber et al. 2008; Nunes et al. 2009; Remoundou et al. 2009; Spurgeon 1992).

Direct extractive uses	Direct Non-extractive uses	Indirect uses	Non-Uses
1. Commercial fishing	1. Scuba diving	1. Fish habitat	1. Existence value
2. Subsistence fishing	2. Snorkeling	2. Nutrients	2. Cultural value
3. Aquarium fish	3. Boating	3. Reduced flooding	3. Option value
4. Sport fishing	4. Pharmaceutical chemicals	4. Less storm damage	4. Quasi-option value
5. Coral jewelry	5. Non-pharmaceutical natural products	5. Fewer deaths from storms and flooding	5. Bequest value
6. Pharmaceutical harvesting	6. Surfing	6. Reduced erosion from storms and flooding	6. Instrumental value
7. Non-pharmaceutical harvesting	7. Underwater photography	7. Mangrove & seagrass protection	7. Intrinsic value
	8. Viewing nature and wildlife	8. Sea life nursery protection	8. Scientific value
	9. Beach sunbathing	9. Global life support	9. Scarcity value
	10. Collecting objects		

Most studies have focused on market benefits, which are relatively easy to incorporate in trade-off analyses. But there are also methods to estimate nonmarket benefits of coral reefs. EPA is applying several of these methods to estimate the market and nonmarket value of coral reef ecosystem goods and services and, in the case of tourism and recreation, is collaborating with the National Oceanic and Atmospheric Administration (NOAA) Office of National Marine Sanctuaries to conduct a market and nonmarket valuation of coral reef-based tourism and recreation in Puerto Rico. The approach focuses on three areas, commercial fisheries, shoreline protection and tourism as represented by resident and visitor perceptions of coral reefs. The methods are outlined in greater detail below.

Commercial fisheries. The Fisheries Research Laboratory (FRL) of the Puerto Rico Department of Natural and Environmental Resources (DNER) disseminates monthly commercial fisheries catch statistics based on fish landing data from commercial fishermen, fish buyers and fishing associations. In addition to this commercial fisheries monitoring effort, several studies have been conducted on the recreational fisheries of Puerto Rico (Agar et al. 2005; Shivlani and Koeneke 2010).

Using the FRL and DNER spatial data, EPA will apply the Economic Valuation Methodology V3.0, developed by the World Resources Institute (WRI) to calculate the economic contribution of reef-associated fisheries for Puerto Rico (WRI 2009). To support the validity of these results, the same methodologies will be used to calculate the economic contribution based on fish productivity of reef area. Where data are available, the economic contribution of fish processing and cleaning, as well as local, non-commercial fishing will be calculated.

In addition to the direct economic impact of Puerto Rican Fisheries, EPA will also calculate the indirect economic impact using an economic multiplier to account for other economic activities that are enabled by the fishery (e.g. boat building, constructing fishing gear, etc.). Multiple methods and data sources will be used where necessary to adequately represent uncertainty around data and results.

Shoreline protection. Coral reefs form natural barriers along the coast, protecting coastlines from erosion, flooding and storm damage (WRI 2009). EPA will value shoreline protection based on an avoided cost approach for storm damage (Farber et al. 2002), which is similar to the valuation method developed by WRI for Jamaica (Maxam et al. 2011). The methods involve using spatial elevation data to identify vulnerable areas based on storm surge and wave heights associated with 25-year storm events. The level of service provided for coastal areas protected by coral reefs is modeled, using a biophysical process model, as a change in the area vulnerable to inundation (Sheppard et al. 2005). Although this varies from the method used for Jamaica, the same protection quantification method was used by WRI in the Dominican Republic (Wielgus et al. 2010). The economic value of shoreline protection is then estimated by determining the property values in areas identified as both vulnerable and protected by coral reefs to estimate the reduction in potential damage attributable to the coral reefs. The damage avoided will be the proportion of property value that is damaged based on the level of inundation, which can be estimated using Federal Emergency Management Agency 'depth-to-damage' curves for Puerto Rico (Davis and Skaggs 1992).

Coral reef-based tourism and recreation. EPA and NOAA, in partnership with the University of Puerto Rico, Puerto Rico Sea Grant, and local agencies and communities are conducting a study to provide the economic valuation information for Puerto Rico's reef-associated tourism and recreation. This project will estimate the use and associated market and non-market economic value and how those values are altered with changes in reef attributes (e.g. water clarity/visibility, coral abundance and diversity, fish and invertebrate abundance and diversity). Illustrations of high, medium and low coral reef conditions (**Fig. 5-6**) were developed using data from EPA's 2010 and 2011 coral reef surveys, and information developed during the expert workshops.

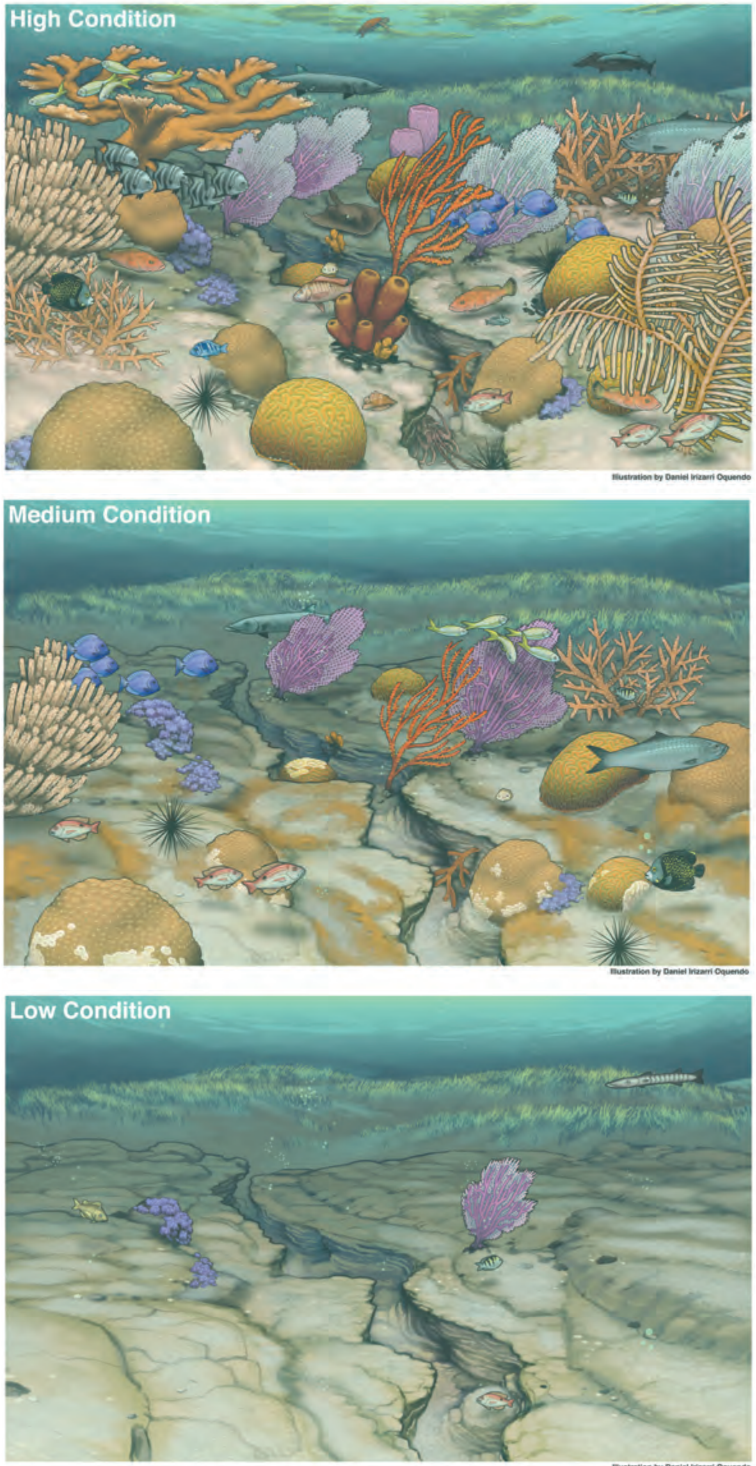


Figure 5-6. Illustrations depicting: High Condition, Medium Condition, and Low Condition, to be used as visual aids during the economic valuation surveys. Note: in each illustration, all attributes are represented at the same condition level (illustrations by Daniel Irizarri Oquendo, Puerto Rico SeaGrant) .

The project is addressing 25 issues of local importance related to natural resource attributes (e.g. water clarity/visibility, coral cover, fish abundance, fish diversity), facilities (e.g. boat ramps, marina facilities, mooring buoys, beach access, beach quality, availability of public restrooms, cleanliness of streets and/or sidewalks) and services (friendliness of people, value for the price, availability of tour guides, public transportation, parking, maps). This list of issues has been customized to issues of importance in Puerto Rico. Survey respondents are being asked how important they feel each issue is to them, and how satisfied they were with their tourist or recreational experience.

The project is conducting separate surveys of visitors and residents. Visitors are being asked a few short questions when departing Puerto Rico (e.g. airports) during two different seasons–winter and summer, and based on demographic and use information, recruited to internet-based surveys. Residents will be surveyed through a probabilistic survey by short in-house face-to-face interviews, and then asked to mail back a longer survey questionnaire.

Data will be analyzed and reported at the whole territory level, as well as for five (5) sub-regions (northeast, southeast, southwest, northwest, and the islands of Vieques and Culebra) (**Fig. 5-7**). Survey respondents' time and values will be attributed to region(s) based upon their responses. This will provide economic information in support of Puerto Rico's four (4) coral reef priority areas (Culebra, the Northeast Reserves, Cabo Rojo and Guánica).

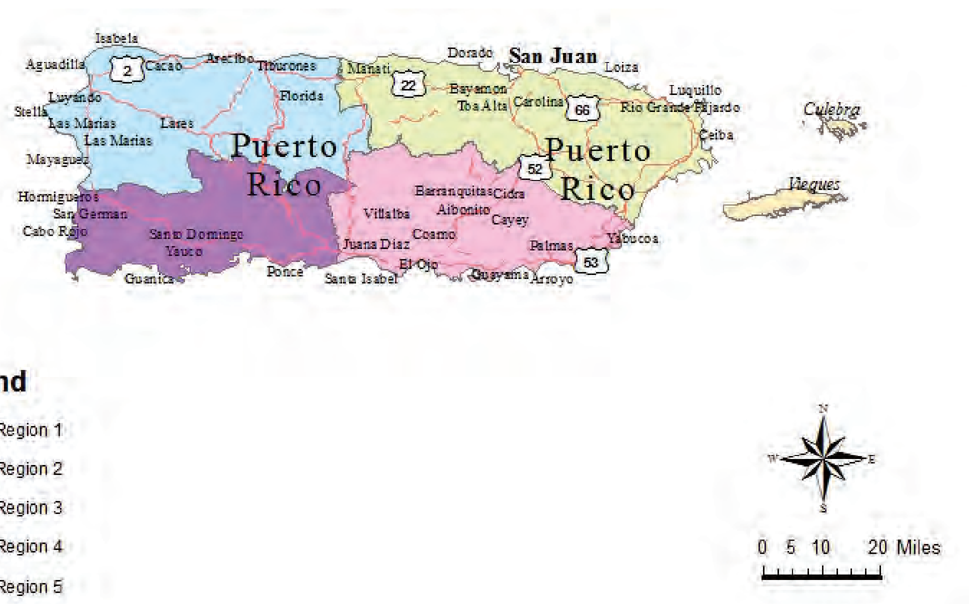


Figure 5-7. The economic valuation of Puerto Rico's coral reef-based tourism and recreation will be analyzed and reported at the whole territory scale, as well as for five (5) sub-regions: northeast (green), southeast (pink), northwest (blue), southwest (lavender), and the islands of Vieques and Culebra (yellow) (credit for map layers: Regional boundaries from the PR Ministry of Tourism.)

5.3.4 Effects of water quality and availability on human health

In addition to environmental objectives, such as restoring coral habitat and ecosystem services, stakeholders at the three EPA workshops also identified a number of human health objectives and identified a need for public education and citizen involvement (**Table 5-10**).

Table 5-10. A subset of objectives that reflect the social concerns of stakeholders at the three Guánica EPA Workshops.

Objectives	Measures	Actions
Environmental		
Improve water quality	Nutrients, Coliforms	Educate community Convert WWTP to tertiary
Social		
Promote education	Environmental attitude, Community involvement	Promote pro-environmental attitudes, Promote capacity building in communities
Improve health	Connection to WWTP	Increase participation in PRASA, Conduct studies on key health issues, Survey home owners
Promote sustainable communities	Demonstration projects	Create opportunities for public involvement

Sanitation. EPA has initiated a project to increase public and community awareness of sanitation issues in the lower Guánica watershed by initiating a Citizen Science project to survey water quality and sewage infrastructure. As a part of the Region 2 Citizen Science Program, the University of Puerto Rico has assembled groups of citizen volunteers (4-H Club members) and trained them to collect water samples from targeted locations throughout the Guánica Bay/Rio Loco area (**Fig. 5-8**). University of Puerto Rico obtained georeferenced land use data from the Puerto Rico Governmental Portal for Geographic data (PR 2015) and clipped the land use data in ArcGIS to the Lajas Valley and Rio Loco watersheds so that linkage can be made among nutrients, fecal contamination and land-use (Rodriguez et al 2014).

Figure 5-8. Volunteer 4-H Club members take water samples for the Region 2 Citizen Science Program testing for water quality in southwestern Puerto Rico (photo credit: Cristina López, UPR).

Data are being analyzed to identify unsanitary conditions and any point or non-point sources of contamination. Participating citizens will further characterize those high-risk areas by documenting the type of treatment (i.e., septic, wastewater treatment plant) and condition of sewer infrastructure. Mapping the results will help to identify risks associated with potential contact and ingestion exposures. Public awareness is expected to increase as citizens recognize the situations that lead to unsanitary conditions, where those unsanitary conditions are and what is causing them. It is anticipated that an informed citizenry will be better prepared to make decisions relating to bacterial and (by extrapolation) nutrient pollution effectively and efficiently. It is believed that this could serve as a model for additional projects to improve citizen awareness and action toward reducing sanitation problems across Puerto Rico.

In **Section 5.4**, we discuss two useful tools for integrating expert opinions, empirical data, and predictive models for evaluating the effects of different decision alternatives on stakeholder objectives.

5.4 Decision-support tools for evaluating alternatives

Information, data, and models are being integrated into decision-support tools to predict effects of alternative management scenarios on environmental, social, and economic endpoints. Two possible modeling approaches are presented here, Bayesian Belief (probability) Networks and spatially-explicit dynamic models.

5.4.1 Bayesian networks

Environmental management decisions are characterized by high uncertainty (Gregory et al. 2012; NAS 2013). Uncertainties can arise from a number of sources including lack of data, data measurement error, model assumptions, or even from ineffective communication. Workshops to clarify objectives and performance measures (**Chapter 4**) can help to alleviate sources of uncertainty by helping to more rigorously define stakeholder goals and eliminate ambiguity and vagueness. Identifying and quantifying uncertainties can bring insight to a decision, can help prioritize information needs, can help to explore the risk tolerance of decision-makers and can identify where additional information may be needed (Rehr et al. 2014). Scientific research should reduce uncertainties by providing information, data, and models (**Section 5.3**). The value of information provided by scientific research can be evaluated by tracking probabilities (measures of uncertainty) for outcomes of different decisions.

Bayesian Belief Networks (BBNs) are particularly helpful in problems characterized by high levels of uncertainty among experts. BBNs begin with a simple conceptual model representing cause and effect relationships between variables, and subsequently quantify the relationships among the variables using probabilities (**Fig. 5-9**). BBNs allow the conditional probabilities to be quantified independently, based on combinations of: (1) empirical data, (2) statistical associations derived from historical data, (3) mathematical representations of dominant mechanistic processes, and (4) probabilistic quantities elicited from scientific experts (Woolridge et al. 2005).

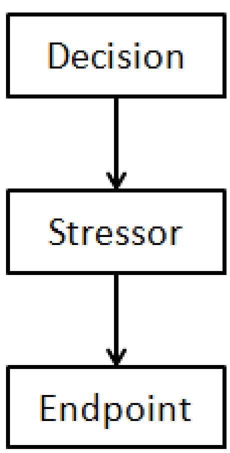


Figure 5-9. **Nodes (typically displayed as circles or boxes) in a Bayesian belief network (BBN) represent random variables, and arcs (displayed as arrows) are used to indicate a conditional relationship between the parent and child nodes** (Kjaerulff and Madsen 2008). Arrows are described by conditional probabilities, and may be derived from expert opinion, statistical models, or mechanistic models.

A hypothetical example will demonstrate some of the inferences that might be made using a BBN for management decisions.

Reservoir sedimentation. An issue identified in the Public Values Forum was the availability of fresh water for domestic purposes. Puerto Rico is an island with relatively small watersheds and little natural water storage (e.g., lakes and ponds). Consequently, numerous reservoirs have been built to supply water for irrigation and domestic purposes. However, development and farming in the mountains has caused soil erosion that is filling in many Puerto Rico reservoirs with sediment. This general phenomenon is also seen in the Guánica region.

Figure 5-10. Lago Lucchetti in southwestern Puerto Rico receives water from its watershed as well as through a tunnel from upstream reservoirs (photo courtesy of Autoridad de Energia Electrica de Puerto Rico; URL: http://waterdata.usgs.gov/pr/nwis/uv?site_no=50125780). The reservoir (20.35 Mm^3 volume) stores water for irrigation and domestic purposes.

In the 1950s, as part of the Southwestern Puerto Rico Project, five reservoirs and interconnecting tunnels and canals were built for the multiple purposes of irrigation, water supply, power generation and flood control. The fourth in this string of reservoirs, and one of the largest, is Lago Lucchetti (**Fig. 5-10**). Sediment has filled in the reservoirs such that, collectively, they can store only about half the water they originally held (Webb and Soler-Lopez 1997; Soler-Lopez 2001, 2002; Soler-Lopez and Webb 1999). Although erosion is a natural process, some of the sediment undoubtedly originates from coffee farms and other human development. When the eroded soil is washed by rainfall into a reservoir, it is either trapped in the reservoir or transported downstream. If it is transported downstream it clogs irrigation canals, reshapes rivers, and degrades biological habitats. In this sense, the reservoirs have not only provided agricultural and domestic water storage, but protected downstream environmental and economic interests from some sediment pollution. However, as the reservoirs fill in with sediment, their trapping efficiency decreases (a smaller proportion of incoming sediment is trapped) and more sediment is transported downstream.

The Guánica Bay Watershed Management Plan (CWP 2008) proposed two actions to address sediment accumulation in the reservoirs: dredging the reservoirs and converting coffee-farming areas from sun-grown to shade-grown cultivation. The latter was intended to increase foliage and thereby reduce soil erosion from coffee farms. As part of its information gathering effort to estimate consequences, EPA used a Bayesian Belief Network (BBN) model to estimate the effects of these two options on sediment accumulation in the reservoirs (Bousquin et al. 2014). This was conducted using reservoir life expectancy (before the reservoir fills in completely) as the endpoint.

For the reservoir study, EPA first established a conceptual model (**Fig. 5-11**) that characterized the annual sedimentation of Lago Lucchetti, which drains the sub-watershed that has the greatest amount of coffee farming. The conceptual model identified the major factors in sediment trapping: rainfall, land use, incoming water and incoming sediment. This model is complicated by the fact that Lago Lucchetti has incoming water and sediment from its watershed as well as through a tunnel from upstream reservoirs.

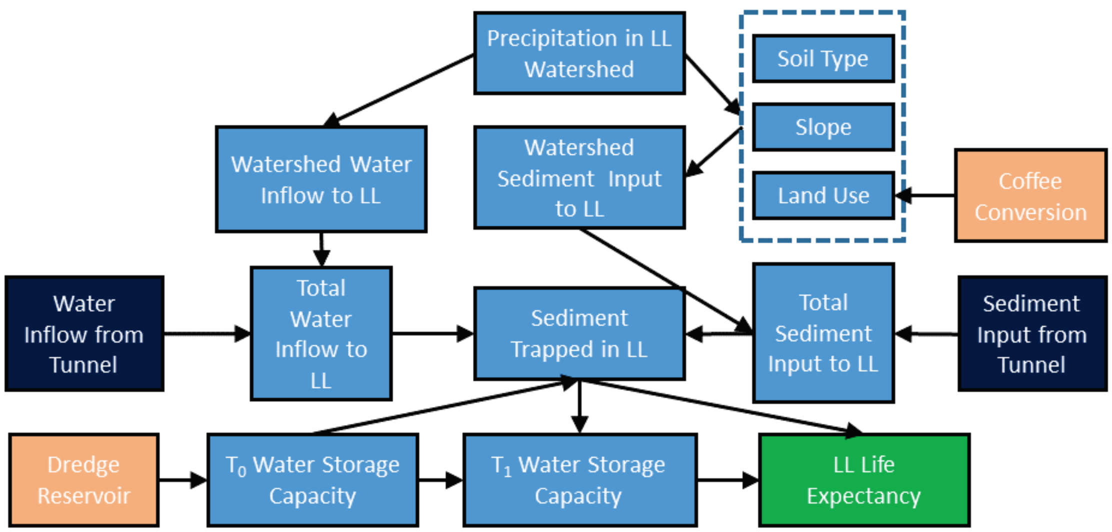


Figure 5-11. Conceptual diagram of model to estimate the life expectancy of Lago Lucchetti (LL) under two management options: coffee conversion and reservoir dredging (adapted from Bousquin et al 2014).

The conceptual model was recast quantitatively in a BBN using a variety of measures and relationships between nodes (**Fig. 5-12**). The software package Netica (Norsys 2010; Carriger et al. 2011) was used to develop the BBN, where arrows represent the conditional relationships among variables. Each of the variable nodes contains probabilities expressed as percentages and illustrated as 'belief bars' (horizontal histograms). Empirical data and models can be used to define the initial probabilities of variables such as precipitation and water flow (yellow boxes, **Fig. 5-12**). A user can define their certainty that a certain scenario will be implemented, for example 100% certainty that the conversion implementation will remain at status quo or that the starting water storage capacity was at a certain level (light blue boxes, **Fig. 5-12**). Netica then updates the probabilities in the other nodes (tan boxes, **Fig. 5-12**), which contain equations to calculate the probabilities of conditional relationships. The resulting model was a probabilistic model that could account for effects of dredging and coffee conversion, singly or together, on sediment accumulation in Lago Lucchetti.

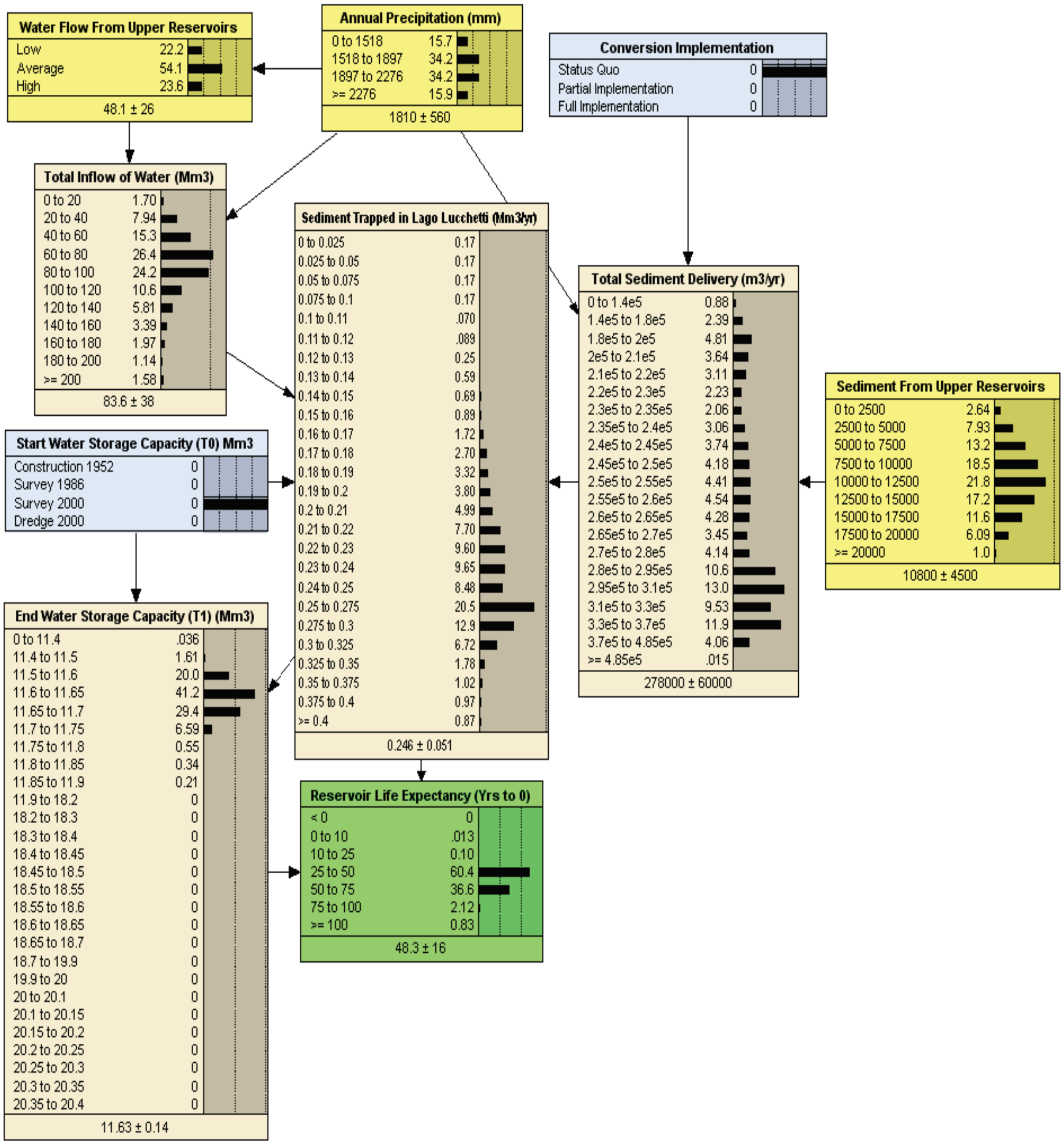


Figure 5-12. Bayesian belief network (BBN) model derived from the conceptual model in Fig. 5-10 and showing distributions of probabilities for life expectancy (in years) of Lago Lucchetti under two management options: conversion to shade-grown coffee (Conversion Implementation node) and reservoir dredging (Start Water Storage Capacity node, reflecting potential dredging levels) (source: Bousquin et al, 2014).

The results from this model (Bousquin et al. 2014) can be summarized in a simple consequence table, looking at the effects of different management options on a performance measure, in this case the life expectancy of the reservoir (**Table 5-11**). Results indicated that conversion of all the existing sun-grown coffee acreage in the Lucchetti watershed to Shade-grown cultivation would create only a minor decline in sedimentation of the reservoir. Dredging the reservoir would obviously re-set the clock on sedimentation and would greatly extend the life expectancy.

Table 5-11. Life Expectancy of Lago Lucchetti reservoir under different management scenarios.

Lago Lucchetti Life Expectancy	
Management Option	**Years beyond 2000**
*Coffee conversion	
No conversion	48.3 ± 16
Partial Conversion	51.7 ± 17
Full Conversion	56.1 ± 18
**Dredging	
No dredging	48.3 ± 16
50% of sediment	74.8 ± 18
100% of sediment	80.5 ± 19
Combined	
Partial Conversion/ 50% dredge	78.7 ± 19
Partial Conversion/ 100% dredge	84.6 ± 18
Full Conversion/ 50% dredge	83.1 ± 19
Full Conversion/ 100% dredge	88.9 ± 18

*Options include no, partial (50%) or full conversion of sun-grown coffee acreage to shade-grown coffee
**Options include dredging 50% and 100% of the sediment in the year 2000, when the last sediment accumulation data were available

This example represents predictions regarding a single stakeholder objective – it is not uncommon with multi-objective decisions to build predictive models separately for each objective (Marcot et al. 2012). Consideration of the tradeoffs across multiple objectives may require integrating a number of different predictive models into the analysis. BBNs can accommodate both quantitative and qualitative data and can be built in a modular fashion. This means that additional nodes can be added as greater detail is required or new science gaps are uncovered. A BBN allows decision makers to start with a simple model and allow it to get more complex as the need arises.

5.4.2 Spatially dynamic modeling with Envision

When estimating consequences of alternatives, variability in space and time can make outcomes difficult to predict (Gregory et al. 2012). For some decisions, spatially-explicit models may be important for better understanding consequences. For example, there is a spatial element to agricultural Best Management Practices (BMPs) such as hydroseeding, reforestation, or riparian buffers. The location and spatial extent of these actions can have consequences for the outcomes of decision alternatives on stakeholder objectives.

In the past several decades there has been a dramatic increase in the use of scientific, quantitative methods for informing landscape change (e.g., Geographic Information Systems, GIS) and decision-making in the presence of high uncertainty. ***'Envision'*** is a GIS-based tool for scenario-based community and regional planning and environmental assessments (**Fig. 5-13**), created to allow examination of the nature and properties of coupled human and natural environmental systems (Bolte 2009; Yee et al. 2012b).

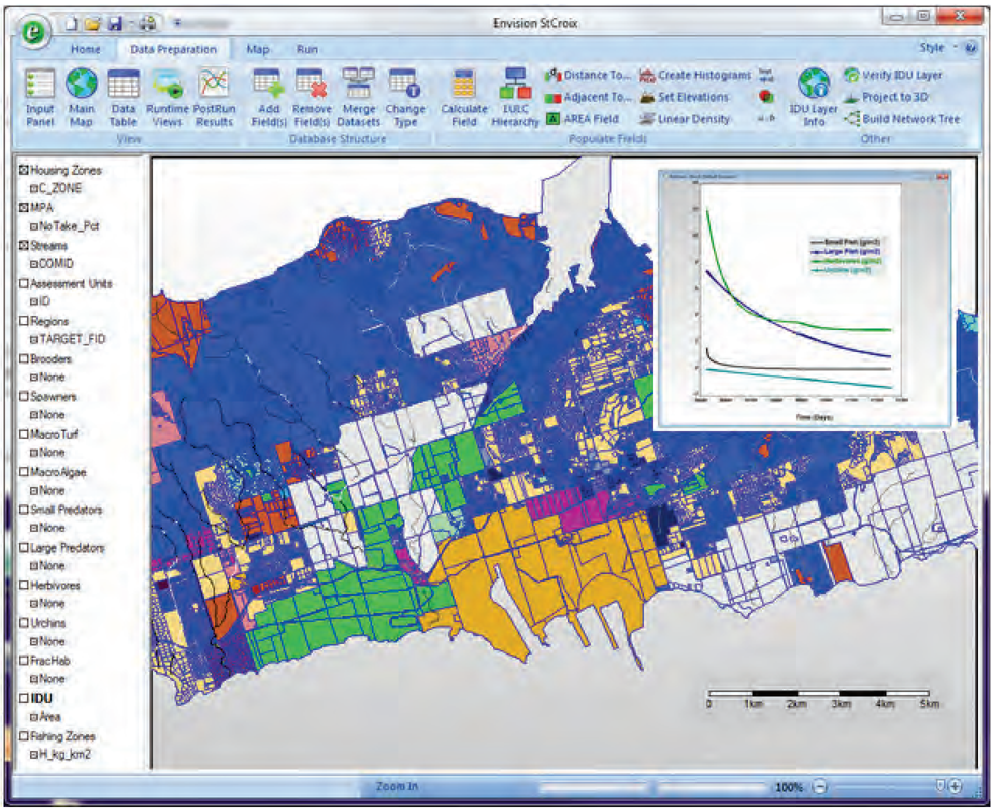


Figure 5-13. Screenshot of Envision decision-support tool.

Central to Envision are three-way interactions of independent actors, the landscape that is changed as these decisions are made, and the policies that guide and constrain decisions (**Fig. 5-14).** Actors are entities that make decisions (decision-makers) about the management of particular portions of the landscape for which they have management authority. Policy sets describe a list of potential decision alternatives the actors may choose to implement or be required to implement, and may reflect a given future scenario being modeled, such as comparing the suite of alternatives in a management plan vs. the status quo. The actors must balance a set of objectives reflecting their particular values, mandates, and the policy sets in force on the parcels they manage.

They do this within the scope of policy sets that are consistent with the assumptions and intentions of a chosen future scenario. These policies are operative on particular landscape elements over which they have decision-making control.

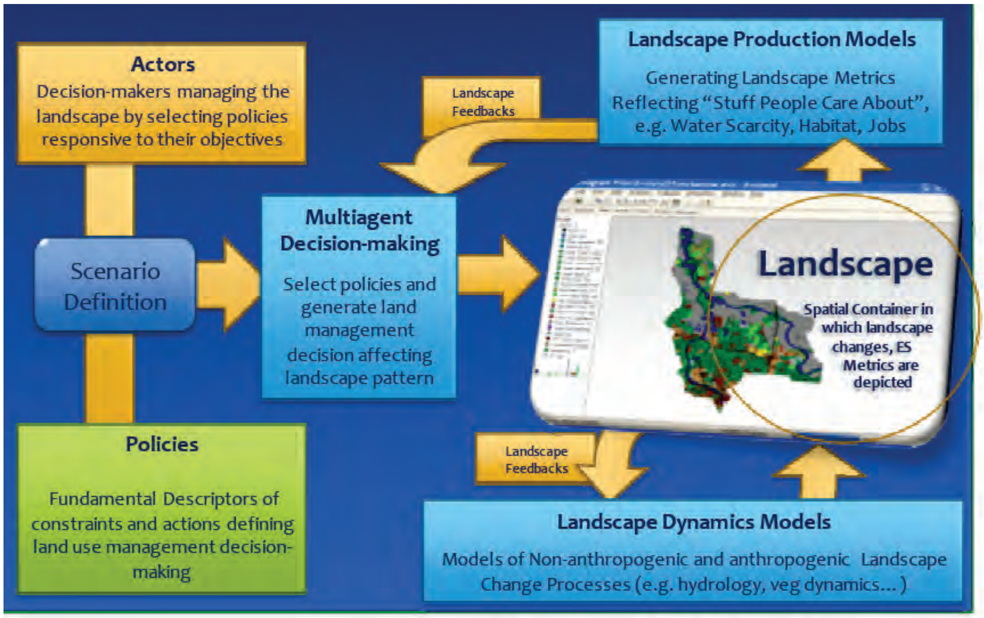


Figure 5-14. Envision's conceptual framework. Envision includes a powerful "multiagent modeling" subsystem that allows for the representation of human decision-makers in landscape simulations. Envision "actors" make management decisions in parallel with landscape change models using a variety of decision models that can reflect actor values and incorporate landscape feedbacks.

Envision represents a landscape as a set of polygon-based GIS maps and associated information containing spatially-explicit depictions of landscape attributes and patterns. Taken as a modeling approach, Envision employs a spatially-explicit multi-agent construct that models relationships of actor's values and behaviors, policy intentions, and landscape metrics of production, as the actors attempt to achieve the outcomes they value.

For development of a tool to explore watershed management scenarios for the Guánica watershed, models of projected human population change in southwestern Puerto Rico must be integrated with projected changes in landuse and landcover (**Fig. 5-14**). Envision spatially displays landscape data including landuse/landcover, human population density, and benthic habitats (**Fig. 5-15A**). Model plug-ins describe how socio-economic changes in human population density lead to changes in landcover (**Fig. 5-15B**). Changes in landcover potentially have consequences for sediment and nutrient runoff into the coastal zone, which can be modeled with water system models using the '*Flow*' framework within Envision, which uses hydrological models (Bergström 1992) to model sediment and nutrient export into the coastal zone (**Fig. 5-15C**). Ecosystem models describe how changes in landuse affect natural resources (**Fig. 5-15D**).

The Corset model for coral reef dynamics is used to link stressors derived from coastal development, marine stressors (e.g. overfishing), and climate stressors (e.g. hurricanes), to coral condition (Melbourne-Thomas 2010). Ecosystem services production functions (see **Tables 5-6, 5-7**) can then be used to project how changes in coastal condition or landcover may affect the production of ecosystem goods and services such as fisheries or recreational opportunities. Once the Guánica data layers and models are incorporated into Envision, it can be used as a tool with stakeholders and decision-makers to help visualize the consequences to key endpoints of alternative decision scenarios (**Fig. 5-15A/B/C/D**).

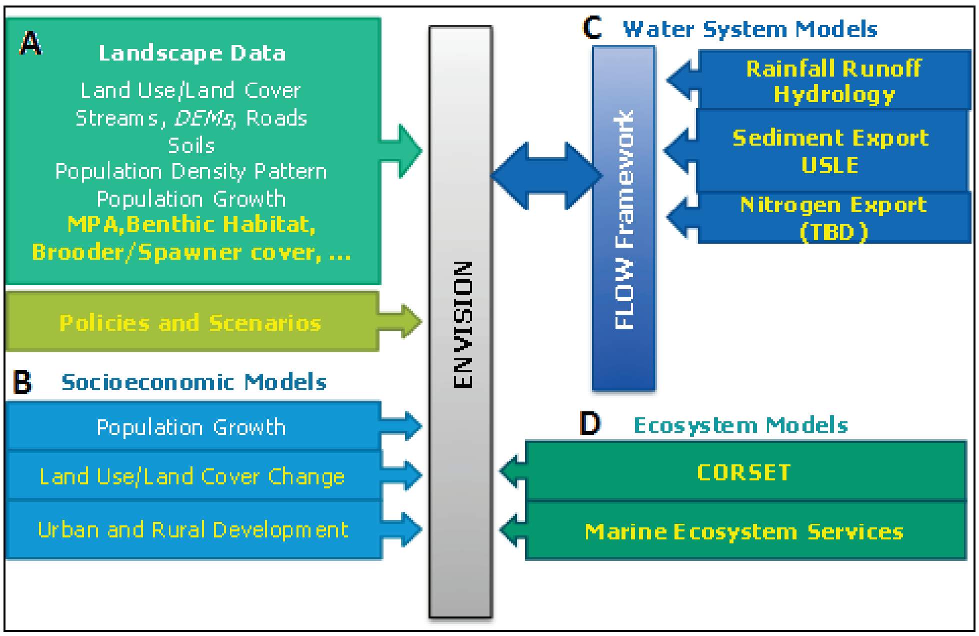


Figure 5-15 A/B/C/D. Illustration of Envision input models for the Guánica Bay watershed.

5.5 Evaluating trade-offs, implementation and monitoring

Once a consequence table is populated with the best available information from models and expert judgment and clear win-win alternatives cannot be found, the next step in the decision process is to explore tradeoffs that stakeholders are willing to make among the objectives; in other words, how much of one objective are they willing to sacrifice to have more of another (Keeney 1992). In a decision analysis approach, a key goal is to implement decisions that optimally combine value-based tradeoffs, which reflect the opinions of stakeholders, with technical trade-offs derived from outcomes of expert-based assessments, which can include science and local knowledge (Gregory et al. 2012). Although facts (e.g. information, models, data, expert judgment) are used to populate the consequence table, the ultimate decision is informed by the trade-offs from stakeholder values.

Methods such as direct ranking and swing weighting can be used to examine trade-offs holistically and in a decomposed manner (Gregory et al. 2012). In swing weighting, participants are asked to assign importance points to different performance measures to reflect their relative importance by their preference for "swinging" from a worst-case to a best-case condition (von Winterfeldt and Edwards 1986; Failing et al. 2007). Importance weights are then combined to provide a score *S* for each alternative (*k)* described in the consequence table (**Table 4-5**), under simplifying assumptions as

$$S_k = \sum w_i U_i$$

where w_i are the weights assigned to each objective and U_i are the values of each performance measure, scaled from 0 to 1, predicted for each alternative in the consequence table. Though these methods are highly quantitative, the goal of these methods is generally to provide greater insight to the deliberation process, not to quantitatively define a solution (Gregory et al. 2012). An example is shown in **Table 5-12**.

Table 5-12. Example of how the predicted change in performance measures from the worst-case scenario to best-case scenario (derived from Tables 4-5, 4-6 and 4-7) might be considered in a swing-weighting exercise. Individuals would assign ranks and weights based on their own values and preferences, here for example, for someone who highly values protecting economic opportunities.

Objectives	**Performance Measure**	***Best-case scenario***	***Worst-case scenario***	***Rank***	***Weight (%)***
Protect and create economic opportunities	*$/hectare of crop production* *$ of jobs created* *Cost of water infrastructure*			1	50
Restore and conserve the land environment	*Index of species biodiversity* *% reduction in soil erosion*	From consequence table	From consequence table	4	10
Restore and conserve the aquatic environment	*Water turbidity* *Diversity of aquatic life* *# of recreation activities* *Hectares forested*			3	20
Promote social & cultural opportunities	*Environmental attitude* *% people connected to wastewater treatment plants*			2	20

Multi-attribute approaches are also generally more satisfying than strict cost-benefit methods, which emphasize a comparison of options expressed in monetary terms (Failing et al. 2007). Methods for exploring tradeoffs are particularly valuable in facilitating discussion, identifying areas of agreement, identifying areas where further dialogue or information may be needed, and improving the quality of value judgments by participants by ensuring they were well informed of the facts and explicit about tradeoffs (Failing et al. 2007). As decisions are implemented, the performance measures that align with stakeholder objectives (see **Chapter 4**) should be monitored to gauge the success of implementation and the need for corrective actions or reassessment of the decision context.

5.6 Summary

Consequence tables (**Table 4-7, Table 5.11**) provide a useful tool for examining how different alternatives may affect the objectives. Because consequence tables focus on the relative performance of alternatives, they can help to focus the conversation on obtaining the information needed to estimate consequences (Gregory et al. 2012). Although the full consequence table (**Table 4-7**) was not explicitly populated in support of an extensive tradeoff analysis for the Guánica watershed, EPA research has been addressing a number of key uncertainties toward a better understanding of potential consequences of management actions both on coral reefs and throughout the watershed. In many cases, there may be budget or time limitations toward fully populating consequence tables with models and data. However the most important role of a consequence table often isn't an extensive quantitative analysis of alternatives, but instead to identify uncertainties where more information is needed, expose key trade-offs, and provide a communication tool for stakeholders and decision-makers.

Chapter 6. Tools Supporting the Decision Process

The preceding chapters outline a structured decision process (SDM), and its use via interaction with stakeholders and decision-makers to inform the key steps in the process, such as decision context, objective hierarchies, valuation and tradeoffs. The events described and information developed provides an example of a "*requisite modeling approach*". Requisite modeling entails building a model that contains all the necessary context and information essential for resolving a particular problem (French et al. 2009; Philips 1984). The process of building the model creates new questions and insights that add to the problem description. Through collaboration and iteration a common understanding of the problem is achieved; this is a requisite model. From this model new future alternatives for management can be evaluated.

Requisite modeling (Philips 1984):

- Captures the multi-faceted nature of a decision problem
- Uses consultation and collaboration to arrive at a shared understanding of a decision context
- Adapts to new insights until stakeholders agree
- The requisite model can then be used to create and evaluate new alternative futures

While SDM is highly beneficial to structuring environmental management problems, integrating, analyzing, and displaying information generated from that process could be greatly enhanced through computerized tools designed to support decision-makers. Developing requisite models using tools that facilitate and track the SDM process are described in this chapter.

6.1 Practical approaches to support decision-makers

A key component of SDM includes the concepts and practices of decision analysis (Gregory et al. 2012), which are fundamental to a requisite model. Decision analysis has three broad areas of study (French et al. 2009)–normative, descriptive, and prescriptive (**Fig. 6-1**). Normative decision analysis is concerned with decision models subject to mathematical rigor, and descriptive decision analysis captures the psychology of why and how people make decisions. Prescriptive decision analysis seeks to provide decision makers with the rationality of normative decision analysis tempered with the reality of real decision-making.

Three broad decision analysis study areas*:*

- *Normative* decision theory studies what an ideal decision-maker would choose.
- *Descriptive* decision theory studies how decision-makers *actually* choose.
- *Prescriptive* decision analysis studies how decision-makers can *improve* their decision-making.

The merging of normative and descriptive approaches in a practical way (prescriptive) enables the creation of requisite models that are rigorous and defensible, yet adaptable to the way people really think and make decisions (**Fig. 6-1**). These ideas formalized in computerized tools facilitate the effective application of analytical models like those described in **Chapter 5** in developing a decision model that is requisite for a particular decision context. For large, complex decision contexts with multiple, widely dispersed stakeholders (like the Guánica Bay watershed) it becomes necessary to organize and communicate management deliberations and analysis effectively for timely decision-making. Web-based decision-support tools consistent with SDM approaches are a promising way to achieve this. The following gives a brief background on the technical aspects and functional considerations in designing decision tools capable of supporting environmental management issues like those faced by the stakeholders of Guánica Bay.

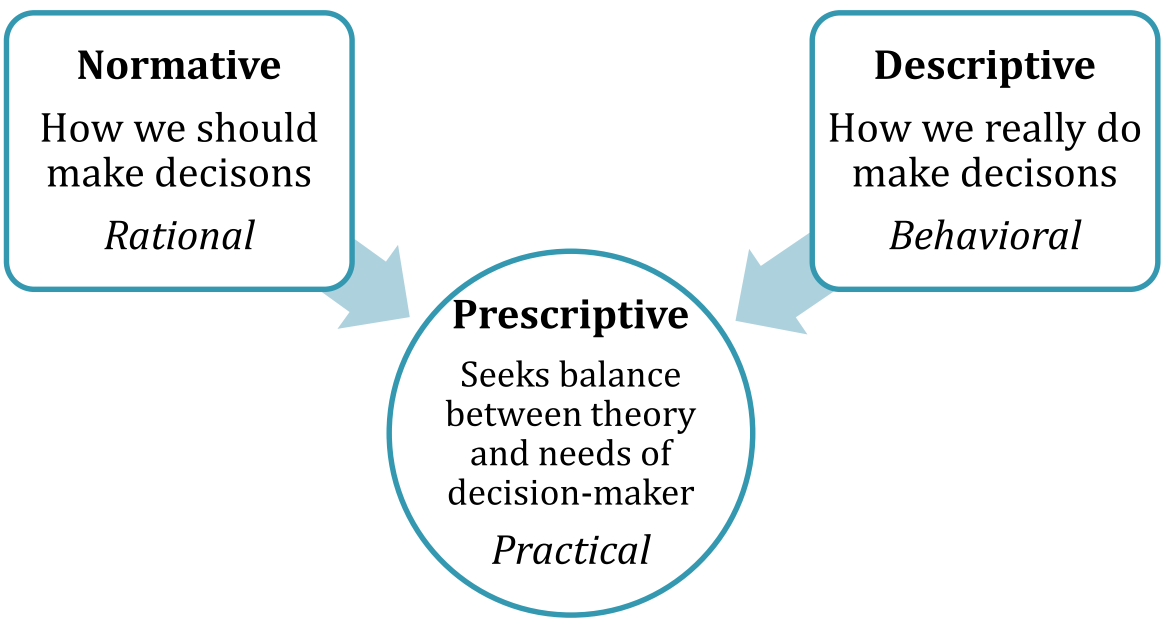


Figure 6-1. Decision analysis conceptual approach to requisite model development using decision-support tools (adapted from French et al. 2009).

6.2 Decision-support tool design: considerations and characteristics

The development of computerized tools supporting SDM often includes integrated and interacting functions geared towards aiding decision-makers. The general term used for tools such as these is decision-support system (DSS). A DSS can incorporate several levels of decision-making (**Fig. 6-2**). For Guánica Bay, a Level 3 DSS is most appropriate due to the need to evaluate multiple alternatives under uncertainty. The decision analysis method on the far right of Level 3 options is preferable for its flexibility in adapting to specific and complex decision landscapes such as the one developed for Guánica Bay.

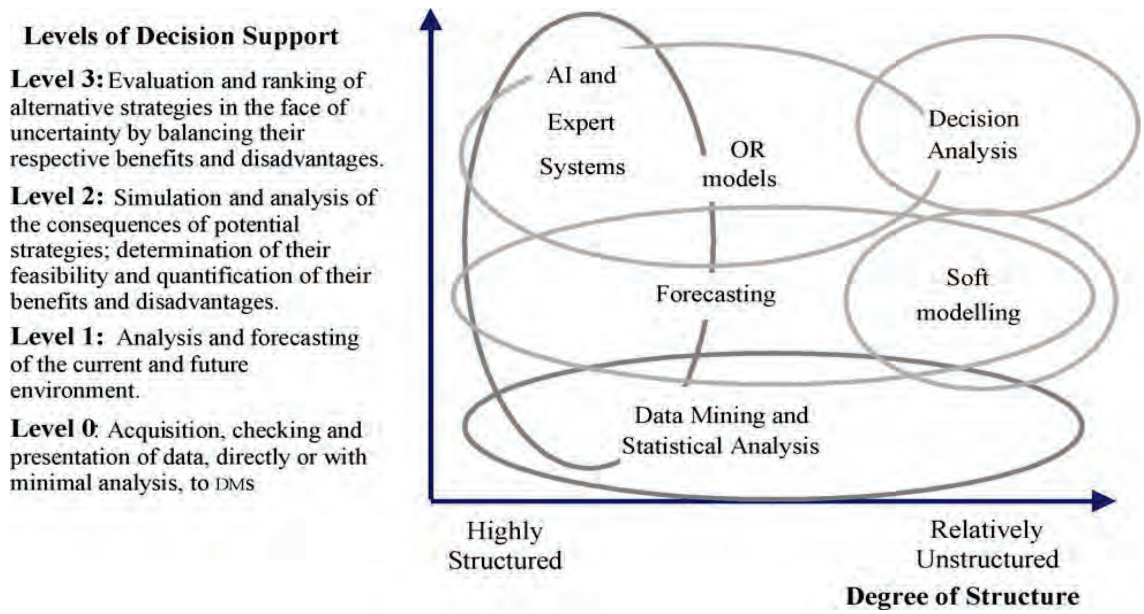


Figure 6-2. Categorization of decision-support system (DSS) options based on degree of problem structure and support delivered (source: Black and Stockton 2009). Decision Analysis (Level 3) is appropriate for Guánica Bay issues because it allows more flexibility (relatively unstructured) in requisite model creation. Other Level 3 approaches such as Operations Research (OR), Artificial Intelligence (AI), and Expert Systems, also support evaluation of alternatives but are suited for more defined (structured) problems, e.g. disease diagnosis, and industrial process efficiency.

Fig. 6-3 shows the basic set-up for a decision analysis DSS. Three components working together provide decision support: the user interface, knowledge base, and inference engine (Black and Stockton 2009). The user interface is what the user sees e.g. program screen or webpage, of the DSS and should be designed to suit the operational needs and preference of users. The knowledge base holds information necessary for informing the decision problem, e.g. databases, and the means to access and manipulate it. This knowledge is called upon and processed through models (inference engine) e.g. ENVISON, BBNs. Together these components form a system supporting decision-making.

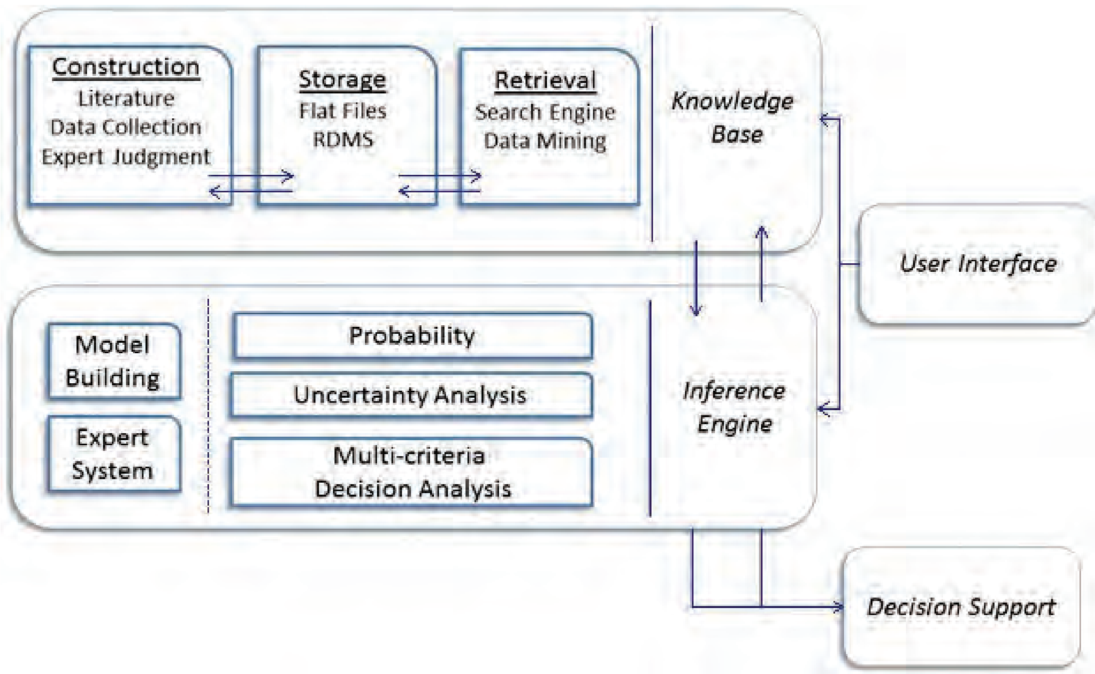


Figure 6-3. Generic architecture for a decision-support system (EPA 2012b; adapted from Black and Stockton 2009).

As noted in **Section 1**, the Internet possesses inherent functionality that presents a promising option for the development and application of decision-support tools. Web-based architecture has the capacity to provide a knowledge base and user interface inherent to a decision analysis DSS. Supplemented with open source programming languages like R (CRAN 2013), the linkage of analytical tools and inference models provide a framework for decision analysis (French et al. 2007; Black and Stockton 2009, EPA 2012b).

6.3 Decision-support illustration: DASEES

EPA has initiated development of a Web-based application, *Decision Analysis for a Sustainable Environment, Economy, and Society* (DASEES) to facilitate the application of structured decision-making (EPA 2012b). The following images (web page screen shots) of the DASEES user interface illustrate its functionality in assisting the SDM process for Guánica Bay. The images are for demonstration purposes and are not intended to convey a full decision analysis using DASEES. The images contain much of the same information presented in **Section 2.5** of this report, but for clarity in a print format they are simplified in content. The user works through the decision process in DASEES with a sidebar navigation pane (**Fig. 6-4**). The steps in the sidebar pane are consistent with and support the steps describes in this report, e.g., developing the decision landscape, objectives, etc.

Decision Landscape information (**Section 3.1**) for Guánica Bay is entered directly into the Decision Landscape page (**Fig. 6-4**) via typing or through the standard editing (copy and paste) functions. This information can be in the form of text, figures, videos, hyperlinks that are supported by the browser, i.e., Firefox, Chrome.

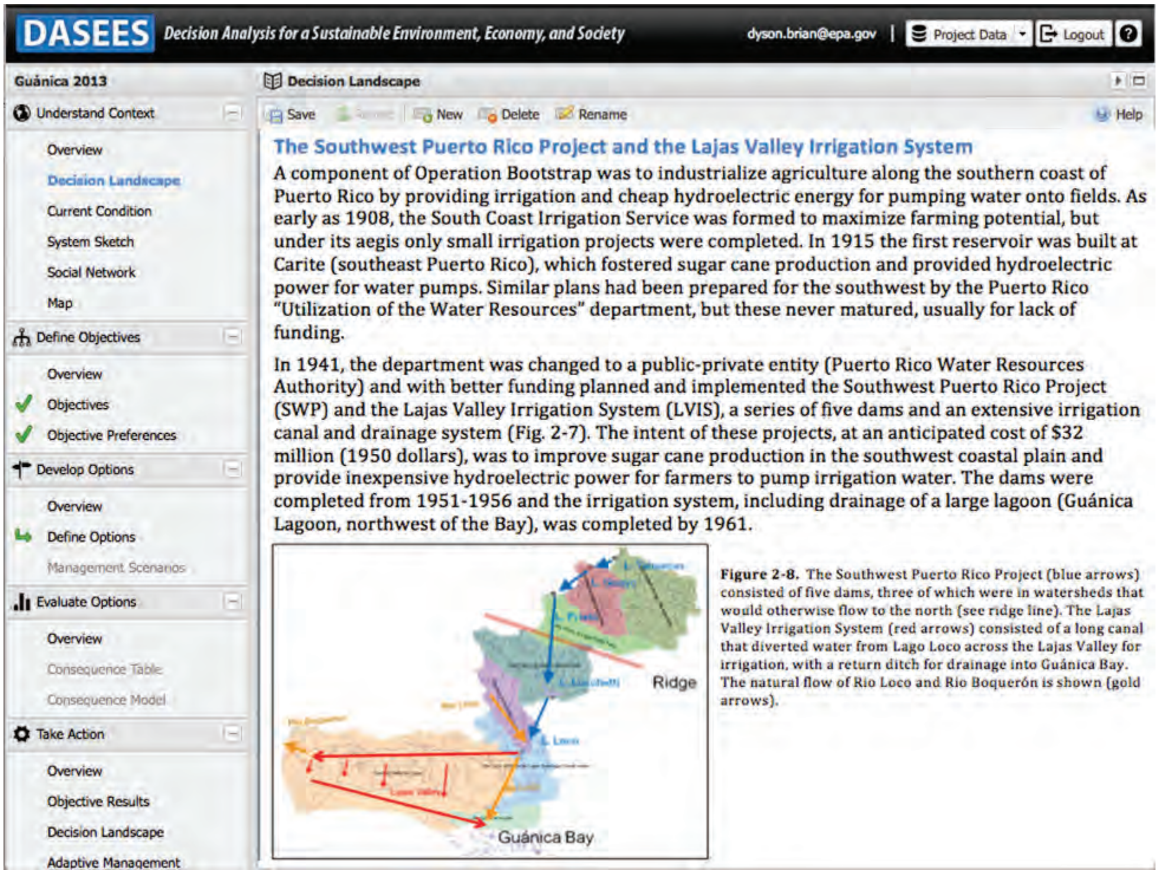


Figure 6-4. Contextual information for the Guánica Bay Decision Landscape in *Decision Analysis for a Sustainable Environment, Economy, and Society* (DASEES).

SystemSketch is a tool embedded in DASEES that supports DPSIR-based systems thinking (**Section 3.3**) about the decision context. It dynamically visualizes system connections following the DPSIR framework to help stakeholders better understand system context.

The user begins by choosing a DPSIR category in the left-hand panel (**Fig. 6-5**) for which they want to explore linkages shown in the right-hand panel. Linkages are pre-determined based on existing scientific understanding and general in nature, i.e. not specific to a user's context. The tool allows users to generate and follow linkages (akin to surfing web-pages) to gain a new or better understanding of DPSIR systems connections.

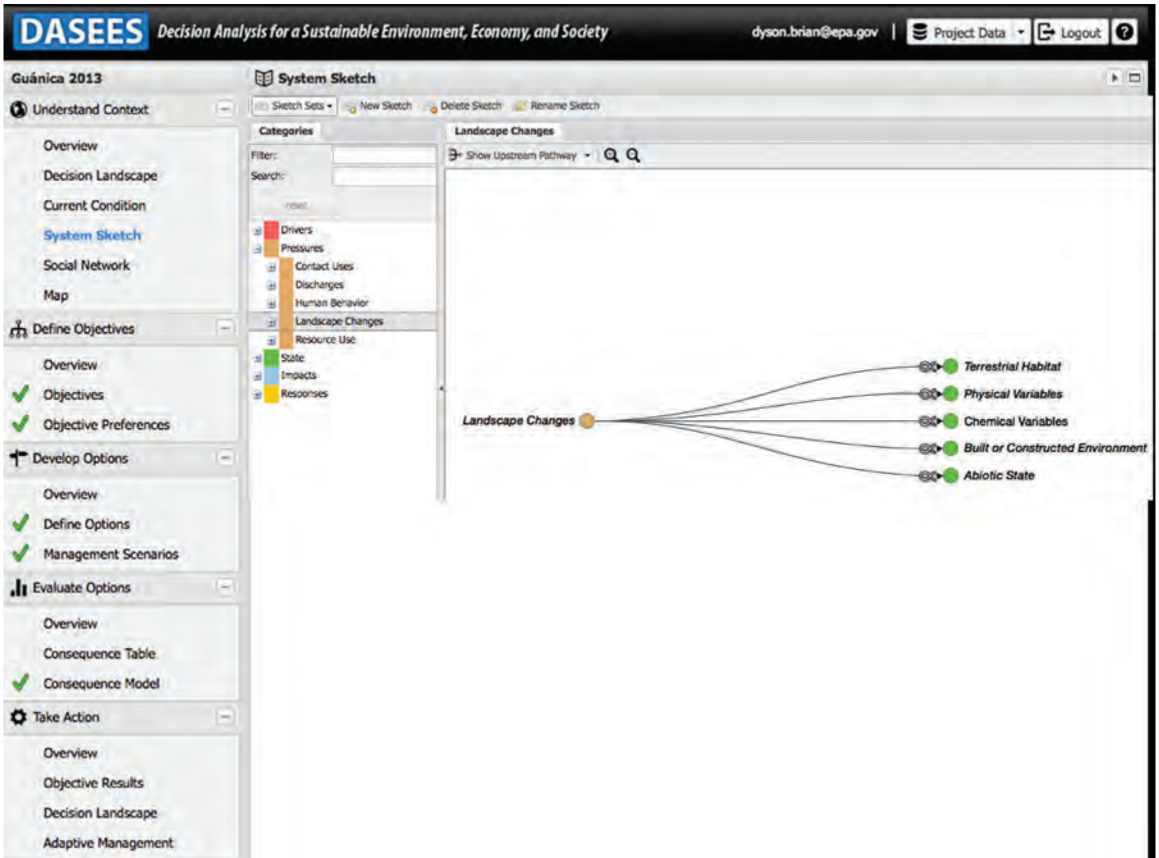


Figure 6-5. SystemSketch tool in Decision Analysis for a Sustainable Environment, Economy, and Society (DASEES) showing a linkage between the Pressure (P), Landscape Changes, and States (S) such as Terrestrial Habitat, Built Environment, and Abiotic State. Clicking next on the Terrestrial Habitat node would then open a new set of DPSIR categorized paths to follow. Linkages are further visually explored with the intent to help identify unrecognized connections, missed objectives, possible performance measures, and management actions.

Objective Hierarchies (**Section 3.4**) developed through workshops to elicit stakeholder values (**Section 5.3**) are entered either directly in the Web interface or can developed in a word processor document and imported into *Define Objectives* (**Fig. 6-6**). Large Objective Hierarchies can be expanded and collapsed to view specific Objective Categories as needed.

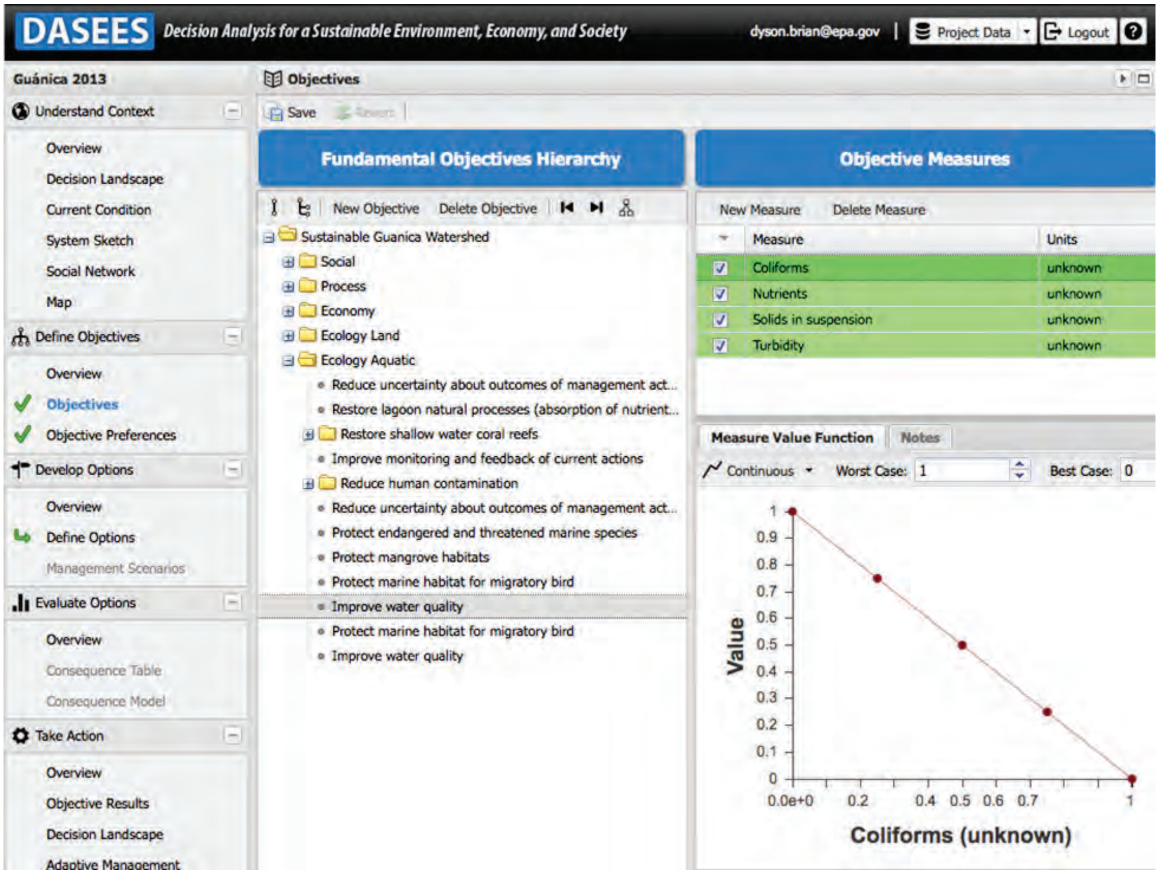


Figure 6-6. Segment of the Guánica Bay Objective Hierarchy focusing on aquatic ecology. When the objective *Improve Water Quality* is highlighted in the left-hand panel, specific measures to track achievement the objective are listed in the right-hand panel.

An important feature in DASEES is the dependence of the three middle steps [*Define Objectives (***Fig. 6-6***)*, *Develop Options (***Fig. 6-7***)*, and *Evaluate Options* **(Fig. 6-8***)*] on input from the prior step. This is to ensure that information and stakeholder deliberation from each decision step is used in subsequent decision steps. For example, the measures identified in *Define Objectives* are necessary in *Evaluate Options* to ensure that options evaluation is linked directly to stakeholder driven objectives, which are ultimately a reflection of their values.

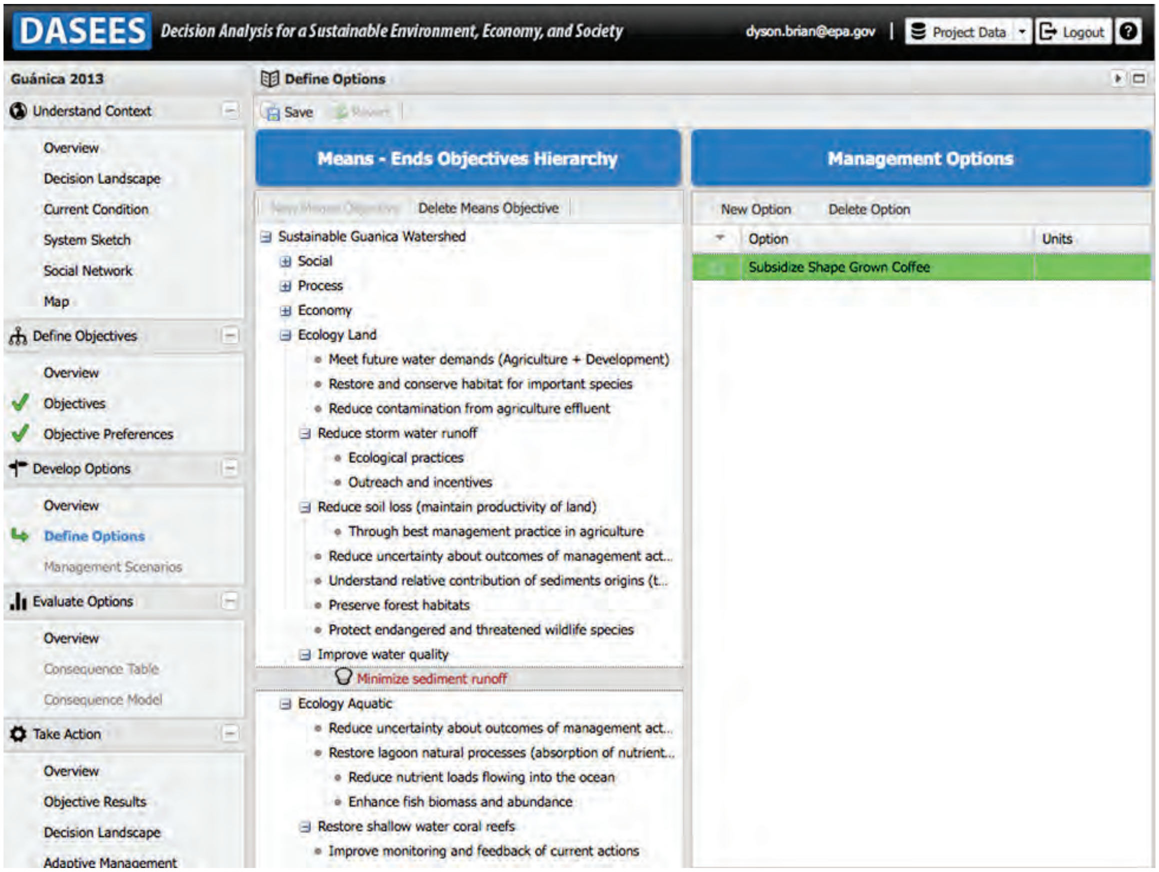


Figure 6-7. Means objectives *Minimize sediment runoff* associated with the fundamental objective *Improve Water Quality* (left-hand panel) and management option *Subsidize Shade-grown Coffee* (right-hand panel) developed by Guánica Bay stakeholders.

The measures (attached to fundamental objectives) and management options (attached to means objectives) developed in these two steps as displayed in **Fig. 6-8** as nodes in a BBN (**Section 5.3**). The management option *Subsidize Shade Grown Coffee* (yellow) and the four measures *nutrients, coliforms, solids in suspension* and *turbidity* (green) are pre-loaded into the model from input in the previous two steps (*Define Objectives and Develop Options).* Stakeholders create the causal connections (red) between decision (means objective) and endpoint (fundamental objective). From this model, alternative options are evaluated against multiple fundamental objectives, trade-offs assessed and decisions made.

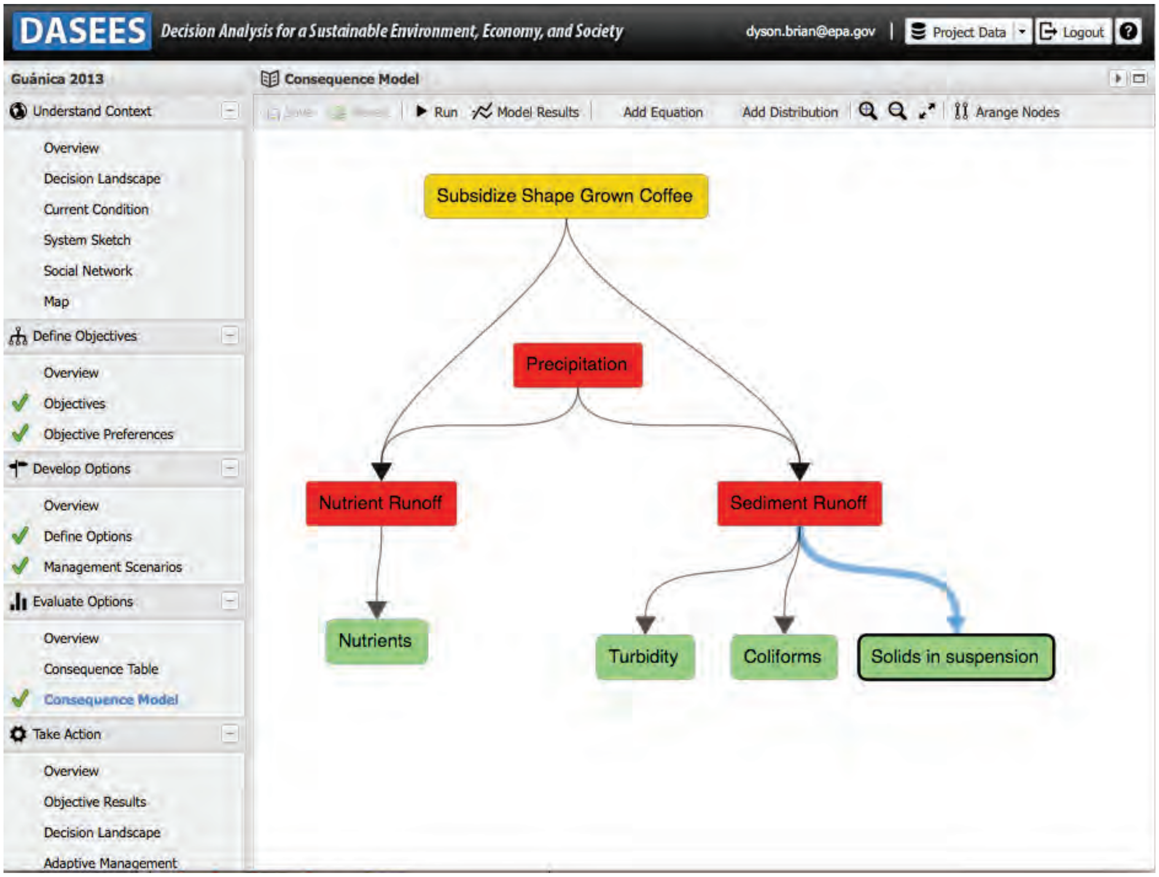


Figure 6-8. An influence diagram for a Bayesian Belief Network showing the management option (*Subsidize Shade-grown Coffee*), the environmental state variables (*nutrient runoff, precipitation,* and *sediment runoff*), and the corresponding measures (*nutrients, coliforms, solids in suspension* and *turbidity).*

A common desire voiced by groups faced with complex environmental management decisions is to be able to bring their information together in one place (e.g., to have a 'thinking space' to see how everything fits together) (Boumans 2012). DASEES supports this with the demonstrated tools and interfaces and as a common repository for data and documents pertinent for the management problem (**Fig. 6-9**). The *Sharing* tab facilitates transparency in decision-making by making available to all interested parties the information used throughout the decision.

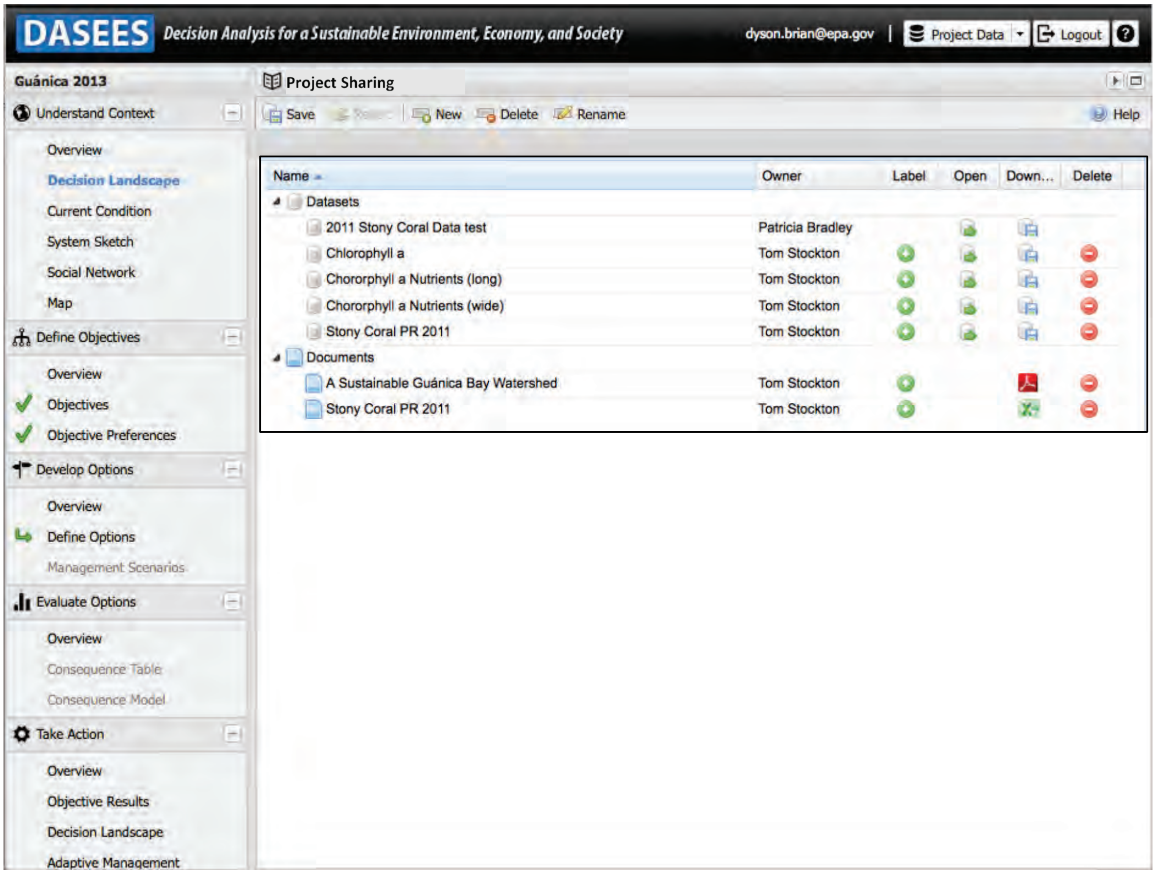


Figure 6-9. The *Decision Analysis for a Sustainable Environment, Economy, and Society* (DASEES) sharing interface provides a place for storing all the data and information needed to make a decision.

6.4 Benefits from decision-support tools

Generic model-based DSSs are suitable for a wide range of applications when choosing among alternatives using multiple criteria is a prime need of decision-makers. In the environmental field, this ranges from management of ecosystems to community sustainability planning to high-level government agency policy analysis. A DSS supports the structured decision-making process, providing a way to deal with "*wicked*" (Balint et al. 2011) environmental problems previously considered intractable. Web-based DSSs like DASEES foster greater participation of traditionally excluded stakeholders and enhances collaboration for the creation of better solutions to complex problems. Additionally, the graphical modeling approach used by Bayesian Belief Networks (**Fig. 6-9**) is suitable for exploring competing hypotheses in relation to the causal mechanism between proposed actions and expected results. This capability highlights the potential for tools like DASEES to be useful for structuring and analyzing scientific research as well as informing environmental management decisions.

Chapter 7. Evaluating the Formal Decision Process in Guánica Bay

In **Chapter 1** of this report, the potential benefits of ‘value-focused’ thinking (as opposed to ‘alternatives-focused’ thinking) were described as worthy of the additional time and effort required to identify and characterize stakeholder values, particularly in those situations with multiple stakeholder groups and the potential for a variety of competing objectives. Value-focused thinking in environmental management requires that the decision process be opened up to stakeholders, allowing for a more transparent and inclusive process that does not restrict decisions to technical experts or to authorities with a narrow range of mission-oriented values. Keeney (1992) prepared a list of potential advantages to values-focused thinking (text box). Although EPA did not complete every step, **Section 2.5** in this report illustrated the steps taken to incorporate values following a structured decision process for a case study in Guánica Bay, Puerto Rico. Using Keeney’s (1992) list, it is possible here to assess the process.

Possible Advantages of Value-Focused Thinking (modified from Keeney 1992):

- Guiding information collection – Values help prioritize the spending of limited resources on gathering information relevant to what is important
- Improving communication – VFT keeps the discussion on what is important to the whole group and not on specific, technical aspects of alternatives
- Stakeholder involvement – All parties, regardless of education or socio-economic status know what is important to them and can communicate that
- Interconnecting decisions – Decision-makers make decisions in different contexts. It is important to be able to see if decisions in one context affect how a decision will be made in another. Values help to see how decisions affect strategic level objectives
- Guiding strategic thinking – Inter-related decisions show the necessity of clarity of values for strategic level decision-making
- Creating alternatives – Creating new alternatives that are directly responsive to stakeholder values have a better chance of acceptance and successful outcome
- Evaluating alternatives – Linking a value model to a consequences model makes it possible to analyze desirability of alternatives.

7.1 Guiding information collection

The decision landscape presented in **Chapter 3** is a direct outcome of a structured decision process. The initial decision context, protection of coral reefs, led to a proposal of management alternatives that affected several facets of the watershed (CWP 2008). Systems thinking (i.e., DPSIR) allowed EPA and stakeholders to begin to assemble information in an organized manner, and to see what tradeoffs might occur under different alternatives. In particular, systems thinking provided a means to quickly identify consequences of management actions beyond protection of coral reefs and broadened the decision context to recognize potential trade-offs with agriculture and potentially positive effects on tourism, fisheries and human health. From this, an initial characterization of key uncertainties was identified, including mapping human use and activity in the watershed, the source and fate of pollutants within the complex Guánica watershed hydrologic system, the impacts of stressors on coral reefs, and better characterization of stakeholder values.

Information gained from discussions in the workshops revealed several science gaps, some of which spurred studies by EPA and others. One of the greatest areas of uncertainty concerned sediment efflux from Guánica Bay and its potential effects on coral in the nearby coastal zone. Although all the management efforts proposed by the CRTF were to protect coral reefs from sediment and associated nutrient and contaminant loads, there is no existing evidence that the condition of reefs outside Guánica Bay is more degraded than reefs occurring elsewhere along the southern coast, and if the condition is degraded there is no evidence that terrestrial sediment is a primary contributor to the decline. EPA initiated studies, most still in progress, to address these science gaps:

- Measuring the distribution of terrestrial sediment vs. oceanic sediment in coastal waters near Guánica Bay *(are there high concentrations of terrestrial sediment?)*
- Surveying coral reefs in southwestern Puerto Rico to characterize the condition of coral reef assemblages *(is the condition of reefs near Guánica Bay degraded relative to other reefs?)* and comparing the biological condition of sites with high and low terrestrial sediment influx *(can terrestrial sediment be linked to degraded coral reef condition?)*
- Testing the effects of sediment collected inside and outside of Guánica Bay on the survival and growth of Caribbean coral species in laboratory dosing experiments *(what source and levels of sediment have adverse effects on corals?)*
- Developing a conceptual model (the BCG) of how coral reef condition changes as human disturbance increases *(can we link coral reef condition to human factors?)*

Another area of uncertainty was where terrestrial sediment entering Guánica Bay originated and whether proposed management actions would significantly reduce soil erosion and transport to the bay. EPA studies to address these science gaps included:

- Modeling the hydrology and sediment loading of the watershed area to better characterize sediment sources *(where does the sediment originate?)* (Yuan et al. 2013; Bousquin et al. 2014; Hu et al. 2015)
- Modeling the water storage capacity of reservoirs in the SWP to project the future ability to capture sediment from the mountainous areas and protect downstream habitats *(at what rate will sediment trapping by reservoirs decline?)* (Bousquin et al. 2014)

Human health issues arose in the workshops, particularly related to flood protection, sanitation and the quality and availability of drinking water. EPA initiated studies that included:

- Modeling the water storage capacity of reservoirs in the SWP to project useful lifespan for flood protection and drinking water provision in light of increasing sedimentation *(at what rate will freshwater storage capacity decline?)* (Bousquin et al. 2014)
- Initiating a Citizens Science Project in Guánica Bay to monitor water quality, fecal coliforms and sewer infrastructure *(what communities are at risk for sanitation and waterbodies are safe for contact?)* (Sotomayor 2015).

Consideration of different options raised in the workshops created questions about the relative value of outcomes. EPA initiated several studies to identify ecosystem services from coral reefs and the terrestrial watershed area as the related to stakeholder values:

- Developing production functions to quantify and map coral reef ecosystem goods and services, such as fishing potential, tourism potential, pharmaceutical potential, shoreline protection, and supporting services) using data from coral reef condition surveys *(what quantity of services do coral reefs provide?)* (Principe et al. 2012; Yee et al. 2011, 2014b).
- Developing production functions to quantify and map provisioning of terrestrial ecosystems services such as sediment and nutrient retention and air pollutant removal *(what quantity of services might be affected by decisions in the watershed?)* (Smith et al. In Review).
- Conducting on-site and web-based surveys of residents and visitors to estimate the use and associated market and non-market economic value of Puerto Rico's coral reef-based tourism and recreation, and how those values change with changes in reef attributes *(how valuable are coral reefs for tourism and recreation and how important is reef condition to that value?)* (Bradley et al. 2014a).

For updates on these and other projects related to Guánica Bay contact EPA’s Gulf Ecology Division, Gulf Breeze, Florida.

To characterize stakeholder values, EPA used the systems-thinking frameworks and discussions from the 2010 workshop to identify key stakeholder groups within the Guánica watershed for follow-up workshops. These included community leaders, environmental groups, farmers, fishermen, tourism and recreation groups, and government agencies. Stakeholders recognized the importance of protecting coral reef habitats, but identified a number of other values, including forest biota, agricultural productivity, cultural heritage, water availability and economic independence through opportunities such as fisheries, eco-tourism, and agriculture. The ensuing workshops not only initiated broad discussions on those values but also helped to identify perceived threats to those values, such as pollution, loss of agricultural land, loss of habitat and biodiversity, poverty, economic instability, lack of representation, and lack of education.

Restoration of the Guánica Lagoon was a topic that is a good example of how workshop discussions guided information collection. Different stakeholder groups with different objectives disputed the proposed restoration. One group cited protection of coral reefs and habitat provision, the other cited loss of agricultural land in a farming-dependent economy. Through the discussion, the absence of technical data for several facets of the system became clear, in particular the origin of sediment and nutrient stressors (from Lajas Valley irrigation ditches or from Rio Loco), the effects of the stressors on coral reefs, and the actual value or contribution of a restored lagoon in reducing those stressors.

Using information gained in the workshops and developing the decision landscape, EPA has initiated the following studies to address specific science gaps (for updates contact EPA’s Gulf Ecology Division, Gulf Breeze, Florida):

- Measuring the contribution of terrestrial sediment in Guánica Bay coastal waters
- Surveying coral reefs in southwestern Puerto Rico to characterize the condition of coral reef assemblages and comparing sites with high and low sediment influx, differences in condition related to sediment presence and the provision of coral reef ecosystem services
- Testing the effects of sediment collected inside and outside of Guánica Bay on the survival and growth of Caribbean coral species in laboratory dosing experiments
- Surveying coral reefs along the entire southern coast of Puerto Rico to characterize the provision of ecosystem goods and services (fishing potential, tourism potential, pharmaceutical potential, shoreline protection, and supporting services)
- Modeling the hydrology and sediment loading of the watershed area to better characterize the source of sediment

- Modeling the water storage capacity of reservoirs in the SWP to project the useful lifespan remaining as sedimentation increases, and to project the utility of various decision options (i.e., farming practices and dredging reservoirs)
- Developing production functions to quantify and map coral reef ecosystem goods and services
- Developing production functions to quantify and map provisioning of terrestrial ecosystems services such as sediment and nutrient retention and air pollutant removal.
- Developing a conceptual model (the BCG) of how coral reef condition changes as human disturbance increases
- Conducting on-site and web-based surveys of residents and visitors to estimate the use and associated market and non-market economic value of Puerto Rico's coral reef-based tourism and recreation, and how those values change with changes in reef attributes
- Initiating a Citizens Science Project in Guánica Bay Watershed to monitor water quality (sanitation) and sewer infrastructure.

Additionally, Ridge to Reefs Inc., Protectores de Cuencas, and Puerto Rico DNER have completed an economic valuation study of Guánica Lagoon. UPRM Mayagüez and Protectores de Cuencas led the study. The financial costs and benefits of lagoon restoration have been evaluated and are summarized in a report (Lozado and Mora 2014). Public stakeholder meetings were held to provide input into the study. Key benefits identified in the report are listed below:

- The restored lagoon will provide ecological benefits. It will once again provide habitat for native and migratory birds.
- The restored lagoon will provide ecotourism opportunities. There will be a visitor center with educational exhibits and information, a boardwalk for nature hiking with interpretive displays along the walk, areas for camping, an observation tower for bird watching, and local micro-businesses (e.g., kayak rental services and guided tours, arts and crafts, food and sale of locally caught fish).
- The restoration of Guánica Lagoon will provide socio-economic benefits to the residents of adjacent communities. By 2020 they expect 23 new community enterprises with total expected sales of $250,000 in 2015 and almost half a million dollars in 2020. The restoration of Guánica Lagoon could generate between 45 and 60 jobs during the first year of operations and by 2020 the number of jobs would reach a minimum of 69 and a maximum of 92. In addition to the employees of the micro-enterprises, there will also be new jobs in guesthouses and restaurants, interpretive guides, and suppliers.

NOAA has completed a baseline assessment of Guánica Bay, Puerto Rico, and its surrounding coral reef ecosystem (Whitall et al. 2013). The report details:

(1) A biogeographic assessment of the coral reef ecosystem outside the bay.
(2) Contaminant (e.g., PAHs, PCBs, pesticides, heavy metals) magnitudes and distributions in surface sediments (inside the bay, outside the bay and in the watershed streams) and in coral tissues (mustard hill coral, *Porites astreoides*).
(3) Spatial and temporal patterns in sedimentation rates and surface water nutrient concentrations. Sediment samples from Guánica Bay, Puerto Rico, contained high concentrations of PCBs, chlordane, chromium, and nickel as compared to other sites sampled by the NOAA National Status & Trends Program, a nationwide contaminant-monitoring program that began in 1986. These concentrations represent toxic threats to corals, fish, and benthic infauna—organisms that burrow into and live in the seafloor.

EPA has conducted a source identification investigation, but did not find records of any spills or releases that could explain the source(s) of the contaminants. There remains uncertainty about the human health effects of the contaminated sediment. A human health risk assessment has not been conducted for Guánica Bay (personal communication with Mark Reiss, EPA Region 2).

A key point for a structured decision process is the distinction between scientific information and values information, both of which are important. Information on stakeholder values helps to prioritize collection of scientific data, focusing cost and effort where it will be most relevant to decisions.

7.2 Improving communication

Limited communication was a major concern for stakeholders in the watershed. Many expressed frustration with the apparent lack of communication with government agencies and the resulting lack of local influence in decisions, both historically and currently. Many also felt there was poor communication among government agencies (both Federal and Commonwealth), leading to conflicting directions in management decisions and skepticism by local stakeholders. Stakeholders also recognized that there was poor communication among citizens and stakeholder groups in the watershed, limiting the potential for shared effort and a stronger community voice.

The three EPA-sponsored workshops made steps toward resolving some of the communication issues, not only by bringing stakeholders and decision-makers together, but also by demonstrating the tools used to clarify and organize values and alternatives. DPSIR conceptual maps that were employed in the 2010 Decision-support Workshop provided the backbone for systems thinking that broadened decision context and ultimately generated discussion among groups that do not normally interact (like farmers and fishers).

In both the 2010 Decision-making Workshop and the 2013 Public Values Forum, participants provided information that was captured in SNAs (**Fig 4-2**) (Bradley et al. 2015) (**Fig. 4-6**). The SNA competed in 2013 had three unconnected clusters: a large cluster, with NOAA playing a central role; a 2nd smaller cluster of mostly EPA employees that work interactively but have connection with only one external participant (NOAA); and 3rd small cluster of individuals representing Puerto Rico departments that are interactive with FWS and NRCS but not with the broader NOAA network. The 2013 SNA showed that the 2nd smaller cluster of EPA employees has been integrated into the large cluster, but the 3rd small cluster remains independent. While this is a significant improvement, given EPA's EPA mission and regulatory responsibility for managing and regulating land-based sources of pollution, effort must be made to better link FWS and NRCS into the larger network. It should be noted that both SNAs were developed with only the participants at the workshops, and a more comprehensive SNA might link the clusters.

Importantly, the focused discussions during the workshops allowed stakeholders to hear similar and differing views on values and issues related to environmental decision-making. Formal decision tools, such as objective hierarchies, means-ends networks, consequence tables and electronic voting served to organize and prioritize values and options in a transparent process. In this process, everyone in attendance had some idea of why one alternative was supported over another. Beneficial to the success of this approach was the constant reinforcement to distinguish science from values and objectives, allowing that validity and accuracy of science could be argued but that values could not be questioned.

During the 2012 Decision-Making Workshop, participants identified a lack of communication between local stakeholders and decision-makers in government agencies as a historical and continuing problem. They felt that Federal and Commonwealth agencies, most of which are located in San Juan, were making the majority of environmental decisions and that local citizens had little influence on the process. Consequently, the decisions were not always in the best interests of local communities. Documentation of this concern, here or elsewhere, could lead to greater efforts to bridge this gap. A stronger determination by stakeholders to infuse themselves into the process may also result.

Workshop stakeholders also emphasized that government agencies don't always consult with other government agencies before making decisions; or if they do, the decisions sometimes conflict with other programs. This is believed to lead to a patchwork of individual decisions that do not support a long-term goal for the watershed. The USCRTF was established as a means to bring Federal Agencies together with a shared purpose, and this was certainly true in Guánica Bay, where EPA worked with NOAA, USDA/NRCS, USFWS and Puerto Rico environmental agencies to jointly confront the problem of coral reef decline. Communication among agencies was, in this case, relatively high even though the decision context was relatively narrow (coral reef protection). Yet, it was also clear from the Public Values Forum that the USCRTF needs to expand its decision context into broader watershed issues and engage a broader spectrum of stakeholders. This fact is currently under discussion both in Puerto Rico and within the USCRTF Watershed Initiative Program, largely as a consequence of the Guánica Bay experience.

7.3 Stakeholder involvement

One of the clearest messages from the Decision-Making Workshop and the Public Values Forum was the desire of stakeholders to be informed, educated and engaged in local environmental decisions. This was driven in part by sensitivity to decisions made outside the community and in part by a desire for strong environmental stewardship within the community. Decisions made outside the community have little transparency and were perceived as not reflecting local values.

The three EPA decision science workshops provided local decision-makers and stakeholders an opportunity to become better informed and more engaged in environmental issues. Moreover, the workshops opened the decision process to a broader conceptualization that considered wider benefits and tradeoffs across the watershed and coastal zone. Although the original context for the 2010 Decision-support workshop was coral reef protection, it was immediately clear that there were a variety of linked environmental issues to consider. Particularly valuable in this process was the ability of stakeholders to hear other viewpoints in a constructive environment and to recognize that there are ways to move through disagreements. Separating values and objectives from science facts and knowledge was extremely useful in this respect.

Also beneficial in the Public Values Forum was that it demonstrated to participants how transparency increased the success of an informed decision process. Work groups identified values and alternatives from different stakeholder perspectives and shared them with all participants iteratively; and the groups considered and amended their ideas publicly throughout the Forum, finally selecting those they thought were most worthy. Then everyone was allowed to vote on the priorities anonymously. Important to this transparency is that even the most avid supporter of a particular alternative, regardless of the voting outcome, had to recognize the inclusive expression of community values.

7.4 Interconnecting decisions

Archival research to characterize the decision landscape was very valuable for identifying a variety of interconnecting decisions. At the earliest steps of EPA involvement, the USCRTF had identified a single objective of their mission—protection of coral reefs in the coastal zone. The WMP (CWP 2008) developed to support that objective proposed a suite of management options, including coffee farming practices, restoring an historic coastal lagoon, dredging reservoirs, planting riparian zones, removing hydrology infrastructure and upgrading sewage treatment.

Following the 2010 Decision-support Workshop, EPA summarized the growing recognition of interconnections, developed a Guánica Bay Watershed DPSIR (Bradley et al. 2014b), and proposed a values-focused framework, which included development of objectives hierarchies, means to achieve the objectives (means-ends networks), performance measures and potential desired and undesired outcomes (Carriger et al. 2013). This led to a broader recognition of values in the watershed and adjacent coastal and marine systems, and set the stage for further stakeholder interaction on the broader range of topics.

The primary environmental issue tackled by the USCRTF was runoff of sediment and nutrients from watershed activities that was affecting coral reef ecosystems (CWP 2008). The stressors, as illustrated in Carriger et al. (2013), were also affecting the environment, economy and society further up in the watershed. At its source, sediment runoff represents a loss of topsoil that is essential to farming. As the sediment travels downstream, it collects in riverbeds, reservoirs, lagoons and embayments. In the Guánica Bay watershed, sediment in the reservoirs, the Guánica Lagoon and in the Bay itself is a concern for all inhabitants, human and otherwise.

In particular, sediment accumulation has reduced the water storage capacity of the five reservoirs of the Southwest Puerto Rico Project (SWP) to roughly half of their original (1950s) volumes, yet water demands for irrigation and domestic purposes have risen. The lack of storage capacity also reduces the potential to protect coastal areas from flooding during major storm events (endangering the humans and causing property damage). The cost of dredging sediment from the reservoirs is so high that building new reservoirs is becoming a reasonable option. These interconnecting issues have become topics for EPA scientific investigation.

The fact that sediment is accumulating in reservoirs in the mountain ridges indicates that erosion is occurring from upper watersheds, meaning that mountain roads, municipalities, and farming, especially coffee farming, are potential sources of sediment. Interconnecting management options include subsidies, education and incentives to influence coffee farming practices (e.g., shade-grown vs. sun-grown coffee) that require a full consideration of trade-offs, particularly for farmers who must adopt new practices that may affect their economic status (at least in the short-term).

Sediment in the irrigation canals and drainage ditches was another interconnecting issue that arose during the Public Values Forum. As sediment passes through and out of the reservoirs into the Lajas Valley Irrigation System, it settles in the canals and drainage ditches, thereby reducing capacity for water flow needed for irrigation and drainage. The only way to remove the sediment is through dredging, which is not only costly but creates piles of sediment along canal levees that in turn creates upland flooding and eventually washes back into the canals. Reducing sediment in the canals and drainage ditches is a means objective in need of viable alternatives.

In general, agriculture was widely supported by stakeholders, whether coffee-growing in mountain ridges, or cultivation of vegetables and rangeland for cattle in the valley. Discussions of water availability for irrigation led to discussion of incentives for farming and preservation of farmland. In 1999, this public value led to the Agricultural Reserve Law, but farmers argue that the Law has done little to protect farmland. Participants discussed a variety of options, which were largely focused on best management practices, farmland protection, provision of incentives and pricing.

The Guánica Lagoon restoration was introduced by the USCRTF as a means to settle sediment and filter nutrients from Lajas Valley water before it enters Guánica Bay. It had been drained in the 1950s as part of the 'South West Puerto Rico Project' that consisted of converting wetlands areas in the Valley to agricultural lands. The USCRTF recommendation to restore the lagoon has instigated several related decisions, including how much (depth, area), with what water flow (to prevent stagnation) and by whose authority. This issue has a strong scientific component, and the USCRTF has funded several studies to address stakeholder concerns. 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, cited in Bradley et al. 2014b, show more precisely the impacts that restoring the Guánica Lagoon may have on the agriculture of the surrounding area.

The Guánica Wastewater Treatment Plant (WWTP) generates an estimated wastewater flow volume of about 1.2 millions of gallons per day (MGD), with an associated nutrient (mostly nitrogen and phosphorus) load of approximately 54,000 lbs/yr. The WWTP is the largest discrete source of nitrogen in the Guánica Bay watershed. The WWTP provides advanced secondary treatment, which minimally reduces nutrient discharges to the Bay (CWP 2008). Nutrient standards in Puerto Rico, as well as background concentrations from the watershed, suggest that the WWTP's effluent is currently 7-15 times higher than background levels in the area, and exceeds the current water quality standards for total nitrogen in Puerto Rico.

The WMP proposed a constructed wetland system as means to reduce nutrients from entering the bay and coastal zone. Constructed wetlands are treatment systems that use wetland vegetation, soils, and their associated microbial assemblages to improve water quality (EPA 2004). The proposed project is anticipated to help reduce the current annual nutrient loading to the Guánica Bay by 50-80%, and thus improve water quality conditions in the area. US Army Corps of Engineers issued public notice SAJ-2014-01994 on August 21, 2014, regarding the Ridge to Reefs, Inc. application for a Department of the Army permit pursuant to Section 404 of the Clean Water Act (33 U.S.C. §1344) and Section 10 of the Rivers and Harbors Act of 1899 (33 U.S.C. §403). Ridge to Reefs, Inc. has developed a mitigation plan, permitting is nearly complete and they hope to begin construction soon.

In addition to the nutrient loading, there is an associated concern over public health and the absence of strong sanitary controls in communities near Guánica Bay and river systems. This issue has been identified by EPA Region 2 as an issue throughout Puerto Rico where roughly half of the households are not connected to municipal wastewater treatment plants. A consequence is that water quality is unsafe for fishing and swimming in Guánica Bay and the immediate coastal zone. Nonetheless, subsistence fishing persists in the Bay creating a clear health threat for local citizens. EPA has initiated a Citizen Science project to better educate local communities on water sanitation issues.

The coastal zone was the first concern of the USCRTF (effects of sediment and nutrients on coral reefs). Most stakeholders generally agree with protecting coral reefs and reef fisheries, but there is little information available on how much sediment and nutrient reduction is needed to produce a positive result. Moreover, a variety of stressors has affected reefs and reef fisheries, including high sea surface temperature events (resulting from global climate change) and over-fishing. Decisions to protect coral reefs through management of human activities in the watershed must be couched within the effects of other global and local anthropogenic factors. Implicit in this discussion is deciding the level of desired improvement for coral reefs ("how good is good?") and the sacrifices necessary to achieve it. EPA is developing a generalized stressor gradient for coastal and estuarine systems. The generalized stressor gradient will reflect cumulative stress from multiple stressors and will be spatially explicit. Stressor categories will include (at a minimum) land-based stressors (nutrients, sediments, toxics), fishing pressure, and climate change related stressors (sea surface temperature and pH). The stressor gradient will be used as the x-axis of the Biological Condition Gradient (BCG).

A larger context –ecotourism—emerged through the three workshops. Several different stakeholders felt that ecotourism was a viable economic alternative for southwestern Puerto Rico, and that protection of coral reefs, restoration of the lagoon, improved fisheries and greater biodiversity were all means to achieve this objective. Ecotourism has the potential to conserve environmental resources while providing economic benefits. While communities of southwestern Puerto Rico and the Puerto Rico Ecotourism Board share the goals for ecotourism, there has been little interaction between them. EPA initiated an ongoing study to better characterize coral reef ecosystem services and a valuation study for coral reef-based tourism and recreation in Puerto Rico. Ridge to Reefs Inc., Protectores de Cuencas, and Puerto Rico DNER are initiating an economic valuation study of a restored Guánica Lagoon.

In summary, the original focus to protect coral reefs, through the process of stakeholder engagement, led to elucidation of several potential decisions—a broader portfolio—reflecting stakeholder values in agriculture, water supply, fisheries regulations, habitat restoration, public health, environmental stewardship and support for eco-tourism.

7.5 Guiding strategic thinking

Strategic thinking (Keeney 1992) is characterized by consideration of core values that are not likely to change over the long term and that can influence a number and variety of decisions. Higher-level values, such as equality, justice, quality of life, well-being and respect and care for the land and sea, could be considered strategic objectives because they influence many lower objectives with more specific alternatives. Archival research outlined in **Section 3** demonstrated a long history of decisions that had economic independence and poverty reduction as strategic objectives.

Review of the results from the 2010 Decision-support Workshop and several associated documents led Carriger et al. (2013) to propose maximizing ecological integrity as an appropriate strategic objective for the Guánica Bay watershed and ecosystem-based management (EBM) as the means to achieve that objective. EBM is widely recognized as an approach that considers multiple values across diverse categories of costs and benefits to society and the environment. Diagrams prepared during the workshop clearly indicated diverse concerns of stakeholders, from property values to potential economic impacts from watershed restoration. After the workshop, two figures were prepared to demonstrate the change in perception from a set of management actions to achieve a single objective (restoring coral reefs; **Fig. 7-1**) towards much broader objectives and effects in other parts of the watershed (**Fig. 7-2**). This simple graphic reflects broader strategies to support different economic sectors and human health.

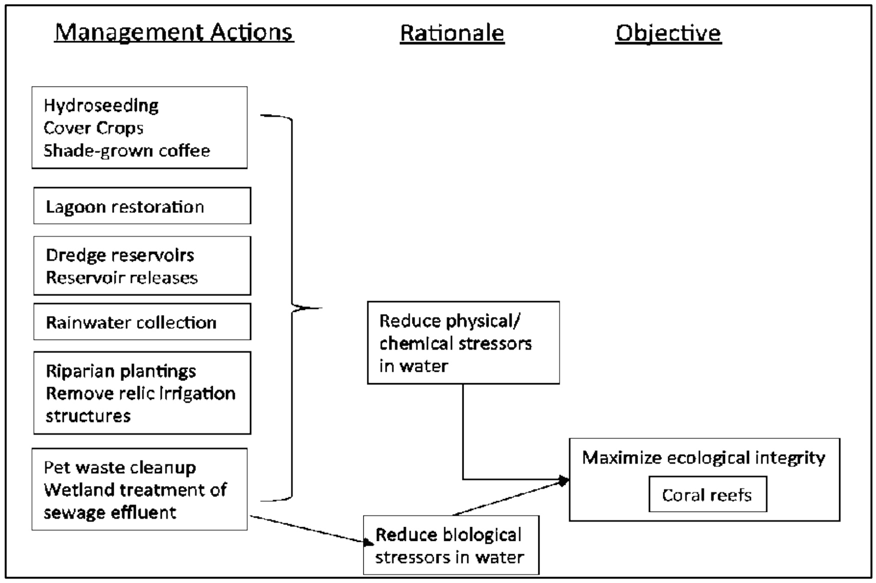


Figure 7-1. The Watershed Management Plan (CWP 2008) graphically illustrating its primary objective of restoring high ecological integrity to coral reefs.

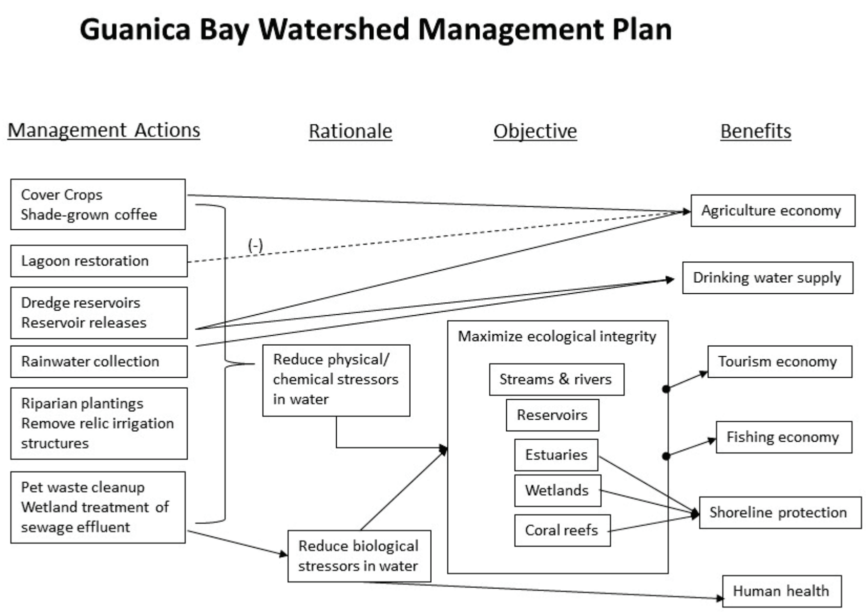


Figure 7-2. Elaboration of objectives and benefits of proposed management actions derived from discussions during the 2010 Decision Support Workshop. The dotted line from lagoon restoration to farmland represents a potential negative impact due to loss of farmland.

One of the key benefits of strategic thinking is the possibility of developing creative solutions that meet multiple objectives, such as a sequential combination of decision options (Gregory et al. 2012). During the Public Values Forum, participants were able to outline such a sequence based on completion of ‘low-hanging fruit’ and progressing through more challenging alternatives.

An encompassing benefit of the structured decision process was the more inclusive context of inter-related decisions and issues. Application of a systems approach (i.e., DPSIR) allowed EPA researchers and stakeholders alike the opportunity to explore interconnectedness, alternatives and possible outcomes. Conceptual mapping (Yee et al. 2011), used in the DPSIR approach, was conducive to transparent community discussion and organization of cause-effect relationships. During these discussions, stakeholders were able to identify things they knew and things they didn't. Analysis of these values and priorities can lead to documentation for supporting strategic objectives and even greater clarity in decisions.

7.6 Creating alternatives

The structured decision process emphasizes a clear distinction between decision-making focused on alternatives (means objectives) and decisions based on values (fundamental or ends objectives). For example, it was quickly evident to workshop participants that phrases such as 'reduce sediment load' were means not ends objectives. Alternatives are made from means objectives and should aim to satisfy ends objectives. Alternatives should be evaluated against ends objective measures. This helps clarifies how alternatives should be created and assessed for decision-making.

Systems thinking and conceptual mapping, as stated earlier, provided a strong impetus for creating alternative paths to achieve objectives. During the 2010 Decision Support Workshop, participants created DPSIR conceptual maps linking coral reef condition to a variety of pressures, driving forces and impacts (e.g., ecosystem services). Through this process they identified alternatives and additions to the WMP (Bradley et al. 2014b). Many of these have been captured in subsequent planning documents (see Carriger et al. 2013). For coral reef protection, some of these alternatives included, among others, establishment of a marine reserve, stronger enforcement of fishing regulations, eradication of marine invasive species (lionfish), and ecological threat responses, installation of mooring buoys, increased volunteer opportunities, creation of green certification programs, and increased learning opportunities.

An interesting outcome of the Public Values Forum accompanied a discussion of the easily implemented decision alternatives (e.g., the "low-hanging fruit"). Representatives of several different stakeholder groups began to realize that many of the alternatives were well within their grasp at the local level and did not require outside authorization or funding. These included alternatives to form partnerships, to inform and educate community members, to interact with government representatives, and to lobby officials in support of local positions.

The consequence table that was framed during the Public Values Forum provides another good example of alternative decisions evolving from the decision process. There was ample recognition among Forum participants that restoration of the Guánica Lagoon supported several objectives related to quality ecosystems, but had potential adverse effects on agriculture. An alternative emerged that allowed for a gradual restoration and monitoring followed by intermittent assessment and a capacity to change direction with new information (adaptive management).

7.7 Additional benefits

There were additional benefits recognized through the application of SDM to Guánica Bay. To be successful, decisions made in the Guánica Bay watershed should be as much a social undertaking as an ecological and scientific undertaking. The engagement of stakeholders in the SDM process helped to gain acceptance and understanding of the management actions proposed to restore the watershed. This will benefit the communities by reducing contention; the stakeholders perceived the SDM process as clear, consistent, and adaptive. Moreover, involving stakeholders early in the process also gets them engaged and excited about implementing the decisions.

The SDM process of engagement brought together stakeholders on a relatively narrow issue at first, which broadened with continued interaction. The stakeholders did not at first view themselves as counterparts in the management process, but the range of discussions led many to begin to consider that a broader management plan with an overarching vision was needed. The process fostered this interaction.

Additionally, the SDM process helped to identify both scientific uncertainty and the stakeholder uncertainty regarding scientific information. This acknowledgement allows the incorporation of these uncertainties into estimates of consequences. The ultimate benefit is that stakeholders are more aware of the likely effectiveness of proposed actions.

The Guánica Bay Watershed was an EPA pilot study to research, develop and test transferable and scalable conceptual frameworks, mathematical models, assessment methods, metrics and indicators that could be used by decision-makers. The approach and lessons learned have provided a foundation for new case studies, including one in San Juan, Puerto Rico. Some of the tools and approaches have already been applied in Culebra (Sturm et al. 2014) and Cabo Rojo (Sturm et al. 2015), most notably workshops to elicit stakeholders' values and develop potential management options.

7.8 Challenges

Despite the success of a formal decision process (SDM) in the Guánica Bay application, there were particular challenges that were not easily or convincingly met. They include:

- Ensuring a broad representation of stakeholders from a complex landscape
- Quantifying and accepting scientific uncertainty
- Inclusion of nonmarket benefits
- Framing tradeoffs in the watershed

With greater experience some of these challenges can be overcome. The SDM process represents a departure from conventional practices and methods of regulatory and environmental management. Most agencies have a defined mission with goals focused on a relatively narrow context—but with consequences ranging across commercial, municipal, social and cultural issues. Engaging communities in systems thinking, value deliberations, goal setting and tradeoff analysis will require a dedicated management force with a thorough grasp of strategic thinking and structured decision-making. This can only come with continued exposure to the process, appropriate resources for workshops and public forums, and dedication to improving the manner and method of engaging stakeholders in balanced resource protection.

The Guánica Bay interagency program highlighted communication and interactions among agencies as another challenge. To improve this interaction, care must be taken to include all potentially affected parties at the very beginning of the program. Any omission can lead to confusion over project goals and can ultimately create unanticipated obstacles to program completion. Parties that enter late into the program should take steps to become fully familiar with the project goals and attempt to assimilate new work into ongoing activities. As the approach becomes more familiar, a better process for agency interaction will undoubtedly evolve.

Perhaps the most daunting challenge is transitioning the process from 'research' into a standard approach for communities and environmental agencies. The decision approach outlined here for Guánica Bay is very comprehensive and incorporates relatively unique concepts that may be difficult for local governing bodies and citizens to embrace. Tools, training and education are extremely important. The process holds great promise for the future of environmental decision-making. Overcoming these challenges is within reach and the benefits are well worth the effort.

7.9 Future research

There are a variety of future research topics that will improve EPA's ability to empower and engage communities in sustainable governance. At the top of this list is a usable framework, described in this report, which will provide a path for supporting watershed and coastal zone economies and provide equitable benefits and costs (market and nonmarket) to present and future generations. The framework is widely applicable to a broad suite of decision-makers and characterized by its flexibility and insight to complex, 'wicked' decision problems (see **Section 1**).

Within this framework, several issues still need to be resolved. Whereas the workshops described in this report generated insightful products (e.g., objective hierarchies, table of consequences), most decisions will require additional information. Of particular interest are:

- Means to ensure stakeholder inclusion and transparency
- Information and models to evaluate uncertainties
- Performance measures for social values (e.g., cultural heritage)
- Evaluating tradeoffs for multiple stakeholder values
- Costs of management actions
- Defining a 'requisite model' (when are we finished?)
- Adaptive Management that triggers points at which to evaluate decision results and revisit the SDM process with new information
- A means to transfer the successful processes to other communities
- A means to transfer the successful processes to actions by individuals, communities and local, PR and federal managers

A values-focused thinking framework applied to watershed protection and restoration issues can bring opportunities to create a management framework that is inclusive and widely supported for achieving objectives and benefits that have greater permanency. Stakeholder support can increase the likelihood for action implementation and prevent delays due to conflicts and ongoing debates. Putting values at the forefront of decision-making brings less contention as the public has greater awareness that agencies are working for the common good. Values facilitate communication, which helps bring understanding and transparency to decision-making. Moreover, understanding the value that can be achieved or lost from decisions can leverage resources in a fashion where learning is explicit, easier to define, and more successfully addresses areas of uncertainty.

In order to be fully successful, the Guánica Bay Watershed Project should be as much a social undertaking as an ecological one. The SDM process described in this report can help to gain acceptance and understanding of the management actions undertaken to restore the watershed. This should result in less contention down the road, since the stakeholders perceive the SDM process as clear, consistent, and adaptive.

Additionally, the ability of the SDM process can deal with uncertainty by identifying uncertainty (both scientific and stakeholder perception) and incorporating that uncertainty into estimates, helps to alleviate concerns about the efficacy of taking action, and therefore increases the likelihood to leading to action.

Watershed restoration is challenging. Getting everyone involved at the early stages of thinking about recommended strategies also gets people excited about helping to implement them later on. The SDM process can be used to develop a resourcing strategy by: 1) identifying the resources currently dedicated to watershed restoration; 2) determining the gaps in funding; and 3) combining and leveraging resources.

Value-focused thinking can help broaden the discussion and set the framework for a participatory process. Stakeholder workshops can provide important information to decision-makers on how stakeholders characterize, define, and consider their wide-ranging values. However, identifying the categories of stakeholders needed for a particular decision context and getting them to the table are challenges. This is a particularly critical issue for complex watershed and coastal zone management issues, where the broader issues generate an almost unending potential for additional stakeholders.

7.10 Afterwards

Conducting decision science research in a real-world decision context has inherent challenges. In the Guánica Bay case study, EPA researchers had to maintain a balance between independence and engagement with the decision-makers and stakeholders. The decision-making environment was fluid: in responding to watershed problems the USCRTF was itself a “learning organization” (Shiffman et al. 2008). The EPA workshops provided a learning opportunity for the Guánica Bay watershed managers, who incorporated the new knowledge into their planning and implementation for the watershed. But the Guánica Bay watershed managers were also holding their own meetings, and they sometimes felt the EPA workshops merely confirmed what they had already learned through their own channels.

Regardless, the point of the EPA research was to provide a utility assessment of tools and approaches that could be used for decision support at the watershed level. Information elicited during the 2010 decision workshop was organized, examined and structured using formal decision science concepts. This information (stakeholder identification, decision context, etc.) provided the foundation for the future EPA research in the Guánica Bay watershed. The Guánica Bay watershed managers subsequently conducted several activities raised during the 2010 workshop (e.g., grounding response program, studies to reduce uncertainties about the lagoon restoration project, and coral nurseries).

All of the workshops showed the importance of fully engaging the stakeholders, and using the stakeholders' values as the foundation for future work. As the USCRTF moves forward into new watersheds, they are adopting principles of structured decision-making and conducting workshops with stakeholders to better understand their goals and objectives before developing watershed management plans (e.g., Cabo Rojo and Culebra). The SDM process described in this report can help to gain acceptance and understanding of the management actions undertaken to restore the watershed. This should result in less contention down the road, since the stakeholders perceive the SDM process as clear, consistent, and adaptive.

The Guánica Bay watershed managers will soon be updating the 2008 Watershed Management Plan. Much of the information gleaned during the EPA research can contribute to the revised plan. It is strongly recommended that the Guánica Bay Watershed Managers also hold additional stakeholder workshops to elicit values, share knowledge and increase stakeholder engagement.

Additionally, the Caribbean Landscape Conservation Cooperative (CLCC) is employing SDM. The tools and approaches described in this report can help the CLCC to more efficiently plan and organize conservation activities throughout the U.S. Caribbean.

Finally, EPA will be conducting a second decision science case study in the San Juan Bay Watershed. Most of the approaches described in this report will be also applied in San Juan to validate their efficacy.

Appendix A. The Guánica Bay Watershed–An Historical Perspective

Spanish Colonization (1508-1897)

The narrow channel and calm waters of Guánica Bay have made it a natural refuge for ships sailing the Caribbean Sea, including those of Juan Ponce de Léon, who landed there when he came to settle Puerto Rico in 1508 (Kent 1992). The native Taíno Indians called the island *Borikén*. Christopher Columbus, who came ashore in 1493, renamed the island *San Juan Bautista*. Ponce de Léon's exploration and settlement of the island began in Guánica Bay where the village of Guainía (Guainía = "*a place with water*") was established (**Fig. A-1**). At the time, Guainía was the Taíno political and socioeconomic center (Silvestrini and Sánchez 1988). The settlement was destroyed in 1511 during an uprising of indigenous Taínos. Interest in Guainía faded as the Europeans recognized better fortifications could be established in the northeast at San Juan (then called *Porto Rico* by the Spaniards). The island was renamed Puerto Rico in 1521 with San Juan the capital, as it remains today. Guainía would later become its own municipality with the name Guánica (1914), from which the Bay inherited its name.

Figure A-1. Paintings of Christopher Columbus and Juan Ponce de León (photo credits: left – original painting at the Metropolitan Museum of Art, Sebastiano del Piombo, 1519; right – anonymous sixteenth century portrait).

During the Spanish colonial period, the economy of Puerto Rico, and that of the Guánica Bay area, was shaped by agriculture (e.g., tobacco, coffee and sugar cane farming). Early agriculture was subsistence only. Spanish rule was restrictive of trade, requiring all imports and exports to go between San Juan and Seville, Spain (Carrión 1983). Such shipments from Seville could be sparse, at times with none for years at a time, so a significant quantity of goods were smuggled and traded illegally with other nations and their colonies. Sugar was introduced to Puerto Rico in the early 1500s and many small landowners began to rely on its export as a source of income. By the middle of the 16th century there were many sugar mills in operation and sugar was the colony's greatest export (Dietz 1986). Further growth was limited because sugar mills were capital intensive - relying heavily on slave labor or cheap labor (**Fig. A-2**).

Figure A-2. Workers cutting sugar cane in a field in Puerto Rico (photo credit: American Museum of Natural History).

By 1600 sugar had declined and less resource intensive crops such as ginger and tobacco began to gain popularity. Tobacco was native to the Americas and initially grown mainly for domestic use and later for illegal trade. Tobacco became the dominant product in the mid-1600s, (Carrión 1983). Coffee grown in Puerto Rico was insignificant until 1736, and even then it was grown mostly for personal and domestic use. This changed in the late 1700s when Spain started opening Puerto Rico to foreign markets. With the Haitian Revolution in 1791, Haiti, the largest exporter of sugar and coffee, was removed from markets, increasing prices and encouraging development of both products in Puerto Rico. In the mid-1800s, French immigrants from the Mediterranean island of Corsica settled around Yauco and began exporting the premium coffee for which Puerto Rico is known today (**Fig. A-3**).

Figure A-3. Cigars have been produced in Puerto Rico for centuries (photo credit: Breezy Baldwin).

There were many changes to Puerto Rican society during the Spanish colonial period, including the adoption of Spanish as the native tongue and importation of African slaves to support first gold mining and then labor-intensive sugar cane agriculture. By 1800, Puerto Rico's population was approximately 150,000, about five times greater than in 1700, and most of the people were employed in coffee, sugar or tobacco agriculture (Miller and Lugo 2009).

After nearly 400 years of Spanish rule, many Puerto Ricans desired autonomy. In 1812, Puerto Rico was temporarily elevated by Spain to the status of 'province', which gave it representation for the first time in the Spanish parliament. But this was quickly revoked and replaced with the 'Royal Decree of Graces' (1815), which offered free land to

European settlers. To improve exports of agricultural products, Spain also ruled that all landless and nonprofessional Puerto Rican males must secure employment on coffee farms. Despite this infusion of human capital, coffee farming was very susceptible to hurricanes and other strong storms that battered crops.

Near the turn of the century (1897) Puerto Rico was granted constitutional autonomy and representation in the Spanish parliament. By spring of 1898, under the leadership of Luis Muñoz Rivera, elections for a Puerto Rican legislature were held. But before the new legislature could be seated, events took a dramatic turn.

U.S. Invasion of Guánica Bay (1898)

In February of 1898, just prior to the Puerto Rico elections, the *U.S.S. Maine* exploded in Havana Harbor where it had been sent to aid a Cuban revolt against Spain. Members of the U.S. Congress believed the *Maine* had been sabotaged by Spain. Despite any verification, this led to a decision in April to liberate Cuba, the Philippines and Puerto Rico from Spanish domain through an act of war. On July 25th, over 16,000 U.S. soldiers landed at Guánica Bay (**Fig. A-4**) and began a march to San Juan (Miller and Lugo 2009). The Spanish-American War was resolved quickly in Puerto Rico and elsewhere, and by August Spain ceded Puerto Rico to the U.S. Many Puerto Ricans were outraged that Spain could '*cede'* Puerto Rico when the island nation had only one year earlier been granted autonomy. The Paris Peace Treaty between Spain and the United States was signed in December; it abolished the Puerto Rican parliament and established U.S. military rule for the island.

Figure A-4. A large coral boulder marked with the carved words, "3rd Battalion, 1st U.S.V. Engineers, September 16, 1898", commemorates the invasion (photo credit: Deborah Santavy, EPA ORD).

To many U.S. citizens it seemed that the inhabitants of economically underdeveloped Puerto Rico would be overjoyed at the prospect of association with its new political ruler; the U.S. was an economic giant with a political structure that supported highly successful trade and development. This was viewed as a great opportunity for Puerto Ricans to improve their lot. The perception went beyond purely economic opportunity and was linked to social and cultural progress for Puerto Ricans. As an U.S. observer wrote shortly after the conquest (Wilson 1899): *"Abundant and well distributed as are the various crops, the island produces to but a fraction of its capacity. Thus far there has been no incentive to grow such products as would have value for export, and no means have been available and no forces at work to incite the ambition of the people, and thus give them some inducement to gain a better living. They know nothing of the higher arts of civilization, and if they had more wealth than they now possess they would not know how to use it. With the higher aims which will come from association with the more active, liberal, and highly civilized people of the United States, increased energy may be exerted in the near future in wresting from nature more bountiful and useful crops than are now cultivated."*

Puerto Ricans, on the other hand, were ambivalent about the war's outcome. They had existed under Spanish rule for 400 years and, despite the poverty, lived a simple but reasonably self-sufficient existence. There was no abiding love for the Spanish who lived in Puerto Rico; they had dominated Puerto Rican native populations and set up feudal systems to reinforce Spanish wealth and political standing. But there was also a shared language and a generally accepted way of life. The U.S. presence offered the potential for democracy, economic progress, and possibly a future free of poverty. But Puerto Ricans were still unsure about their autonomy and the likely changes to their existing cultural and political structure with this new and powerful ruler.

The Foraker Act (1900)

Under U.S. influence, Puerto Rico quickly underwent many changes. In 1900 the Foraker Act (formally known as the Organic Act of 1900, signed by President McKinley) was imposed, replacing the military regime with a civil form of governance. It held that:

- The U.S. President appoints a Governor and an 11-member Executive Council
- A U.S. District Court is established and the U.S. selects justices
- Puerto Rican citizenship is established (similar to, but not U.S. citizenship)
- All federal U.S. laws go into effect
- Puerto Rican laws are subject to veto by the U.S. Congress
- Trade treaties with other countries are nullified

- Trade with the U.S. is tariff-free and Puerto Rico pays no taxes
- The Puerto Rican peso is retired at 60¢ per U.S. dollar

Retiring the peso at such a poor exchange rate resulted in a 40% increase in cost of living in Puerto Rico and opened the door for U.S. investors to make vast, inexpensive land purchases for sugar cane production. This required skirting a provision of the Foraker Act that limited land ownership to 500 acres. Initially, the new investment was positive for the economy, but Puerto Ricans were engaged almost exclusively as manual laborers and were largely excluded from profits and ownership.

Jones-Shafroth Act (1917)

In 1917, the U.S. Congress passed the Jones Act (Jones-Shafroth Act, signed by President Wilson), which granted U.S. citizenship for all Puerto Ricans born in the island and provided unrestricted entry to the U.S. mainland. It also reformed the government, providing a 2-house legislature based on the U.S. model and a Bill of Rights. The Governor was still selected by the U.S. President but could now veto legislative actions. As a consequence of the Jones Act and the Selective Service Act passed two months later, 18,000-20,000 young Puerto Rican males were conscripted into the U.S. military to serve in World War I.

The heavy U.S. investment in sugar cane began to pay off by the 1920's when sugar became the main export crop. For Puerto Ricans, however, sugar cane provided a static monoculture economy that employed roughly ¾ of the islands population at extremely low wages (about 63¢ a day). Moreover, the effort came at the expense of other economic sectors that were not developed nor incentivized. Because of low wages, other means of employment were needed for families to survive, but additional employment was unavailable. The German blockade during World War I created a demand for cloth and linen, so many Puerto Ricans took up sewing (needlework). By 1933 over 40,000 families, mostly the women, were employed in low-wage garment production (**Fig. A-5**). This sustained many Puerto Rican families, although at poverty levels, for several years (Silvestrini and Sánchez 1988). As an illustrative economic contrast, the Federal Labor Standards Act was passed in the U.S. in 1938, setting minimum wage at $0.25 an hour. These wages were unsustainable for needlework in Puerto Rico—needlework paid only 3-4¢ per hour—so Puerto Rico requested and received a temporary exemption from this federal law. Per capita income for Puerto Ricans at this time was about $100 a year.

Figure A-5. Women working in a garment factory in San Juan, Puerto Rico in 1942
(photo credit: Jack Delano, Library of Congress).

The New Deal (1933)

President Roosevelt and his New Deal administration created the Puerto Rico Emergency Relief Administration (1933) to establish rural resettlement communities and demonstration farms hoping to make coffee and fruit farming more profitable. At about the same time, the Jones-Costigan Act (1934) was enacted to limit the amount of tariff-free sugar imported from Puerto Rico—this was an attempt to balance sugar imports from foreign (mostly Cuba) and domestic producers like Puerto Rico. But like the Foraker Act, large sugar companies were able to ignore the Act and by 1938, 50 U.S. companies owned over 250,000 acres of Puerto Rican sugar farms and over 90% of the sugar produced was sold in the U.S. market.

The U.S. Department of Agriculture eventually ceased sugar subsidies (lower taxes, lower tariffs) to Puerto Rico and the industry began to wane. Because much of the land that fell out of production was still in U.S. ownership, Puerto Rico was forced to import most of its food from U.S. markets. Prices were held artificially high by U.S. tariffs, so the island became more and more indebted and dependent. The land monopoly was not broken until 1941, when the Land Reform Act limited (once again) ownership to 500 acres. By this time, however, there were few Puerto Ricans who could afford to buy land.

Appendix B. Guidance for Selecting the Decision Context and Developing the Decision Landscape

Selecting the Decision Context

The *decision context* is the problem, issue, or reason for making a decision. The decision context can be narrow (*decrease nutrient loadings from a wastewater treatment plant*) or broad (*achieve a sustainable watershed*), but the context must be relevant to the decision-making potential. For example, the narrow case above (nutrient loadings) must have some potential for nutrient management within the available options; and the broader case (sustainable watershed) must have some potential for influencing socio-economic policy.

Those facing the decision and those with factual knowledge about the decision typically set the decision context. For example, a government agency is deciding whether some proposed activity should be approved. The agency, the proponent (often a private resource-development company) and community or environmental groups outline the decision context. The decision context may be adapted and refined throughout the ensuing process, but a well-thought initial attempt will save later controversy and challenge.

It is important to ensure that the decision context is sufficiently broad that all stakeholders can agree on the context (Brown 1984). Disagreements tend to occur when the initial statement of the decision context explicitly or implicitly excludes objectives or alternatives that some stakeholders consider important (Gregory and Keeney 1994).

Developing the Decision Landscape

The Decision Landscape documents the relevant legal, institutional, and social factors affecting a decision. The decision landscape is drawn from the decision context. It includes some knowledge of issues surrounding the context and should include:

a) Scale of the decision—how big an area, how long a time, how many communities will it affect?

b) Fact (science) knowledge—what is known about relationships between pieces of the decision puzzle, i.e., effects of stressors and potential benefits of reducing them?

c) Current condition—what is the status of the issue and why is a decision needed now instead of later?

d) Unintended consequences—what else, other than its intended purpose, will the decision affect?

e) Decision-makers—who would be making the decision or components of the decision? Who would be funding the actions if decisions were made? Who authorizes the different steps of a potential action?

f) Stakeholders—who will be affected, both positively and negatively?

g) Legal status—who owns or is responsible for property that might be altered by decisions? What laws are applicable and who is responsible for enforcing them?

h) History—what have past decisions been and how did they lead to the existing situation? Are there planning or visioning documents in place relevant to the issue?

The decision landscape can be characterized in a variety of ways. A graphic representation or flow chart of the issue to be resolved and the likely effects of different decisions could be very useful to organizers as well as workshop participants. One organizing concept that is commonly used is the DPSIR (Driving Force, Pressure, State, Impact, Response) framework, which promotes a comprehensive 'systems' approach. Another possibility is an issue or 'white paper' that briefly characterizes the decision landscape. The issue paper could include a DPSIR diagram. Any materials that will help workshop participants understand the most relevant aspects of the decision context will be useful.

Systems Thinking and the DPSIR Framework

The DPSIR Framework can help us inform decisions by organizing the decision context from a systems viewpoint, that is, considering the effects of different decision options beyond the immediate purpose. In its simplest form DPSIR relates:

- Driving Forces: human needs (sometimes thought of as fulfilled by economic sectors)
- Pressures: human activities to fulfill needs that stress the environment
- States: changes in the condition of the environment
- Impacts: effects of a change in state on ecosystem services
- Responses: reactions to losses of ecosystem services

A DPSIR tutorial http://www.epa.gov/ged/tutorial/index.htm provides a step-by-step process for generating a DPSIR tool. (See Fig. B-1).

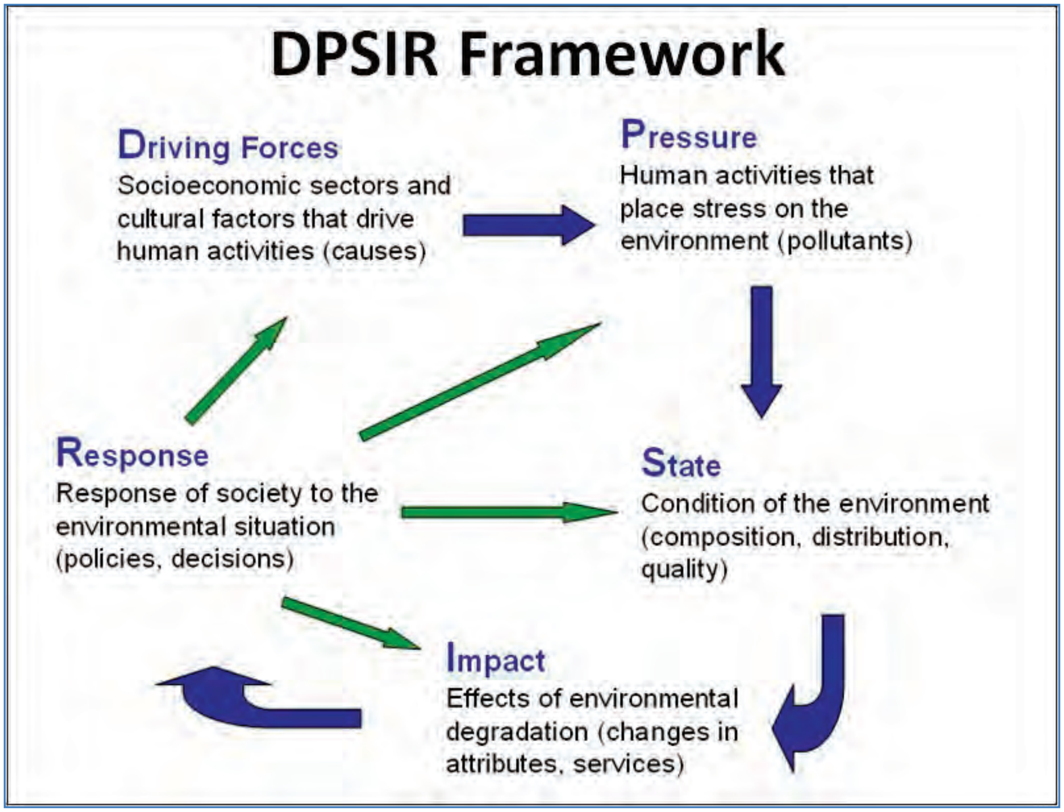


Figure B-1. The DPSIR (Driving Forces, Pressures, State, Impacts, Responses) framework (source: Bradley et al. 2014c).

The basic steps to building a DPSIR concept map are to:

- Define the system, problem, or management concern
- List key concepts or keywords related to the concern
- Determine concepts or keywords that are linked uphill (causing the problem) or downhill (result from the problem) to the central topic.
- Continue building uphill/downhill until all five sections of DPSIR are filled with relevant, linked concepts

The flexibility of the DPSIR framework allows the initial concept to be anywhere within DPSIR, depending on the specific economic, ecological, or management concerns of the decision maker. Although starting with a narrow set of concerns, framing the problem within DPSIR encourages the decision-maker to adopt a systems approach, and think about the uphill and downhill challenges to the problem within the larger system.

The process of creating a conceptual model allows decision-makers, stakeholders, or scientists to characterize major stressors, interactions, and tradeoffs related to an issue, or to brainstorm alternative decision options. The DPSIR Framework provides a scaffold to help guide discussion, and ensure key concepts (e.g. economic driving forces, human well-being, and decision options) are not overlooked. Questions can be used to guide discussion, stepping through each DPSIR category to elicit information toward building a conceptual model for the given issue under consideration.

Discussion Questions:

- ***Driving Forces:*** What are the key Economic Sectors (e.g. transportation, construction, tourism, fisheries) in the community, watershed, or region that may be creating pressures on the environment?
- ***Pressures:*** What human activities (e.g. overfishing, automobile emissions, wastewater discharges, landuse changes) may be creating pressure on the environment?
- ***State:*** How do human activities affect the Environmental State, including the condition of the abiotic environment (e.g. contaminants, sediment, water temperature) or living biota (e.g. forests, wetlands, birds, invasive species)?
- ***Impact:*** What do humans gain from the environment in the form of Ecosystem Services (e.g. fisheries production, shoreline protection, recreational opportunities, drinkable water)?
- ***Trade-off Driving Forces:*** What are the costs of loss or benefits of ecosystem services to the economy or society? What Economic sectors may be most strongly impacted by changes in ecosystem services?
- ***Response:*** What actions or Responses can be taken to affect driving forces, pressures, state, or impact?

An example DPSIR framework linking watershed and coastal activities to coastal ecosystems is shown below (Fig. B-2) (source: Yee et al. 2014a).

Archival Research

Archival research is a type of primary research that involves seeking out and extracting evidence from original archival records. Archival research is an approach that can provide much of the information needed for the Decision Landscape.

Planning

Before starting the research, the researcher(s) should determine the decision context. This includes:

- The geographic area(s) of concern
- Key historic decisions
- Research questions or issues to be addressed with respect to each historic decision
- Previous research known to have been done on such issues
- The amount and kind of information expected to be needed to address the decision context

- The types of sources to be used
- The types of methods to be used
- The types of personnel likely to be needed
- Where possible, expectations about what will be learned, or hypothetical answers to major research questions.

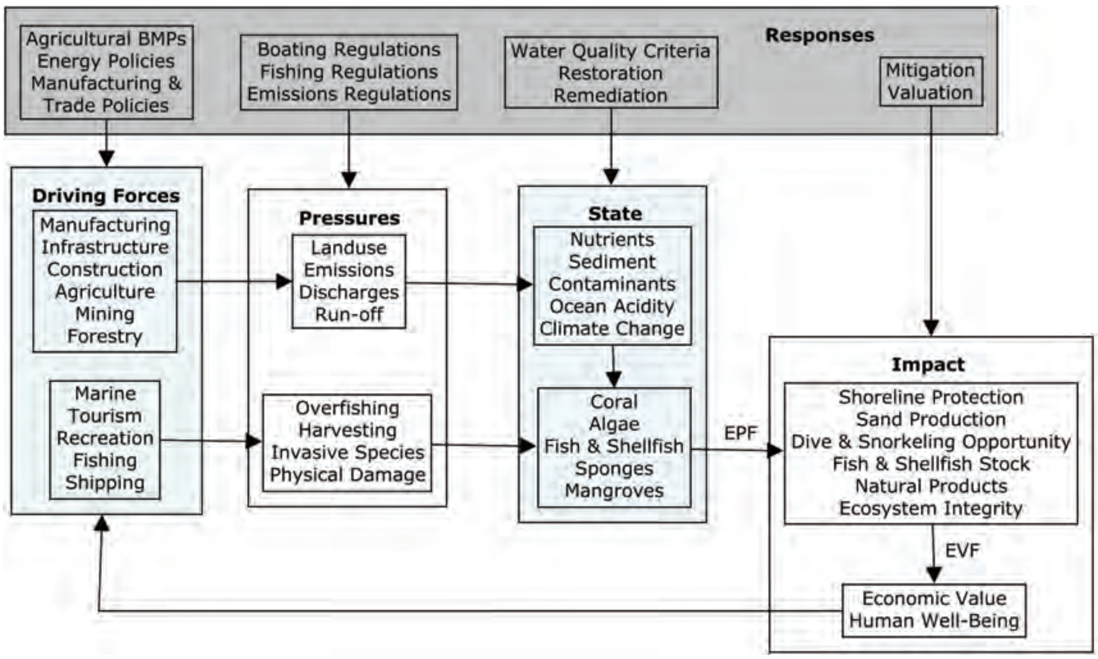


Figure B-2. Example DPSIR framework linking watershed and coastal ecosystems (source: Yee et al. 2014a).

Primary Sources

Primary, or original, sources include actual material that has been preserved from the period of interest: written or published documents and graphic material, as well as the artifacts themselves. Examples of archival records include:

- Government files and records
- Graphic material (plat maps and other historical maps, old photographs, bird's-eye views, and historical prints)
- Back issues of local newspapers and periodicals
- Family papers and records, including keepsakes, letters, and personal diaries, ledgers, canceled checks, and receipts
- Accounts of travelers and early ethnographic accounts
- Industry and business records
- Census reports, deeds and wills, tax rolls

Secondary Sources

Secondary sources are those written by individuals who have studied and interpreted the available original sources. They generally provide a broad overview of the community's history but represent a later interpretation rather than a contemporary record of events or reflection of the spirit of the times. Secondary sources include:

- Local, regional, or State histories: monographs, pamphlets, or other material prepared by local or State historical societies or other groups concerned with particular aspects of State or local history (genealogical societies, e.g., although researchers should be aware that the concerns of genealogists may not be directly related to the issue of establishing the significance of resources).
- Anthropological and sociological works that provide theoretical models of prehistoric and historic social systems, economic systems, and settlement systems, on a regional, national, or worldwide context, that may be relevant to the historical contexts of the community.
- Dissertations, theses, and other research papers on the history and prehistory of the area, available in college and university departments of history, anthropology, and archeology.
- Reports of oral history projects carried out by local universities, colleges, secondary schools, and community organizations.
- General works on the geology, geomorphology, ecology, environment, and land-use history of the region, which may help researchers understand natural constraints on, and results of, trends in the use of land and other resources in and around the community.

Where to find primary and secondary information

- Libraries
- Archives or public records at the local county courthouse or town hall
- Universities and colleges (libraries, faculty members, collections, special research units)
- Museums (artifacts, records)
- State and local historical societies
- Local historic preservation or landmark commissions
- State, regional, and local archeological societies
- State and National Parks (archives of historical information)
- The National Archives

- The Library of Congress
- The National Cartographic Information Center (U.S. Geological Survey, Department of the Interior, Reston, VA 22091)
- Federal agencies, state and territorial agencies
- Planning and development offices of local government or regional intergovernmental organizations
- Non institutional sources (local industries and businesses, newspapers, Neighborhood organizations, residents)

Oral history

Much of a community or neighborhood's history may not be on record anywhere, but may be richly represented in the memories of its people, and its cultural and aesthetic values may be best represented in their thoughts, expressions, and ways of life. For this reason, it is often important to include an oral historical or ethnographic component in the survey.

Oral historical and ethnographic research must be planned and carried out with the full knowledge and cooperation of community and neighborhood leaders and with sensitivity to their cultural backgrounds, values, and modes of expression.

Typically, oral historical or ethnographic researchers meet at regular intervals with members of the community, individually or in groups, to discuss the history and other cultural aspects of those parts of the survey area currently being studied or soon to be studied in the field. It is also often useful to drive or walk through the survey area with knowledgeable residents of the community to obtain their comments on specific properties and areas.

Unless informants object, sessions should usually be tape-recorded so that written descriptions can be transcribed and correlated with other survey information. In order to ensure accuracy of the transcripts, and to respect the confidentiality of informants, those interviewed should be given the opportunity to edit tapes or transcripts. To ensure maximum accuracy, verification of informants' accounts should be sought through interviews with multiple individuals and members of different groups, and through comparison with documentary and field survey data.

Appendix C. 2010 Coral Reef and Coastal Ecosystems Decision-Support Workshop Participants

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Appendix D. 2010 Coral Reef and Coastal Ecosystems Decision-Support 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) Garcia-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 breakout 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: Positive perception from group that Day 1 was beneficial, anticipation of Day 2, and revised exercises completed by morning to assist in the Day 2 sessions.

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

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 breakout 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

Appendix E. 2012 Decision-Making Workshop Agenda

Goal: To evaluate how decisions are made on the use and management of natural resources in the Guánica Bay watershed.

DAY 1 - Understand the Decision-making Process and the Use of Information for Decision-making

9:00 **Introduction**

Process: Welcome participants; introduce the overall purpose of the workshop; and get to know who is attending/who they represent/what their main interests are.
Desired Outcomes: Relaxed, friendly atmosphere.

9:30 **Decision-making structure**

Process: In a facilitated discussion, identify the agency that regulates in some form or manner resources and activities in the Guánica Bay Watershed.
Desired Outcomes: A shared understanding of resource management in the Guánica Bay Watershed.

10:30 **Education and outreach**

Process: In a facilitated discussion, identify the education and outreach efforts provided by the various agencies (federal, territorial, municipal, local).
Desired Outcomes: A shared understanding of available education and outreach available in the Guánica Bay Watershed.

11:30 **Break**

12:00 **Priorities for Guánica Bay**

Process: In a facilitated discussion, prioritize various topics. Reach consensus on the most important priorities, and identify who is responsible.
Desired Outcomes: A prioritized list of top priority actions for the Guánica Bay Watershed.

1:00 **Lunch**

1:30 **Research and Development**

Process: In a facilitated discussion, identify which types of research are being conducted in the Guánica Bay Watershed, who is conducting the research, and who is paying for it.
Desired Outcomes: Shared understanding of ongoing research in Guánica Bay Watershed.

2:30 **Environmental decisions not made (missed opportunities)**
Process: In a facilitated discussion, identify historic decisions on environmental concerns/problems that were not made. Determine reason(s) and who should have made those decisions.
Desired Outcomes: Shared understanding of missed opportunities, responsibilities and rationale.

3:30 **Transparency and Access in Guánica Bay**

Process: In a facilitated discussion, identify the level of transparency (information and outreach about the process of decision-making) on environmental problems/urban infrastructure issues in Guánica Bay. Discuss the barriers and problems with achieving transparency in decision-making in the Guánica Bay Watershed.
Desired Outcomes: Shared understanding of transparency in decision-making.

4:30 **Questions and wrap-up**

Process: Each participant completes the exercise individually, answering the following questions:
- What is the interaction between you and Decision-Makers?
- What would you say works best in terms of the process of decision-making?
- What are some of the problems in the process of decision-making you would address if you were in charge?
- Any comments on today's workshop?

Desired Outcomes: Participants reflect on the day's exercises and provide feedback to EPA.

5:00 **End of Day 1**

Day 2 – Understanding Preferences and Trade-offs in Decision-making

9:00 **Introduction**

Process: Facilitator reviews the agenda and addresses any issues or topics that workshop participants feel should be revisited.

Desired Outcomes: Participants are engaged and ready for day 2.

9:30 Agencies making Investments

Process: In a facilitated discussion, determine which sector of governance (private/government or NGO) invests (commits financial or man-power efforts) on the various activities and natural resources in Guánica Bay.

Desired Outcomes: A shared understanding of investments currently being made in the Guánica Bay Watershed.

10:30 Recommendations for Investments

Process: In a facilitated discussion, identify and prioritize topics (activities, and natural resource conservation issues) for investment (financial or man-power).

Desired Outcomes: A prioritized list of investment opportunities.

11:30 **Break**

12:00 Causes of degradation in Guánica Bay Watershed

Process: In a facilitated discussion, identify the various causes of environmental degradation and who is responsible for the degradation.

Desired Outcomes: A shared understanding of who is causing environmental degradation in the Guánica Bay Watershed.

1:00 Lunch

1:30 Non-market valuation of Guánica Bay

Process: In a facilitated discussion, discuss the various environmental non-market goods and services available in the watershed. Describe the benefits and importance of each. Reach consensus on a relative ranking of the non-market goods and services.

Desired Outcomes: A shared understanding and relative ranking of the environmental non-market goods and services in the Guánica Bay Watershed.

2:30 Cost-Benefits/trade-offs in Guánica Bay

Process: Working with a partner, use the worksheet to analyze a list of management actions, and how the costs would compare to the benefits.

Desired Outcomes: A shared understanding of costs vs. benefits for various management actions.

3:30 Economic Development

Process: In a facilitated discussion, discuss the economic sectors in the Guánica Bay Watershed. Discuss why a given sector should be developed, how, and by whom. , Assign a priority for economic development (low, medium, high), as well as a rationale.

Desired Outcomes: A prioritized list of potential areas for economic development with documented rationale.

4:30 Questions and Wrap-up

Process: Each participant completes the exercise individually, answering the following questions:

- What is the interaction between you and natural resources?
- What would be something you would change in the way decision-makers manage the use of natural resources?
- What are some of the problems you would address, and how?
- Comments on today's workshop?

Desired Outcomes: Participants reflect on the day's exercises and provide feedback to EPA.

5:00 End of Workshop

Process: Facilitator thanks participants and reviews how the workshop results will be used.

Appendix F. 2012 Decision-Making Workshop Participants

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Appendix H. Guidance and Sample Agendas for Public Values Forum and Objectives Workshops

A workshop or series of meetings is one way to engage the community but must be well organized, with clear goals. The primary purpose of the workshop(s) is to identify and understand the values (objectives) of the stakeholders. An iterative process to elicit and organize objectives, generate decision alternatives, and summarize effects of decision alternatives on multiple objectives will serve to identify, refine, characterize and reinforce knowledge of stakeholder values.

Workshop Invitees

Potential workshop participants should be selected to represent those who are most likely to be affected by the decision context. It is useful to develop a balanced list of stakeholder categories (interested and affected parties) to vet with your key stakeholders. Having a balanced list of categories and balanced representation avoids preferential selections, intended or otherwise, and is critical to eliciting a variety of viewpoints and objectives. Invitees should be trusted to speak for their peers. Balanced participation by multiple stakeholder groups will lend defensibility and relevance to the outcome.

Although the specific categories of stakeholders for a given engagement process will be largely dependent on its goals and objectives, a typical generic profile of stakeholders may be categorized into the following types:

- Government agencies
- Industry or sector representatives
- Research (e.g. scientific, technical specialists) or academic institutions
- Special interest groups
- Resource users (e.g., hunters, fishers, bird watchers)
- Members of the general public or community at large who are impacted by the decision or have an interest in the outcome of the decision

There are several things that can be done to engage participants and stakeholders before the workshop. At the least, participants should be informed of the decision context and provided some of the more relevant background material assembled to describe the decision landscape. They could also be told why they were selected, i.e., which particular occupation or interest group they are representing, and asked whether they are the best representative for this group. They can also be informed about what is expected of them and asked to begin thinking about, even writing down, some of their objectives regarding the issue.

Sample Workshop(s) Agenda
Workshop #1: Public Values Forum

Goal: to produce ***one*** common set of objectives that everyone agrees will be used to evaluate alternatives.

9:00 Welcome and Introductions

9:15 **The Decision Context** (four invited presentations)

Purpose: To provide participants a common factual base relevant to the decision context.

Process: The facilitator will introduce each speaker. Each talk will be 30 minutes. An unbiased presentation of existing management plans or of a systems framework (e.g., DPSIR) could be used to tie together different factors. A 30-minute facilitated question and answer session will follow the talks.

12:00 **Lunch**

1:00 Stakeholder Values

Purpose: To provide participants an opportunity to individually generate a list of values.

Process: Once the stakeholders have an understanding of the decision context, participants are given time to independently write down what is important to them relevant to the decision context (e.g., their values). Stakeholders can be asked to generate objectives from their personal perspective, from the perspective of the group they represent (institutional) and from a societal perspective.

This can be framed by open-ended questions or prompts, such as (Keeney 1992):

- What are we trying to achieve?
- What concerns are we trying to address?
- What are the specific issues or concerns you'd like to see addressed?
- What do you think should happen?
- What criteria can we use to compare alternatives?
- What would make a great (or terrible) alternative? Why?

Objectives consist of a statement of the thing that matters and (sometimes) a verb indicating the preferred direction of change.

1:30 **Brainstorming Objectives** (Breakout Groups)

Purpose: Each breakout group will develop a simple, concise list of objectives that captures all of the ideas from the members of the group

Process: Participants are assigned to breakout groups (6-8 members). The breakout groups can be organized based upon the stakeholders' expertise, around a particular aspect of the decision context, or for comprehensive representation. Each breakout group will have a facilitator/note-taker.

The stakeholders share their objectives with others in the group, and work on developing a comprehensive list that includes everyone's objectives. There are no 'wrong' objectives so all suggestions should be included. The group can merge objectives if everyone agrees the result accounts for all the ideas. The facilitator can assist by ensuring all perspectives are being heard, spurring new ideas, and helping to define the objectives being discussed.

Next the group will turn their brainstormed list into a set of simple, concise objectives. Objectives should state the thing that matters and the direction you'd like it to move (Mollaghasemi and Pet-Edwards 1997; Dunning et al. 2000; McDaniels 2000; Keeney 2007; Gregory et al. 2012). Use the terms 'maximize' and 'minimize' to clarify the preferred direction of change (e.g., more or less is better).
For example, objectives for addressing threats to coral reef ecosystems from exposure to pollution may be to:

- Minimize point source pollution discharge in coastal waters
- Minimize nonpoint source pollution discharged to coastal waters

Key Ideas:

- Objectives only need to state the thing that matters, and what direction you'd like it to move.
- Make sure all objectives have a single, clear direction that can be understood by everyone.

4:30 **Master list of objectives**

Purpose: Develop a master list of objectives.

Process: When the groups are brought back together, each group reports their list of objectives and a summary of the group's discussion. When all groups have reported, the workshop facilitator creates a master list. Redundant objectives from different groups can be merged if the result accounts for all the ideas.

5:00 **End of first workshop**

Between Workshops 1 and 2

Facilitators examine the list of objectives generated during the first workshop to formulate questions for better understanding, edit objectives into a common format, propose further merging of objectives as appropriate, and form preliminary groupings of objectives by topic. The edited list will be presented to the participants at the next meeting.

Workshop #2: Developing an Objectives Hierarchy

9:00 **Welcome and Introductions**

9:30 **Review 1st Meeting**

Purpose: Provide a review of the first meeting and present one common set of objectives that everyone agrees will be used to evaluate alternatives

Process: The facilitator will present a review of the first meeting, including an overview of the decision context, important aspects of the decision landscape, and development of the master list of objectives. Participants should be given an opportunity to review the master list, especially if facilitators have proposed changes. Participants should also be given some time to consider additional objectives.

10:30 **Review and Organize Objectives**

Purpose: Participants will separate objectives into fundamental objectives (which reflect the ends we are trying to achieve) and means objectives (which are important ways of achieving them).

Key concepts:

- *Fundamental* objectives are the outcomes or *ends* you really care about, no matter how they are achieved.
- *Means* objectives refer to particular ways of achieving the fundamental objectives.

Process: The facilitator will present a preliminary breakdown of the master list into major topics. This will vary with the decision context but the number of topics should be aimed at the number of subgroups that can be formed. Breakout groups can be selected as those most interested or with expertise in the topic or by equal representation of stakeholder categories, as noted above.

Prior to breaking into small groups, the facilitator will give a simple example of the process, such as the one provided by Compass Resource Management (2015) on their Structured Decision Making website:

Participant: “We should increase the reed coverage of the lake from 10% to 20%”

Facilitator: “Why is that important?”

Participant: “To provide habitat for dragonflies and other insects and to provide cover”

Facilitator: “Why is that important?”

Participant: “Because dragonflies are an important food source for fish, and the cover reduces predation”

Facilitator: “Why is that important?”

Participant: “Because we want to protect native fish from extirpation”

Facilitator: “Why is it that important?”

Participant: “Because — it just is!” (Fundamental objective reached)

Presentation of one or two examples of this type of organization should suffice.

Breakout groups should be given time to organize the objectives that fall within their topic area. Organizing the objectives may lead to introduction of new objectives or refinement of existing objectives. Good objectives are:

- Fundamental
- Complete
- Concise
- Sensitive
- Understandable
- (Preferentially independent) (Gregory et al. 2012)

To clarify and structure objectives, the facilitator will ask three questions:

- *Why is this important?*
- *What do you mean by that?*
- *How do I achieve this?*

The breakout groups should be asked to document by text or graphics the organizational scheme. A good tool to document the organization is an influence diagram (or means-ends diagram). The influence diagram visually shows the relationship between fundamental objectives (ends) and management actions (means) (**Fig. H-1**); illustrates where and how stakeholder values are addressed; and forms a starting point for identifying evaluation criteria (Gregory et al. 2012).

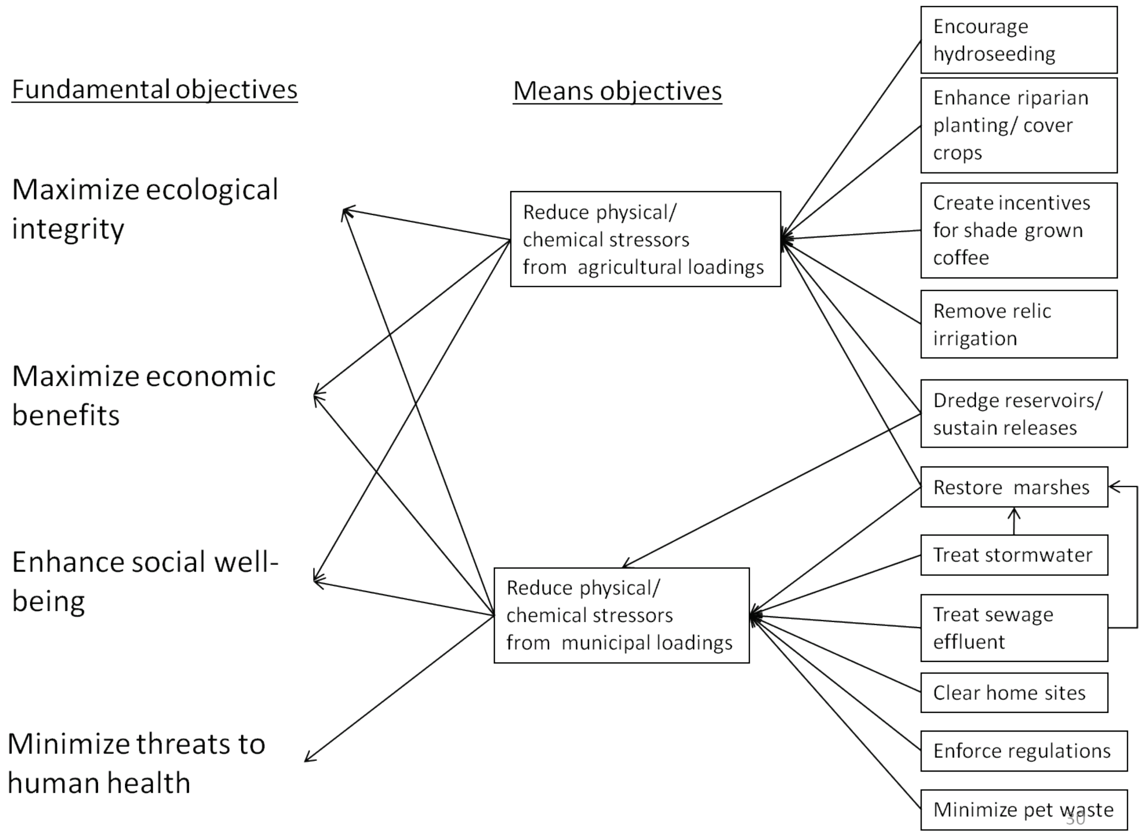

Figure H-1. An influence diagram is a tool to separate means and ends. In this example, the ends are shown to the far left, and the means are to the right.

The breakout groups should be asked to focus attention on decision alternatives for objectives, particularly on lower-level objectives that are more likely to have clear implementable options that can be measured. Achievement of higher-level objectives is likely to occur from the aggregation of completed objectives at lower-levels.

The group should also identify process and strategic objectives. For example:

- Fundamental – Maximize air quality
- Means – Minimize industrial emissions
- Process – Maximize public involvement in the process
- Strategic – Be consistent with departmental vision

12:00 **Lunch**

1:00 **Objectives Hierarchy**

Purpose: Breakout groups each develop an objectives hierarchy to group similar objectives.

Process: The facilitators will lead the breakout groups in developing an objectives hierarchy (**Fig. H-2**).

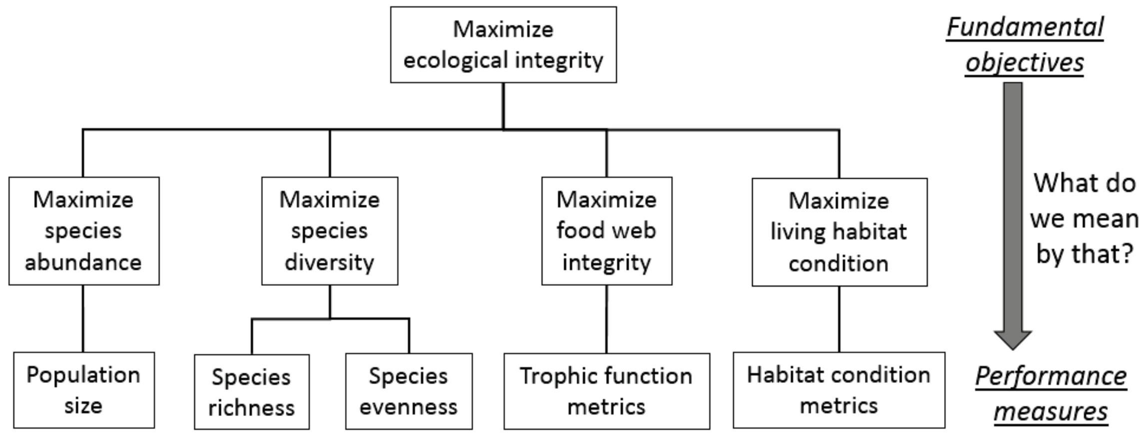

Figure H-2. Example objectives hierarchy for one of the proposed fundamental objectives from the Guánica Bay Watershed (Carriger et al. 2013).

Any objective may have different interpretations depending on the decision context. Through this hierarchy you have defined exactly what you mean by each fundamental objective for this context. With the objectives hierarchy, you have defined all the important elements that can be affected by this decision.

After completing the objectives hierarchy, the participants will next discuss performance measures for each ends objective. Some performance measures may have already been brought up during earlier brainstorming sessions (e.g., influence diagram exercises, separating means and ends) and these should be revisited. The group will also brainstorm additional performance measures. Regardless of how a performance measure is identified, there are a few criteria that it should meet to qualify as a good measure. Good Performance measures are (Keeney and Gregory 2005):

1. Unambiguous: the performance measures should not have uncertainty in their portrayal of potential outcomes from the decision
2. Comprehensive: the performance measures should reflect the concerns specified in the objectives
3. Direct: the range of the performance measures should cover the range of potential outcomes from the decisions
4. Operational: the performance measures should have data or modeling capabilities for assessing the impacts of the decisions and be usable in trade-off analysis
5. Understandable: the performance measures should be understandable to all parties

4:30 **Reconvene** large group - breakout groups present their results

Purpose: A merged list of objectives organized by topic and hierarchy, with an accompanying list of decision alternatives and performance measures. The list of decision alternatives will likely include those originally defined in the decision context as well as those generated through discussion of objectives.

Process: The large group will reconvene and each breakout group will present their objectives hierarchies. This will be followed by a facilitated discussion to merge the breakout group objective hierarchies into a single hierarchy.

5:00 **End of second workshop**

Between Workshops 2 and 3

Between workshops, the facilitators should examine the relationships generated by the subgroups for objectives, edit and adapt as necessary and compile them in a common format. The list of decision alternatives should also be coarsely organized and merged as appropriate. All edits and organizational changes must be vetted with the participants at the next meeting.

Workshop #3: Developing and Analyzing Alternatives

9:00 **Welcome and Introductions**

9:30 **Review 1st and 2nd workshops**

Purpose: Bring all participants to a shared understanding of progress to date.

Process: The facilitator presents a review of the first and second workshops, including a brief overview of the decision context and decision landscape, development and organization of objectives and decision alternatives. Participants should be given an opportunity to review all materials, especially if facilitators have proposed changes.

10:30 **Facilitated discussion** - Participants are given an opportunity to review all materials, especially if facilitators have proposed changes.

11:00 **Introduction to estimating consequences and evaluating tradeoffs**

Purpose: To introduce various approaches for estimating consequences and evaluating tradeoffs.

Process: The facilitator will provide a brief introduction and then the participants will complete several exercises that each demonstrates a different approach.

Eliciting objectives and decision alternatives is informative, but simple tools can be used to generate meaningful stakeholder comparisons of different decision options. A *consequence table* and *democratic voting* are two of these tools. A decision-maker looking at results from either tool can see what the stakeholders perceive as acceptable and less acceptable. Acceptable decision alternatives may be low-hanging fruit that could be easily implemented. Less-acceptable decision alternatives may still be worth implementing but stakeholders perceived too many negative tradeoffs (that could be mitigated), too much uncertainty (that might be alleviated with focused research and education), too high a cost (which could require a funding scheme), or confusion over what would be done (which could require improved outreach). Decision-makers can benefit not only from knowledge of those decisions that were supported but also from analysis of those that were not.

Several workshop exercises are possible for evaluating decisions, a consequence table, democratic vote, direct weighting and swing-weighting. All rely on previous discussions and organization of objectives and decision alternatives. The consequence table should precede the other exercises.

11:15 **Exercise 1:** The Consequence Table

Purpose: Complete a consequence table

Process: Through a facilitated discussion, a consequence table is filled out collaboratively by all participants and is intended to summarize what they have presented for objectives and decision alternatives. Facilitators can make this process more efficient by filling in the top row and first column with objectives and decision alternatives, respectively. This is best done with using a screen so that participants can see and consider each matrix addition. Facilitators walk participants through each cell of the matrix to elicit opinions on direction and strength of a decision on each objective.

The consequence table is immediately useful to a decision-maker by summarizing how a decision alternative will affect multiple objectives. It can identify whether decisions benefit or detract from different objectives, and can be used to identify 'low-hanging fruit' (low cost, low complexity, good scientific understanding, and no detraction from objectives). The consequence table begins to prioritize actions and may also provide a sequence, based on timeframes, for implementing decisions.

A consequence table is constructed with alternate decisions listed down the first column and different objectives across the top row. The matrix is filled with coarse rankings that signify strongly positive, weakly positive, neutral, weakly negative or strongly negative. Up, down and horizontal arrows can be used to fill in the boxes. The outcome is a summary of how each decision is expected to affect each objective.

Additional columns added to the consequence table can further characterize the decisions; this could be a column for complexity, short-, medium- or long term action, funding necessity, or more information needed. Similarly, additional rows for objectives characteristics could be added, such as short-term or long-term objective, perceived beneficiaries, or perceived 'weight' in the decision context.

Table H-1. Hypothetical consequence table.

	Objectives						
	A	**B**	**C**	**Complex?**	**Need Science?**	**Need Funds?**	**Time-frame**
Decision 1	↑↑	↓	↔	Low	No	None	Short
Decision 2	↓	↔	↑↑	High	Some	Some	Med
Decision 3	↔	↑	↑	Low	Yes	None	Short
Decision 4	↑	↑↑	↔	High	No	Many	Long
Goal	Long-term	Short-term	Short-term				
Importance	High	High	Med				

Best Practices for Developing Consequence tables (Gregory et al. 2012; Compass Resource Management 2015)

- Use the best available information
    - Predictive models
    - Expert judgment
    - Local and traditional knowledge
- Identify uncertainties
    - Epistemic - incomplete knowledge (e.g., measurement error, systemic error, model uncertainty, subjective judgments, natural variation & randomness)
    - Linguistic - ineffective communication e.g., vagueness, ambiguity, context dependence, under-specificity, indeterminacy)
- Report consequences in consistent terms across alternatives
- Focus on relative performance
- Provide context for interpreting consequences
- Expose key trade-offs
- Refine consequences iteratively

12:30 **Lunch**

1:30 **Exercise 2:** The democratic vote

Purpose: To get a sense of how different potential actions are perceived by the stakeholders. The endpoint of a vote is not to select the best decision but whether decisions are viewed as highly supportable, somewhat supportable, or not supportable.

Process: The participants will break into small groups. During a facilitated discussion, each breakout group will identify 10 top action items. Participants will then vote for the top three from that group of 10 actions.

A major concern with the democratic vote is freedom to choose through anonymity. There are often very controversial sides to an issue and some participants might feel pressure to vote one way or another by strong advocates. One way to provide anonymity is through commercially purchased voting equipment. The equipment consists of hand-held remote controls for each participant and a receiver with software package that can compile and graph the results almost immediately. Otherwise, using secret ballots or some other anonymous procedure is needed.

The results from voting are very useful to decision makers. Voting implies that individual stakeholders, who represent themselves, their institutions and the "*greater good*" of society, and who have been exposed to wide-ranging discussions on objectives, scientific evidence, complexity, and unintended consequences, have formed opinions about different decision alternatives. It is assumed, whether or not a consequence table was generated, that they have taken into account the effects of a decision on all the objectives.

2:30 **Exercise 3:** Direct ranking (source: Compass Resource Management 2014)

Purpose: Each participant will have a list of ordinal rankings that can be compared with the subsequent swing-weighting exercise.

Process: Each participant individually completes this exercise.

1. Using the information in the consequence table, rank the options from #1 (best) to # (worst). More than one option can have the same score.
2. Assign 100 points to any option ranked #1.
3. Score the remaining options based on how well they perform against the option(s) rated #1. For example, if your feel #2 option is nearly as good as the #1 option, assign it close to 100 points. If it is half as good, assign it 50 points. Continue down the list in the ranked order, entering points either the same as or lower than the one before. If an alternative has no value to you, you may assign zero points. All entries must be a whole number between 0 and 100.

Each individual now has both ranks for each option and scores, which indicate the relative value of each option.

Individuals’ scores will be normalized so that they can be compared against other scores. The idea is to show how your initial assessment (Direct Ranking) can change after Swing-weighting (next exercise). It is an evaluation of your consistency and a deeper probe of your preferences. You record results from both scoring methods (described here) and compare.

3:30 **Exercise 4:** Swing-weighting

Purpose: Each participant uses swing-weighting to develop a ranked order in list of performance measures.

Process: Participants each individually complete the swing-weighting task, and may end up with different rankings and weightings. Swing weighting is a useful way to examine trade-offs and is described in more detail in Clemen and Reilly (2014) but summarized below.

Worst and best-case scenarios are first identified using expertise such as knowledge and modeling. Next participants are given **Table H-2** and told to imagine a hypothetical scenario where all of the performance measures are at their worst level. They can then make a decision to “swing” one of the performance measures from the worst to the best level. Their first choice performance measure to swing from worst to best is then recorded and assigned a rank of 1. They can then swing another performance measure from its worst to best level, which is then recorded and assigned a rank of 2. This process continues until all performance measures are swung from their worst to best level and are ranked in the order in which they are chosen from 1 to the number of performance measures.

Table H-2. **Example of how the predicted change in performance measures from the worst-case scenario to best-case scenario (derived from Tables 4-5, 4-6 and 4-7) might be considered in a swing-weighting exercise.** Individuals would assign ranks and weights based on their own values and preferences, here for example, for someone who highly values protecting economic opportunities.

Objectives	**Performance Measure**	***Best-case scenario***	***Worst-case scenario***	***Rank***	***Weight (%)***
Protect and create economic opportunities	*$/hectare of crop production* *$ of jobs created* *Cost of water infrastructure*			1	50
Restore and conserve the land environment	*Index of species biodiversity* *% reduction in soil erosion*	From consequence table		4	10
Restore and conserve the aquatic environment	*Water turbidity* *Diversity of aquatic life* *# of recreation activities* *Hectares forested*			3	20
Promote social & cultural opportunities	*Environmental attitude* *% people connected to wastewater treatment plants*			2	20

Next, the participants are given the opportunity to refine the weights on the performance measures beyond a simple ranking. The rank ordered list is taken and the first measure that was swung, with rank=1, is assigned a value of 100. Each of the other performance measures is then given a number between 0 and 100 to indicate its preference level in relation to the top performance measure. For example, participants might be asked how less satisfying was it to improve cost from one million dollars to zero dollars vs. improving bird species richness from 2 species to 20 species. If they are almost equally important, the second value might receive a score of 80-100. If the second measure is absolutely not as important, it might receive a score of 0-20. Tie values are allowed and a zero effectively indicates no preference for that performance measure.

Next the weights are normalized to add to one. In Table K-2, The weight for $/hectare of crop production is 100/(100+10+20+70)=0.5.

4:30 **Summary of ranking exercises**

Purpose: To show how the participants' initial assessment (Direct Ranking) can change after swing-weighting.

Process: In a facilitated session, the facilitator will capture the individual participants' results in a spreadsheet. The point of the swing-weighting and direct ranking exercises is NOT to quantitatively obtain an "optimal" or a "majority wins" solution. Instead, it is to help guide discussions of how stakeholders feel about tradeoffs using real ranges of possible outcomes (Carriger and Benson 2012). It can help identify possible areas of consensus or identify the reasoning behind potential conflicts, which may need to be explored further. When faced with realistic tradeoffs, it may also expose potential uncertainties where the specified objectives or performance measures are not adequately reflecting stakeholder concerns, or the proposed decision options may need to be combined or refined, as part of an overall iterative process.

In a facilitated discussion, participants will share the results of their rankings, and compare the results of the different approaches. The facilitator will lead the group towards a consensus on priorities or an understanding about the sources of disagreements.

5:00 **Discussion of additional information needs and next steps**

Purpose: Wrap up any loose ends and develop a list of next steps.

Process: Facilitated discussion.

5:30 **End of third workshop**

Appendix I. Glossary

***Acropora cervicornis* (aka Staghorn coral)**. This species of coral has cylindrical branches ranging from a few centimeters to over two meters in length and height. It occurs in back reef and fore reef environments from 0 to 30 m depth. Staghorn coral is found throughout the Florida Keys, the Bahamas, and the Caribbean islands. The northern limit is on the east coast of Florida, near Boca Raton. Since 1980, populations have collapsed throughout their range from disease outbreaks, with losses compounded locally by hurricanes, increased predation, bleaching, and other factors. This species is also particularly susceptible to damage from sedimentation and sensitive to temperature and salinity variation. Populations have declined by up to 98% throughout the range, and localized extirpations have occurred. On May 4, 2006, Staghorn coral was recognized as a threatened species and placed on the Endangered Species List (71 CFR § 89).

***Acropora palmata* (aka Elkhorn coral).** This species of coral is structurally complex with many large branches. These branches create habitats for many other reef species such as lobsters, parrotfish, snappers, and other reef fish. Elkhorn coral was once one of the most abundant species of coral in the Caribbean and the Florida Keys. Since 1980 it has been estimated that 90-95% of elkhorn coral has been lost. Threats to elkhorn coral include disease, coral bleaching, predation, climate change, storm damage, and human activity. All of these factors have created a synergistic affect that greatly diminishes the survival and reproductive success of elkhorn coral. Natural recovery of coral is a slow process and may never occur with this species because there are so many inhibitors to its survival. On May 4, 2006, Elkhorn coral was recognized as a threatened species and placed on the Endangered Species List (71 Federal Register 89 2006).

actors. In Envision, actors are entities that make decisions about the management of particular portions of the landscape for which they have management authority, based on balancing a set of objectives reflecting their particular values, mandates and the policy sets in force on the parcels they manage.

agriculture. Also called farming or husbandry, is the cultivation of animals, plants, fungi, and other life forms for food, fiber, biofuel, drugs, and other products used to sustain and enhance human life (Wikipedia 2015a).

algae. Any of various primitive, chiefly aquatic, one- or multi-celled, nonflowering plants that lack true stems, roots, and leaves, but usually contain chlorophyll. Algae convert carbon dioxide and inorganic nutrients, such as nitrogen and phosphorus, into organic matter through photosynthesis and form the basis of the marine food chain. Common algae include dinoflagellates, diatoms, seaweeds, and kelp.

Alternative-Focused Thinking (AFT). A form of decision-making where decision makers choose from specified alternatives (Keeney 1992).

alternatives. Alternative solutions open to a decision-maker.

Analytic-Deliberative (A-D). A term coined in the risk field to describe characterization processes able to reconcile "technocratic" and "citizen-centric" approaches (Stern and Fineberg 1996). The *analytic* builds understanding by systematically applying specific theories, methods and data that have been developed by technical experts. *Deliberation* is an iterative communicative process where stakeholders confer, ponder, exchange views, consider evidence, reflect on matters of mutual interest, and negotiate to move towards a consensus decision.

anemone. A cnidarian of the class Anthozoa that possesses a flexible cylindrical body and a central mouth surrounded by tentacles (NOAA 2015).

apex predator. An organism at the top of the food chain, relying on smaller organisms for food (NOAA 2015).

archival research. A type of primary research that involves seeking out and extracting evidence from original archival records (Wikipedia 2013).

artisanal fishing. Small-scale, low technology, low capital, fishing practices undertaken by individual fishing households (as opposed to commercial companies) (Garcia 2009).

attenuation. The gradual loss in intensity of any kind of flux through a medium (NOAA 2015).

attribute. Any measurable component of a biological system (Karr and Chu 1999).

autotrophic. Relating to organisms that have a type of nutrition in which organic compounds used in metabolism are obtained by synthesis from inorganic compounds (NOAA 2015).

Bayesian Belief Network (BBN) or Bayesian Network. A graphical probability network in which the nodes represent random variables and the connections describe dependencies between them.

bedrock. Solid rock layers of the Earth's crust which underlie soil and other unconsolidated material such as alluvial sediments.

benthic. Living in or on the bottom of a body of water.

bequest value. Willingness to pay to preserve environmental quality for future generations.

Best Management Practices (BMPs). Management practices (such as nutrient management) or structural practices (such as terraces) designed to reduce the quantities of pollutants—such as sediment, nitrogen, phosphorus, and animal wastes—that are washed by rain from farms into nearby receiving waters, such as lakes, creeks, streams, rivers, estuaries, and ground water.

biochemicals. Chemicals that result from biological and chemical processes in living organisms.

Biological Condition Gradient (BCG). A scientific model that describes biological response to increasing levels of anthropogenic stressors.

biomass. The mass of living tissues in either an individual or cumulatively across organisms in a population or ecosystem (MEA 2009).

bio-prospecting. An umbrella term describing the process of discovery and commercialization of new products based on biological resources.

biota. The animal and plant life of a given region.

biotic. A term applied to the living components of an area.

brainstorming. A group problem-solving technique in which members spontaneously share ideas and solutions.

brooder. In this reproduction mode, only male gametes are released into the water column. The male gametes are negatively buoyant and are transported by waves and current before sinking to the ocean floor. If encountered, the male gametes are then taken in by female coral polyps containing egg cells. Fertilization occurs inside the female coral and produces a small planula. Planulae are released later through the mouth of the female coral at an advanced stage of development so that it is capable of settling onto hard substrate very soon after release. Thus, brooding species generally disperse their larvae shorter distances from the mother colony than broadcasters (NOAA 2015).

carbon sequestration. The capture and long-term storage of atmospheric carbon dioxide in forests, soils, lakes, and oceans; the net process of storing carbon in a carbon sink. Sinks can include terrestrial (soil, trees), marine, atmospheric, and geological systems (NOAA 2015).

clionid sponges. Any member of the sponge family Clionidae (class Demospongiae, phylum Porifera), noted for its ability to dissolve and bore into calcium-containing substances, such as limestone, coral, and mollusk shells (Encyclopedia Britannica 2015).

coliform bacteria. A group of bacteria primarily found in human and animal intestines and wastes. These bacteria are widely used as indicator organisms to show the presence of such wastes in water and the possible presence of pathogenic (disease-producing) bacteria. *Escherichia coli (E. coli)* is one of the fecal coliform bacteria widely used for this purpose.

Commonwealth. An organized United States insular area, which has established with the Federal Government a more highly developed relationship, usually embodied in a written mutual agreement. Currently, two United States insular areas are commonwealths, the Northern Mariana Islands and Puerto Rico. A United States insular area from April 11, 1899, the Philippine Islands achieved commonwealth status on March 24, 1934 (Public Law 73-127), and remained as such until the United States recognized the Philippine Islands' independence and sovereignty as of July 4, 1946.

conceptual model. An abstract framework used to organize ideas and information into a form that is more easily examined. These models are often helpful when searching for commonalties between apparently unrelated phenomena, or when defining the scope of inquiry when organizing and interpreting measurements of biological conditions.

connectivity. A topological property relating to how geographical features are attached to one another functionally, spatially, or logically.

consequence. Something that logically or naturally follows from an action or condition. A logical conclusion or inference.

consequence table. A summary matrix illustrating the performance of each alternative on each objective.

contaminant. An undesirable substance not normally present, or an usually high concentration of a naturally occurring substance in the environment; a substance in water that might adversely affect the health and welfare of the biota (NOAA 2015).

coral. Species of the phylum Cnidaria, including-- (A) all species of the orders Antipatharia (black corals), Scleractinia (stony corals), Gorgonacea (horny corals), Stolonifera (organ pipe corals and others), Alcyanacea (soft corals), and Coenothecalia (blue coral), of the class Anthozoa; and (B) all species of the order Hydrocorallina (fire corals and hydrocorals) of the class Hydrozoa (16 U.S.C. 6401 et seq. 2000).

coral reef. A wave-resistant structure resulting from cementation processes and the skeletal construction of hermatypic corals, calcareous algae, and other calcium carbonate-secreting organisms (NOAA 2015).

Coral Reef Scenario Evaluation Tool (CORSET). A generic, biophysical model for coral reef systems that couples dynamics from local to regional scales.

crustacean. Any of various predominantly aquatic arthropods of the class Crustacea, including lobsters, crabs, shrimps, and barnacles, having segmented bodies, a chitinous exoskeleton, and paired, jointed limbs (appendages).

crustose coralline algae. Crustose coralline algae are red algae of the division Rhodophyta. They are very important members of a reef community in which they cement and bind the reef together. They are particularly common in high wave energy areas but can also be found throughout all reef zones. Crustose corallines resemble pink or purple pavement. Morphology can range from smooth and flat, to rough and knobby, or even leafy (NOAA 2015).

dam. A structure formed to hold water back, generally built near uncontaminated water collection sources in order to provide a drinking water supply or irrigation to the surrounding communities.

damselfish. A large family (Pomacentridae) of bony fishes that are abundant and common inhabitants of coral reefs. They possess robust, deep, and laterally compressed bodies. The majority of damselfishes do not have particularly brilliant markings or coloration. Exceptions are the brilliantly colored anemone fishes, the banded Sargeant major, and the bright orange garibaldi. Many species of damselfishes are highly territorial (NOAA 2015).

Decision Analysis (DA). The discipline comprising the philosophy, theory, methodology, and professional practice necessary to address important decisions in a formal manner. Decision analysis includes many procedures, methods, and tools for identifying, clearly representing, and formally assessing important aspects of a decision, for prescribing a recommended course of action by applying the maximum expected utility action axiom to a well-formed representation of the decision, and for translating the formal representation of a decision and its corresponding recommendation into insight for the decision maker and other stakeholders (Wikipedia 2015a).

decision context. The environment in which the decision is made, and the environment that will prevail when the effects of the decision are brought to bear, **including** the set of values, preferences, constraints, policies and regulations that will affect both the deciders and those identified as the ultimate beneficiaries.

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 government 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, when an alternative is selected from a set of potential alternatives.

decision-support framework (DSF). An organizing structure to support decision-making.

decision-support tools. Software, models, data sets, maps, etc. to support decision-making.

demographic information. A characteristic used to describe some aspect of a population and that can be measured for that population, such as growth rate, age structure, birth rate, and gross reproduction rate.

***Diadema*.** A genus of sea urchins of the Family Diadematidae and is one of the most abundant, widespread, and ecologically important shallow water genera of tropical sea urchins.

Diadema antillarum. A species of sea urchins in the Family Diadematidae, characterized by its exceptionally long black spines. It was the most abundant and important herbivore on the coral reefs of the western Atlantic and Caribbean basin. When the population of these sea urchins is at a healthy level, they are the main grazers that prevent algae overgrowth of the reef. In 1983, throughout the Caribbean faunal zone as far south as South America and north to the Bahamas, *Diadema antillarum* underwent mass mortality, with more than 97% of the urchins dying.

***Dictyota*.** A genus of algae with branches that fork near their ends. The tips may be rounded or pointed. Generally they form mats of dense to loose packed flat leaves that overgrow the substrate. Light to medium brown and/or green to blue-green, occasionally with bright blue tints.

digital elevation model (DEM). The representation of continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. DEMs are typically used to represent terrain relief.

direct extractive use. Natural resource products of commercial value that are either traded or have the potential for trade.

direct non-extractive. Natural resource services of commercial value provided biodiversity or related to ecosystems or genetic material.

DPSIR. A decision-support framework for capturing the physical and human processes in a decision process; it includes the identification of the **D**riving Forces (socioeconomic sectors that drive human activities), **P**ressures (Driving Force-generated emissions and land use changes that affect the environment), resulting environmental and ecological **S**tates (reflect condition of the natural and living phenomena), **I**mpacts on services and values (effects of environmental degradation of ecological attributes and ecosystem services), and **R**esponses to those impacts (policies and responses).

Driving Forces. In DPSIR, the socioeconomic sectors that drive human activities (Waste disposal, agriculture, construction, fisheries, tourism).

ecological*.* Relating to the interrelationships of organisms and their environment.

ecological integrity. The condition of an unimpaired ecosystem as measured by combined chemical, physical (including physical habitat), and biological attributes (Karr and Dudley 1981).

ecological production function (EPF). A description of the type, quantity and interactions of natural features required to generate outputs of natural products and services. For a simple example, the biophysical characteristics of a coastal wetland (flooding regimes, salinity, nutrient concentrations, plant species abundance, prey and predator abundances, etc.) can influence the abundance of a population of watchable wading shorebirds (the ecological endpoint). The outputs of ecological production functions, when combined with complementary goods and services and demand by humans, produce ecosystem goods and services (adapted from Wainger and Boyd 2009 and Wainger and Mazzotta 2009).

ecosystem. A dynamic complex of plant, animal, and microorganism communities and their nonliving environment interacting as a functional unit (MEA 2009).

ecosystem functions. Physical, chemical, and biological processes that occur in ecosystems.

ecosystem services. Benefits that human populations receive from ecosystems.

ecosystem services valuation functions (EVF). Relate characteristics of society, such as demand, accessibility, or substitutability, to derive value for ecosystem services (Compton et al. 2011).

elicitation. The process of extracting information from something or someone.

Envision. A GIS-based tool for scenario-based community and regional planning and environmental assessments.

erosion. Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

existence or intrinsic value. The amount people are willing to pay to preserve the existence of biodiversity for its own sake

expert opinion. The opinion of a person who has extensive skill or knowledge in a field.

extrapolate. To infer or estimate by extending or projecting known information.

fecal bacteria. Microscopic single-celled organisms (primarily fecal coliforms and fecal streptococci) found in the wastes of warm-blooded animals. Their presence in water is used to assess the sanitary quality of water for body-contact recreation or for consumption. Their presence indicates contamination by the wastes of warm-blooded animals and the possible presence of pathogenic (disease producing) organisms (USGS 2015).

Federal Labor Standards Act (FLSA). A federal statute of the United States enacted in 1938. The FLSA introduced a 40-hour, seven-day workweek, established a national minimum wage, guaranteed "time-and-a-half" for overtime in certain jobs, and prohibited most employment of minors in "oppressive child labor", a term that is defined in the statute.

fleshy algae. Large, soft algae (sometimes called "seaweed") on a reef, including Lobophora (a type of brown algae) and Halimeda (green algae).

flocs. A mass of particles that form into a clump as a result of a chemical reaction; having a fluffy appearance; resembling bits of wool; flaky (NOAA 2015).

Foraker Act. Public Law 56-191, 31 Statute 77, enacted April 12, 1900, officially known as the Organic Act of 1900, is a United States federal law that established civilian (albeit limited popular) government on the island of Puerto Rico, which had recently become a possession of the United States as a result of the Spanish-American War (Wikipedia 2015c).

fundamental objectives. Reflect concerns that are important for their own reasons and not because they contribute to something that is more valuable (Keeney 1992). They are fundamental because most stakeholders will agree with them, even if varying in degree.

Geographic Information System (GIS). A collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display geographically referenced data.

gorgonians. An anthozoan of the subclass Octocorallia, commonly called sea fans and sea whips (NOAA 2015).

grouper. Any species of bony fishes in the subfamily Epinephelinae of the sea bass family, Serranidae. Groupers have a typical sea bass appearance with robust bodies, large mouths and sharp teeth (NOAA 2015).

habitat. A place where the physical and biological elements of ecosystems provide a suitable environment including the food, cover, and space resources needed for plant and animal livelihood (EPA 2009).

habitat structure. The composition and arrangement of physical matter at a location. A complex habitat structure is critical to many species.

herbivores. An animal that feeds on plants (EPA 2010).

heterotrophic. An organism that cannot manufacture its own food, and therefore requires external sources of energy (NOAA 2015).

hydrology. The science of water relating to occurrence, properties, distribution, circulation and transport of water.

hydropower. Power derived from the energy of falling water and running water, which may be harnessed for useful purposes. Since ancient times, hydropower has been used for irrigation, and the operation of various mechanical devices, such as watermills, sawmills, textile mills, etc. Since the early 20th century, the term is used almost exclusively in conjunction with the modern development of hydroelectric power, which allowed use of distant energy sources.

hydroseeding. 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.

impacts. In DPSIR, quality and value of ecosystem services.

indirect use value. Ecological values including services provided by ecosystems, which may not have direct commercial value.

infrastructure. The basic physical systems of a business or nation. Transportation, communication, sewage, water and electric systems are all examples of infrastructure. These systems tend to be high-cost investments, however, they are vital to a country's economic development and prosperity.

instrumental value. The amount people are willing to pay to preserve the existence of biodiversity because it provides a means for acquiring something else of value.

intractable problems. Problems that are difficult to manage, deal with, or change to an acceptable condition. Causes include: irreconcilable moral differences (e.g., conflicts about right and wrong, good and evil), high stakes distributional issues (over who gets what), and conflicts over power and status.

invertebrates. Animals that lack a spinal column or backbone, including molluscs (e.g., clams and oysters), crustaceans (e.g., crabs and shrimp), insects, starfish, jellyfish, sponges, and many types of worms that live in the benthos.

Jones-Costigan Amendment, also known as the Sugar Act of 1934. An amendment to the Agricultural Adjustment Act that reclassified sugar crop as basic commodity, subject to the provisions of the Agricultural Adjustment Act enacted the previous year. Sponsored by Senator Edward P. Costigan (Progressive, Colorado) and Representative John Marvin Jones (Democrat, Texas), the act was a New Deal effort to salvage an ailing sugar industry by imposing protective tariffs and quotas along with a direct subsidy to growers of sugar cane and sugar beet.

Jones–Shafroth Act, **also known as the Jones Act of Puerto Rico, or Jones Law of Puerto Rico.** Public Law 64-368, 39 Statute 951, enacted March 2, 1917, was an Act of the United States Congress, signed by President Woodrow Wilson. The act granted U.S. Citizenship to the people of Puerto Rico. It also created the Senate of Puerto Rico, established a bill of rights, and authorized the election of a Resident Commissioner (previously appointed by the President) to a four-year term (Wikipedia 2015d).

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.

Lajas Valley Irrigation System (LVIS). A series of 5 dams and an extensive irrigation canal and drainage system

land cover. Anything that exists on, and is visible from above the Earth's surface. Examples include vegetation, exposed or barren land, water, snow, and ice.

land use. The way land is developed and used in terms of the kinds of anthropogenic activities that occur (e.g., agriculture, residential areas, and industrial areas).

landscape. The spatial pattern or structure of a geographic area (including its biological composition, its physical environment, and its anthropogenic or social patterns) and is designed to identify repeating patterns associated with dominant land uses in an area. The relative proportion of forest, agriculture, and urban land cover contained in the area also defines a landscape as does the interrelationships between them.

landscape dynamic model. Spatially explicit models aiming at projecting a landscape (structure, function, composition) over time. They can include spatial interactions, community dynamics or/and ecosystem processes. Landscape models are typically used to simulate different management or global change scenarios. Two broad classes of examples are gap/ landscape models (e.g. LANDIS, ForCLIM) and dynamic vegetation models (e.g. IBIS, LPJ).

macroalgae. Non-rooted aquatic plants commonly referred to as seaweed.

macroinvertebrates. Animals without backbones of a size large enough to be seen by the unaided eye. EPA's coral reef surveys document selected commercially and ecologically important macroinvertebrates, including Queen Conch (Strombus gigas), spiny lobster (Panilaurus argus), reef crabs larger than 20 cm, sea urchins and long-spined sea urchins (Diadema antillarum).

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.

mangroves. Salt-tolerant woody plants that grow in muddy swamps inundated by tides. Mangrove plants form communities that help stabilize banks and coastlines (Conservation International 2009).

Marine Protected Area (MPA). Any area of the marine environment that has been reserved by federal, state, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein (EO 13158).

market value. The price at which an asset would trade in a competitive auction setting; this is the true underlying value" according to theoretical standards.

means objectives. Objectives that provide a means to fulfill the fundamental objectives (Keeney 1992).

mechanistic model. A model that assumes that a complex system can be understood by examining the workings of its individual parts and the manner in which they are coupled. Mechanistic models typically have a tangible, physical aspect, in that system components are real, solid and visible.

metric. An observable measure linked to a fundamental (ends) objective used to evaluate an alternative's ability to achieve the objective. Metrics should be understandable, measurable, and operational.

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. For example, meteorologists use models to predict the weather.

Montastraea. A genus of hard (stony) coral that includes the boulder coral and the great star coral (NOAA 2015).

natural products. A chemical compound or substance produced by a living organism–found in nature that usually has a pharmacological or biological activity for use in pharmaceutical drug discovery and drug design. A *natural* product can be considered as such even if it can be prepared by total synthesis.

natural resources. The natural wealth of a country, consisting of land, forests, mineral deposits, water, etc.

Netica. A program for working with belief networks and influence diagrams. It has an intuitive and smooth user interface for drawing the networks, and the relationships between variables may be entered as individual probabilities, in the form of equations, or learned from data files (which may be in ordinary tab-delimited form and have "missing data").

nonmarket values. Most environmental goods and services, such as clean air and water, and healthy fish and wildlife populations, are not traded in markets. Their economic value -how much people would be willing to pay for them- is not revealed in market prices. The only option for assigning monetary values to them is to rely on non-market valuation methods.

nonpoint source (NPS) pollution. Any source of water pollution that does not meet the legal definition of “point source” in section 502(14) of the Clean Water Act. NPS pollution is widespread because it can occur any time activities disturb the land or water. Agriculture, forestry, grazing, septic systems, recreational boating, urban runoff, construction, physical changes to stream channels, and habitat degradation are potential sources of NPS pollution. NPS pollution includes adverse changes to the vegetation, shape, and flow of streams and other aquatic systems. NPS pollution also results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification that can pick up pollutants, and deposit them into rivers, lakes and coastal waters or introduces them into ground water. NPS sources are automobile emissions, road dirt and grit, and runoff from parking lots; runoff and leachate from agricultural fields, barnyards, feedlots, lawns, home gardens and failing on-site wastewater treatment systems; and runoff and leachate from construction, mining and logging operations. Most NPS pollutants fall into six major categories: sediment, nutrients, acid and salts, heavy metals, toxic chemicals and pathogens. The cumulative impact of nonpoint source pollution is significant.

non-use value. Value prescribed to ecosystems not related to direct commercial or indirect use, including the possibility for having the option to use the resource in the future or willingness to pay to preserve the existence of biodiversity.

nutrients. Chemicals that are needed by plants and animals for growth (e.g., nitrogen, phosphorus). In water resources, if other physical and chemical conditions are optimal, excessive amounts of nutrients can lead to degradation of water quality by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae. Some nutrients can be toxic to animals at high concentrations.

objectives. Statements of what is valuable to stakeholders under a certain context (Keeney 1992)

octocorals. Water-based organisms formed of colonial polyps with 8-fold symmetry.

Operation Bootstrap. The name given to the ambitious projects that industrialized Puerto Rico in the mid-20th century. The program allowed "exemption from insular taxes for any corporation that build a plant in a new industry, expanded approved existing industry or constructed a new hotel."

option value. The desire for potentially using a resource in the future, rather than using it in the present.

outcomes. The results, impacts or consequences of making a decision.

***Palythoa caribaeorum*.** A white encrusting zooanthid. Colonies form thick, encrusting mats on dead corals and other hard substrates. The skeleton is hard, somewhat cork-like in consistency. The outer surface is covered with large, round calices surrounded by a low, rounded ridge or lip.

pathogens. An agent of disease. A disease producer. The term pathogen most commonly is used to refer to infectious organisms. These include bacteria (such as staphylococcus), viruses (such as HIV), and fungi (such as yeast).

pharmaceuticals. Man-made and natural drugs used to treat diseases, disorders, and illnesses.

policy. A principle or rule to guide decisions and achieve rational outcomes. Policy differs from law. While law can compel or prohibit behaviors (e.g. a law requiring the payment of taxes on income), policy merely guides actions toward those that are most likely to achieve a desired outcome.

polychaetes. A class of annelid worms, generally marine. Each body segment has a pair of fleshy protrusions that bear many bristles made of chitin. Polychaetes are sometimes referred to as bristle worms.

polygon. A planar (2-D) figure that is bounded by a closed path or *circuit*, composed of a finite sequence of straight-line segments (i.e., by a closed polygonal chain). These segments are called its *edges* or *sides*, and the points where two edges meet are the polygon's *vertices* or *corners*.

population structure. The patterns of demographic variation seen within and among populations.

porosity. The degree to which the total volume of soil, gravel, sediment, or rock is permeated with pores or cavities through which fluids (including air) can move.

pressures. In DPSIR, the human activities that stress the environment (Discharge, boating activities, climate change, land use/land cover change, coastal erosion).

process objectives. Objectives that are designed to improve the decision process itself and do not focus on what should be done, but rather how it should be done (Keeney 1992).

qualitative. Descriptive of kind, type, or direction.

quantitative. Descriptive of size, magnitude, or degree.

quasi-option value. The potential value of a resource for future (direct or indirect use), emphasizing the value of avoiding the risk of losing that resource.

recreation. Refreshment of strength or spirits after work; also: a means of refreshment or diversion (Merriam Webster 2010). Both tourists and residents of a given geographic location enjoy recreational activities. However, the common practice of economists is to differentiate between tourism and recreation based upon the source of demand.

recruitment. The measure of the number of young individuals (e.g., fish and coral larvae, algae propagules) entering the adult population, in other words, it is the supply of new individuals to a population.

reductionist approach. The analysis of complex things (facts, entities, phenomena, or structures) into less complex constituents.

reforestation. The natural or intentional restocking of existing forests and woodlands that have been depleted.

reservoir. A man-made body of water (it is replenished by rain and river or stream flow), which is formed after a dam is built on a river, and is used for the collection and storage of water. In addition to providing municipal water supplies, reservoirs provide recreational areas, are used for irrigation, hydroelectric power, and flood control.

responses. The term “response” is used in two contexts in this report: 1) Human actions, including policies, strategies, and interventions, to address specific issues, needs, opportunities, or problems. In the context of ecosystem management, responses may be of legal, technical, institutional, economic, and behavioral nature and may operate at local or micro, regional, national, or international level and at various time scales (MEA 2009), 2) Ecosystem processes occurring due to the effect of some stressor or combination of stressors.

riparian. Areas adjacent to rivers and streams with a high density, diversity, and productivity of plant and animal species relative to nearby uplands.

root node. In a BBN, the topmost node in a tree. It has no parent nodes. Each node represents a variable.

rugosity. Describes the amount of “wrinkling” or roughness of the physical reef profile. It is an index of substrate complexity. Areas of high complexity are likely to provide more cover for reef fishes and more places of attachment for algae, corals, and various sessile invertebrates (NOAA 2015).

runoff. The flow of water, usually from precipitation, which is not absorbed into the ground. It flows across the land and eventually runs to stream channels, lakes, oceans, or depressions or low points in the Earth’s surface. The characteristics that affect the rate of runoff include rainfall duration and intensity as well as the ground's slope, soil type, and ground cover. Runoff can pick up pollutants from the air and land, carrying them into the streams, lakes, etc.

sanitary sewer system. An underground carriage system specifically for transporting sewage from houses and commercial buildings to treatment or disposal. Sanitary sewers are operated separately and independently of storm drains, which carry the runoff of rain and other water, which wash into city streets. Sewers carrying both sewage and stormwater together are called combined sewers (Wikipedia 2015e).

seagrasses. A flowering plant, complete with leaves, a rhizome (an underground, usually horizontally-oriented stem), and a root system. They are found in marine or estuarine waters. Most seagrass species are located in soft sediments. However, some species are attached directly to rocks with root hair adhesion. Seagrasses tend to develop extensive underwater meadows (NOAA 2015).

sediment. Particles and/or clumps of particles of sand, clay, silt, and plant or animal matter that are suspended in, transported by, and eventually deposited by water or air.

sedimentation. The removal, transport, and deposition of detached soil particles by flowing water or wind.

sessile. Characteristic of an immobile organism because of its attachment to a substrate. The term has also been applied to organisms, such as anemones, that move very slowly (NOAA 2015).

shade-grown coffee. A form of the beverage produced from coffee plants grown under a canopy of trees.

shoreline. The intersection of the land, including man-made waterfront structures, with the water surface. The shoreline depicted on NOAA National Ocean Service (NOS) maps and charts represents the line of contact between the land and a selected water elevation. In areas affected by tidal fluctuations, the shoreline is the interpreted mean high water line. In confined coastal water of diminished tidal influence, the mean water level line may be used. In non-tidal waters, the line represents the land/water interface at the time of survey. In areas where the land is obscured by marsh grass, cypress or similar marine vegetation, the actual shoreline cannot be accurately represented. Instead the outer limit line of the vegetation area is delineated (where it would appear to the mariner as the shoreline); in this case, it is referred to as the apparent shoreline (NOAA 2015).

shoreline protection. The ability of reefs to attenuate offshore wave energy, to provide sheltered nearshore waters, and to protect coastlines from erosion, flooding, and storm damage.

snapper. Any species of bony fishes in the family Lutjanidae. Snappers are found in the tropical and subtropical regions of the Atlantic, Pacific, and Indian oceans. A few are estuarine to entirely freshwater. Many species are popular food and game fishes (NOAA 2015).

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)

sovereign. An independent or non-independent jurisdiction which itself possesses or whose people possess in their own right the jurisdiction’s supreme authority, regardless of the jurisdiction’s or people’s current ability to exercise that authority (DOI 2009).

spatially-explicit model. A model is spatially explicit when the variables, inputs, or processes have explicit spatial locations and, moreover, that location matters to the process being modeled.

spawn. To produce or deposit eggs; the eggs of aquatic animals; the mass of eggs deposited by fishes, amphibians or mollusks; offspring in great numbers or masses; to give forth young in large numbers (NOAA 2015).

species. A category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding. Also refers to an organism belonging to such a category.

species abundance. The number of individuals per species.

species diversity. The number of different species in an area and their relative abundance (NOAA 2015).

species richness. The number of species in an area or biological collection (NOAA 2015).

sponge. A sessile (nonmoving), multi-cellular marine animal whose body consists of a jelly-like endoskeleton sandwiched between two layers of cells. Sponges comprise the phylum Porifera.

stakeholder. Someone having a stake or interest in a physical resource, ecosystem service, institution, or social system, or someone who is or may be affected by a public policy (MEA 2009). All citizens of the nation are stakeholders, including residents of local communities adjacent to coral reefs, tourists and the tourism industry, fishermen and other marine- based industries, land-based industries, conservation and environmental groups, research organizations, and educational institutions.

state. In DPSIR, reflects the condition of the natural and living phenomena (such as air, water and soil parameters and growth, survival and reproductive parameters).

stated choice surveys. A flexible approach to collecting preference data (generally, choices and rankings, whether full or partial) from subjects in hypothetical situations. The objective is to place the decision-maker in a realistic frame of mind to compare a number of alternatives, each described in terms of some number of attributes.

stated preference surveys. An approach that asks people to directly state their values, rather than inferring values from actual choices (e.g., much they would agree to pay for avoiding a degradation of the environment or, alternatively, how much they would ask as a compensation for the degradation).

statistical models. A formalization of relationships between variables in the form of mathematical equations. A statistical model describes how one or more variables are related to one or more other variables.

stony corals. A group of coral species known as hard coral that form the hard, calcium carbonate skeleton. Such types include the brain corals, fungus or mushroom corals, staghorn, elkhorn, and table corals, flowerpot corals, bubble corals and lettuce corals.

stormwater. Water from rain that flows over the ground surface and is subsequently collected by natural channels or artificial conveyance systems, and also includes water that has infiltrated into the ground but nonetheless reaches a stream channel relatively rapidly and that contributes to the increased stream discharge that commonly accompanies almost any rainfall event in a human-disturbed watershed.

stratified random survey. The process of dividing members of the population into homogeneous subgroups before sampling. The strata should be mutually exclusive: every element in the population must be assigned to only one stratum. The strata should also be collectively exhaustive: no population element can be excluded. Then simple random sampling or systematic sampling is applied within each stratum. This often improves the representativeness of the sample by reducing sampling error. It can produce a weighted mean that has less variability than the arithmetic mean of a simple random sample of the population.

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).

stressors. Physical, chemical and biological factors that adversely affect aquatic organisms (EPA 2009).

structured decision-making (SDM). An organized approach to identifying and evaluating alternatives that focuses on engaging stakeholders, experts and decision-makers in productive decision-oriented analysis and dialogue and that deals proactively with complexity and judgment in decision-making. It provides a framework that becomes a decision-focused roadmap for integrating activities related to planning, analysis and consultation.

sun-grown coffee. Product from coffee plants grown in full sun, with all other vegetation having been cleared.

swing-weighting. One of the available methods for eliciting weights for the various criteria defined for multi-criteria analysis. The swing weight method requires specifying hypothetical changes (swings) in the level of performance against different objectives and then obtaining judgments of the relative preferences for obtaining those swings, typically using a 0-to-100 scale. For example, if the most desirable swing is given a swing weight of 100 points, how many points would be assigned to obtaining the next most desirable swing? Although the swing weight method is not necessarily the most accurate method for eliciting weights, for objectives it provides much more reliable results than assigning weights based on abstract "importance" of each criterion.

systems thinking. The process of understanding how things, regarded as systems, influence one another within a whole (Wikipedia 2015f).

Tainos. Seafaring indigenous peoples of the Bahamas, Greater Antilles, and the northern Lesser Antilles (Wikipedia 2015g).

terrestrial. Things related to land or the planet Earth (Wikipedia 2015h).

territory. Under Article IV of the U.S. Constitution, a territory is subject to and belongs to the United States (but not necessarily within the national boundaries or any individual state). This includes tracts of land or water not included within the limits of any State and not admitted as a State into the Union. U.S. territories with coral reefs include American Samoa, Commonwealth of the Northern Mariana Islands (CNMI), Guam, Puerto Rico, and the U.S. Virgin Islands (USVI).

tertiary treatment. Advanced cleaning of wastewater during which nutrients (such as phosphorous and nitrogen) and most suspended solids are removed (Business Dictionary.com 2015).

topographic complexity. The three-dimensional arrangement of structural features over the seafloor surface, spanning all spatial scales (Zawada 2011).

topography. The physical features of a surface area including relative elevations and the position of natural and man-made (anthropogenic) features.

tourists. People who travel to and stay in places outside their usual environment for more than twenty-four (24) hours and not more than one consecutive year for leisure, business and other purposes not related to the exercise of an activity remunerated from within the place visited (UNWTO 1995).

toxic pollutants. Pollutants that are poisonous, carcinogenic, or otherwise directly harmful to plants and animals.

toxics. Any chemical listed in EPA rules as “Toxic Chemicals Subject to Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986” (EPA 2010).

trade-off. A situation that involves losing one quality or aspect of something in return for gaining another quality or aspect. It often implies a decision to be made with full comprehension of both the upside and downside of a particular choice (Wikipedia 2015).

trophic. Describing the relationships between the feeding habits of organisms in a food chain.

turbidity. The amount of solid particles that are suspended in water and that cause light rays shining through the water to scatter. Thus, turbidity makes the water cloudy or even opaque in extreme cases. High levels of turbidity are often harmful to aquatic life.

turf algae. Turf algae are a multi-specific assemblage of diminutive, often filamentous, algae that attain a canopy height of only 1 to 10 mm. These microalgal species have a high diversity (>100 species in western Atlantic), although only 30 to 50 species commonly occur at one time. There is a high turnover of individual turf algal species seasonally and only a few species are able to persist or remain abundant throughout the year. But turf algae, when observed as a functional group, remain relatively stable year round (Steneck and Dethier 1994). They are often able to recovery rapidly after being partially consumed by herbivores. Turfs are capable of trapping ambient sediment and kill corals by gradual encroachment (AGRRA 2015).

uncertainty. Inability to predict outcomes due to random variability (for example, streamflow is sometimes high and sometimes low) or incomplete scientific knowledge regarding causal relationships (for example, how does exposure to a given concentration of sediments affect coral reef growth rates).

United Nations Biosphere Reserves. Sites established by countries and recognized under UNESCO's Man and the Biosphere (MAB) Program to promote sustainable development based on local community efforts and sound science.

United States Coral Reef Task Force (**USCRTF).** 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, seven U.S. States, Territories, Commonwealths, and three Freely Associated States. The USCRTF helps build partnerships, strategies, and support for on-the-ground action to conserve coral reefs.

Universal Soil Loss Equation (USLE). A widely used mathematical model that describes soil erosion processes.

valuation. The process of expressing a value for a particular good or service in a certain context (e.g., of decision-making) usually in terms of something that can be counted, often money, but also through methods and measures from other disciplines (sociology, ecology, and so on) (MEA 2009).

value-focused thinking (VFT). A philosophy to guide decision-makers. It has three major ideas: start with values, use values to generate better alternatives, and use values to evaluate those alternatives (Keeney 1992).

values. The things that people believe are important in the way they live and work.

vertebrate. An animal that possesses a vertebral column (back bone), such as fishes, amphibians, reptiles, birds and mammals (NOAA 2015).

visibility. The distance at which an object underwater can be readily identified. Underwater visibility is measured two ways. There is horizontal visibility — how far you can see looking straight ahead — and vertical visibility — how far you can see looking up or down.

water quality. A term for the combined biological, chemical, and physical characteristics of water with respect to its suitability for a beneficial use.

watershed. The entire area of land whose runoff of water, sediments, and dissolved materials (e.g., nutrients, contaminants) drain into a river, lake, estuary, or ocean.

wicked problem. "Wicked" problems are complex policy problems over natural resources exemplified by intertwined and competing social, economic, and environmental values.

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