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Transferability and Utility of Practical Strategies for Community Decision Making: Results from a Coordinated Case Study Assessment

Office of Research and Development
Center for Environmental Measurement and Modeling
Gulf Ecosystem Measurement and Modeling Division

Transferability and Utility of Practical Strategies for Community Decision Making: Results from a Coordinated Case Study Assessment

By

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Notice and Disclaimer

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Abbreviations and Symbols

Throughout this report, the term "ecosystem goods and services" is often abridged to "ecosystem services" and may include either intermediate or final ecosystem goods and services.

This symbol is used throughout this report to highlight 'Take Home' ideas for integrating ecosystem goods and services into community decision-making.

Acronyms and abbreviations used in this report include the following. Additional words in the abbreviated title, but not specified by the acronym letters, are given in brackets.

AOC Areas of Concern
BUI Beneficial Use Impairment
CCMP Comprehensive Conservation Management Plan
CE(1-6) Common Element 1-6 of the decision framework
DASEES Decision Analysis for a Sustainable Environment, Economy, and Society
DPSIR Drivers-Pressures-State-Impact-Response [Framework]
DSS Decision Support System
EBF Ecosystem Benefit Function
EGS Ecosystem Goods and Services
Envision [An integrated modeling platform]
EPA U.S. Environmental Protection Agency
EPA H2O [EPA's Ecosystem Services Scenario Mapping Tool]
EPF Ecosystem Production Function
FEGS Final Ecosystem Goods and Services
GIS Geographic Information System
GLWQA Great Lakes Water Quality Agreement
HIA Health Impact Assessment
HSI Habitat Suitability Index
HWBI Human Well-Being Index
i-Tree Tools for Assessing and Managing Forests and Community Trees [Model]
MBNEP Mobile Bay National Estuary Program
MEA Millennium Ecosystem Assessment
MNDNR Minnesota Department of Natural Resources
NEP National Estuary Program
NRC National Research Council
NTU Nephelometric Turbidity Units
ODA Oregon Department of Agriculture
ODEQ Oregon Department of Environmental Quality
ODFW Oregon Department of Fish and Wildlife
OWRB Oklahoma Water Resources Board
ORD [EPA's] Office of Research and Development

PM Performance Measures
PNW Pacific Northwest
SDM Structured Decision Making
SJBEP San Juan Bay Estuary Program
TEP Tillamook Estuaries Partnership
USACE United States Army Corps of Engineers
USGS United States Geological Survey
VELMA Visualizing Ecosystem Land Management Assessments [Model]
WMP Watershed Management Plan

Executive Summary

The concept of **Final Ecosystem Goods and Services (FEGS)** explicitly connects ecosystem services to the people that benefit from them. This report presents a case study application of practical strategies for incorporating FEGS, and more broadly ecosystem services, into the decision-making process. Doing so helps decision makers better engage all stakeholders, make a complicated discussion easier to understand through an organizational framework, and directly relate outcomes to benefits by using FEGS-based measures of change. The goal was to look for common elements across a suite of case studies in different regions of the country and dealing with different issues so to inform the transfer and use of these practical strategies in elsewhere. Whether a decision process is in early or late stages, or whether a process includes informal or formal decision analysis, there are multiple points where ecosystem services concepts can be integrated.

This report is centered on **Structured Decision Making (SDM)** as an organizing framework to illustrate the role ecosystem services can play in a values-focused decision-process, including:

- **Clarifying the decision context**: Ecosystem services can help clarify the potential impacts of an issue on natural resources together with their spatial and temporal extent based on supply and delivery of those services, and help identify beneficiaries for inclusion as stakeholders in the deliberative process.
- **Defining objectives and performance measures**: Ecosystem services may directly represent stakeholder objectives or may be means toward achieving other objectives.
- **Creating alternatives**: Ecosystem services can bring to light creative alternatives for achieving other social, economic, health, or general well-being objectives.
- **Estimating consequences**: Ecosystem services assessments can implement ecological production functions (EPFs) and ecological benefits functions (EBFs) to link decision alternatives to stakeholder objectives.
- **Considering trade-offs**: The decision process should consider ecosystem services objectives alongside other kinds of objectives (e.g., social, economic) that may or may not be related to ecosystem conditions.
- **Implementing and monitoring**: Monitoring after a decision is implemented can help determine whether the incorporation of ecosystem services leads to measurable benefits, or what levels of ecosystem function are needed for meaningful change. An evaluation of impacts on ecosystem services from past decisions can provide a learning opportunity to adapt future decisions.

Section 1 of this report introduces the case studies and the bases for comparison. Section 2 reviews common elements of the decision framework in the context of the six case studies with a focus on transferability. Section 3 gives guidance for new adopters of SDM as a tool, as well as the ecosystem services framework, based on the practical strategies and lessons learned from the case study applications of the framework. This Section also gives entry points for each stage that are meant as a guide for new users. Section 4 gives supplementary resources for a deeper dive into the framework and the value of ecosystem services for decision making.

Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

EPA's Center for Environmental Measurement & Modeling (CEMM) conducts research to advance EPA's ability to measure and model contaminants in the environment, including research to provide fundamental methods and models needed to implement environmental statutes. Specifically, CEMM characterizes the occurrence, movement, and transformation of contaminants in the natural environment through the application of measurement and modeling-based approaches. CEMM scientists develop, evaluate and apply laboratory and field-based methods and approaches for use by EPA and its state, local, and tribal partners to characterize environmental conditions in direct support of implementation of EPA programs. CEMM scientists also provide scientific expertise and leadership related to the development and application of complex computational models that provide precise and detailed predictions of the fate and transport of priority contaminants in the environment to inform the environmental policies and programs at the EPA, state, local and tribal level. The methods and models developed by CEMM are typically applied at the airshed, watershed, and ecosystem level.

The following report provides information and guidance on the transferability and utility of an ecosystem services assessment framework. This framework can aid community decision making to increase sustainability. This report describes how the ecosystem assessment framework can be applied across different communities and issues and provides entry points for each step to aid in its use in new communities. This information and guidance support sustainable decision making that promotes human well-being.

Alice Gilliland, Acting Director
Center for Environmental Measurement & Modeling

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Section 1. Introduction and background on coordinated case studies

1.1 Operational framework

Human and community well-being is dependent on sustainable management of environmental resources that support human health and the environment (MEA 2005, NRC 2011). Decisions that lead to sustainable use of resources must balance multiple social, economic, and environmental interests and do so with limited resources in a way that is defendable to stakeholders. As a practical strategy for complex decision making, Yee et al. (2017) laid out an operational framework based on the structured decision-making (SDM) approach (Gregory et al. 2012) and centered on the sustainability of ecosystem services. This framework is intended to guide complex decision making in a way that is transferable across locations and issues and is flexible enough to be useful to a range of decisional authorities. There is growing interest in ecosystem services assessments as a decision tool and this framework can facilitate this interest to maximize how the natural environment benefits people.

Here we apply the concept of Final Ecosystem Goods and Services (FEGS) as an important element of the practical strategy framework (Yee et al. 2017). Ecosystem services come from a suite of categories (regulating, provisioning, etc.; MEA 2005), but can also be separated based on how directly they benefit people (Figure 1.1). For instance, indirect services, such as healthy fish habitat, are important but should be separated from services like catchable fish, which have a direct and identifiable beneficiary (anglers). Because FEGS have a clear human benefit, they can be a better final objective for decision making (DeWitt et l. 2020, Harwell and Jackson 2021).

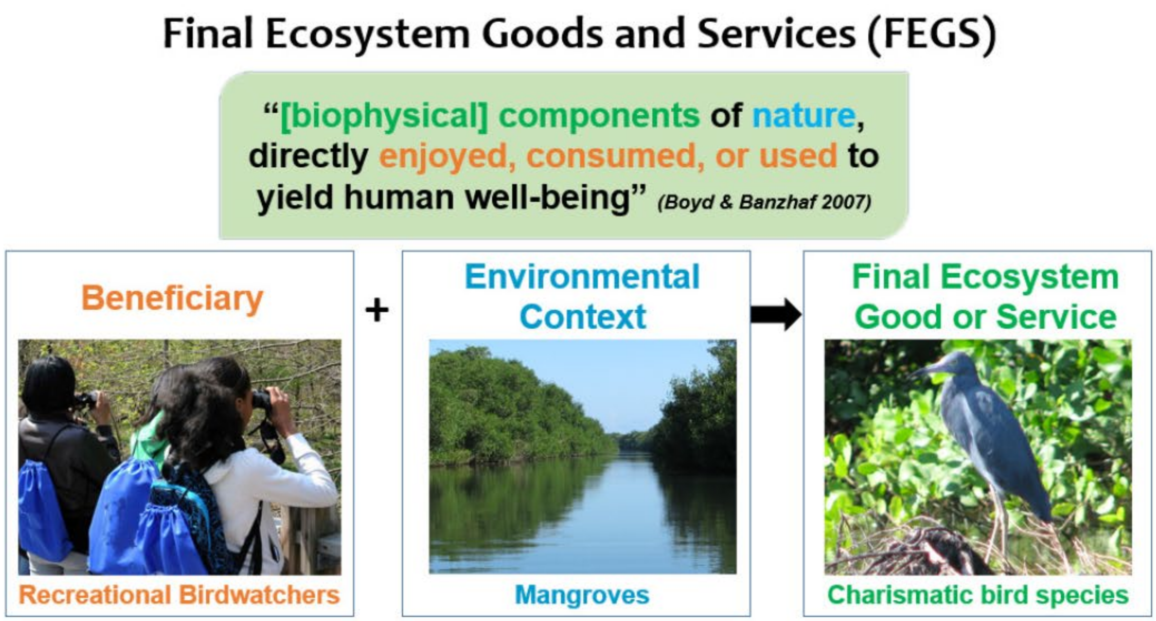


Figure 1.1 Definition of Final Ecosystem Goods and Services is the link between nature and people. Diagram taken from Yee et al. 2017 Figure 1.2.

Decisional frameworks help us organize our thinking around how decisions lead to changes in ecosystem state and function. This is a process that starts with a clear understanding of the decision context leading to measurable objectives that can be integrated with data, models, and tools to estimate consequences of decision options. Once potential consequences are known, trade-offs can be estimated and communicated to stakeholders greatly improving the scientific and social basis for the decision. These are the steps advocated by Yee et al. (2017) (Figure 1.2) and here we apply these steps and the practical strategies associated with each one, in a series of case studies intended to be representative of a range of decision contexts but also comparable across sites to address the utility of each step in each unique situation. Our goal is to inform community decision making in other locations by moving the FEGS decisional framework from concept to application.

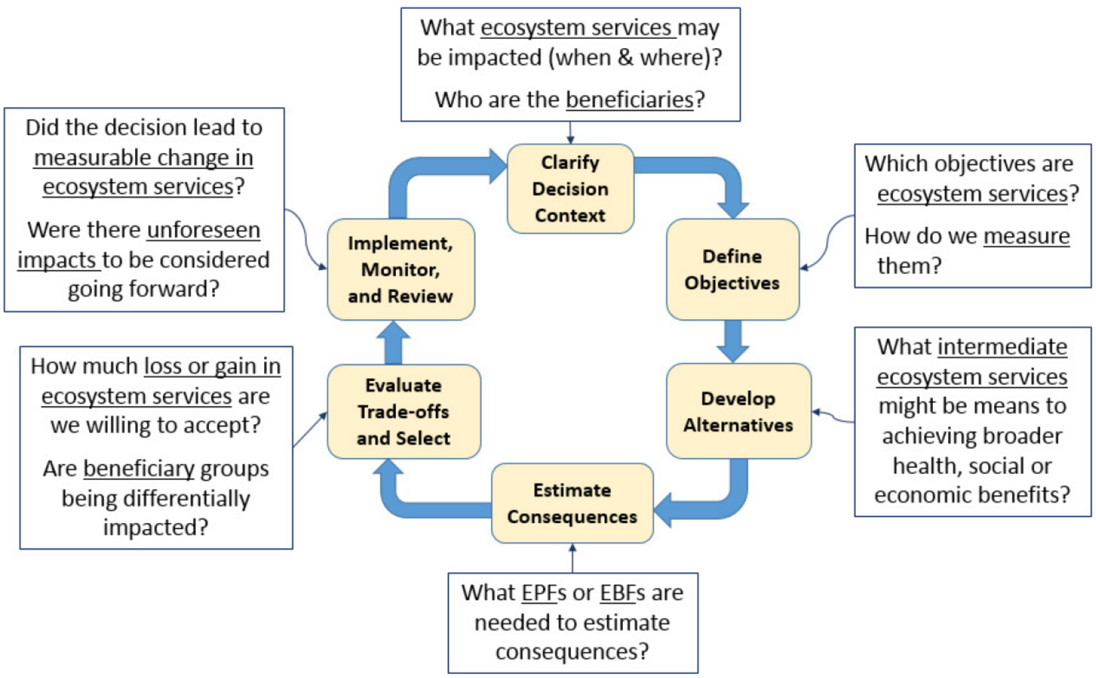


Figure 1.2 The structured decision-making cycle annotated for practical use. Figure taken from Yee et al. (2017) Figure 1.4

1.2 Practical strategies

The intended audiences for this report are community decision makers or agencies that work with communities on integrated decision support as a method for increasing resiliency and sustainability of resources. While many community leaders see the value in an integrated, more inclusive approach to decision making, it can be difficult to know how to get started or how to find the resources necessary. This report is organized around the structured decision-making cycle but also emphasizes a suite of practical strategies intended to help non-technical users get started using the decisional framework. These practical strategies are introduced here but are referenced throughout the report. In Section three we address each practical strategy individually by highlighting ‘entry points’ for each one that were used in the case studies.

The intended users of this report can find common ground in the case studies, identify what SDM steps in Figure 1.2 are most important to their situation, and then find the optimal entry points for that Case study/SDM step combination in Section 3. Tools and approaches for getting started with identified entry points can then be found in the references and links throughout the report.

Take Home: Applying a structured approach that is focused on Final Ecosystem Goods and Services (FEGS) helps decision makers better engage all stakeholders, make complicated discussions easier to understand through an organizational framework, and directly relate outcomes to benefits by using FEGS-based measures of change.

Photo credit: US EPA

The practical strategies for a decisional framework considered in these case studies were derived from a detailed examination of applied SDM (Yee et al. 2017) and a review of how ecosystem services have been applied in community decision support (Fulford et al 2016). From these analyses we developed a set of 17 practical strategies loosely organized around the steps in SDM (Box 1.1). These 17 strategies are intended to be entry points to the six SDM steps and our review of the case studies will include an examination of how these practical strategies were used. We then revisit the practical strategies in Section 3 as entry points for their application in novel communities. Not all strategies were used in all case studies described in this report as the case studies differ in decision context and authority. Nonetheless, we demonstrate how these practical strategies can be used and hopefully the case studies offer some common ground for other communities to make use of the information.

List of Strategies

- Apply FEGS concepts to explicitly connect EGS to people
- Apply principles of SDM to emphasize flexible approaches to FEGS
- Incorporate FEGS concepts at any point in the decision process
- Use FEGS to identify beneficiaries as potential stakeholders
- Use conceptual models as a scaffold to visualize cause and effect
- Use objectives hierarchies to define what is important about FEGS
- Use structured systems as a starting point to identify measurable objectives
- Consider FEGS as means to achieve other objectives
- Use structured paradigms to link EGS alternatives to broader objectives
- Prioritize information and analysis to what is actually needed
- Use conceptual models to visualize relationships
- Quantify FEGS with ecological production functions
- Let objectives drive choice of methods for FEGS benefits analyses
- Use Decision Support Systems to organize and link FEGS analyses
- Compare alternatives and gain insights with consequence tables
- Consider tradeoffs in FEGS benefits relative to other kinds of objectives
- Monitor impacts to FEGS benefits after a decision to inform future decisions

Box 1.1 List of practical strategies as given in Yee et al. 2017. Described here and used in Section 3 to highlight entry points into the SDM steps.

1.3 Case study narratives

We chose six case studies for this comparative study each with its own characteristics and decision context. All six involve either protection or restoration of environmental components that directly benefit people. However, the case studies differ greatly in the relative emphasis placed on the six SDM steps as well as the complexity of the target decision(s). These differences provide a useful palate for comparison. Our goal is to examine the case studies not as isolated examples, but as representative of similar decisions and issues in other locations. For this reason, we will focus on the transferability and utility of approaches in each of the six SDM steps both between locations and across issues.

1.3.1. Mobile Bay Case Study

The **Mobile Bay Estuary Program** (MBNEP) was established in 1995 as a part of the United States National Estuary Program under the Clean Water Act (US Estuaries and Clean Water Act of 2000). The MBNEP seeks to promote stewardship of the water qualtiy characteristics and living resource base of the Mobile Bay estuarine system by bringing together citizens, local, state, and federal government agencies; as well as businesses, environmental organizations, and academic institutions to meet the environmental challenges of Mobile Bay and its watershed. Through partnership, the MBNEP seeks to develop sound scientific information and apply that information to restoring and protecting the integrity of Mobile Bay.

Mobile Bay receives waters from a 43,662 sq mi watershed that includes land in four states. The immediate shoreline of Mobile Bay includes parts of Mobile and Baldwin County, AL and includes one major metropolitan area (City of Mobile) and multiple suburban communities. Mobile Bay is home to a major port and shipyard, as well as an active commercial and recreational fishery. Sub-watersheds of Mobile Bay also drain through urban and suburban areas contributing to recreational use (e.g., hiking, boating), aesthetic value, and residential property value (Vittor 2018). Mobile Bay is subject to multiple stressors including urban-suburban runoff, shoreline degradation, habitat loss, and impacts of shipping activity. The MBNEP is a dominant partner in the effort to reverse the negative impacts of these stressors and protect the services of Mobile Bay for people. To that end MBNEP have developed a Comprehensive Conservation and Management Plan (MBNEP 2019), which is updated every five years to connect broad stakeholder objectives to investment of conservation resources.

The focus of this case study was the sub-estuary restoration effort coordinated by the MBNEP in the D'Olive sub-watershed. D'Olive sub-watershed is located along the eastern edge of Mobile Bay in Baldwin County, AL and includes the cities of Daphne and Fairhope. The sub-watershed consists of three major creek systems (Joe's Branch, Tiawassee, and D'Olive Creeks) and includes one man-made reservoir (Lake Forest), which is maintained with a low-head dam near the top of D'Olive Bay. Restoration activities in D-Olive sub-watershed are representative of MBNEP led efforts in other similar watersheds adjacent to Mobile Bay. EPA research involved the use of ecosystem service assessment models to examine change in service production through time. This provided a baseline for restoration assessment and a tool for restoration planning. Model-based assessment suggests that services lost in D'Olive sub-watershed via changes in land use (i.e., suburbanization) include water quality, flood protection, and recreational access.

Restoration in D'Olive sub-watershed is managed with a watershed workplan developed by MBNEP staff in cooperation with partners using an advisory committee structure established for the purpose (MBNEP 2020). Priorities are set annually based on known impairment and allocation of resources among watersheds of the Bay on a rotational basis. Specific restoration activities are developed by proposals with a fixed set of objectives. In the D'Olive sub-watershed case study, the objectives were to restore a natural flow regime, reduce turbidity delivered downstream to the Bay, and improve habitat quality for fish and wildlife. This was accomplished through stream channel alteration and clearing that reduced the 'boom and bust' cycle of major rain events. Research involved the assessment of these activities from an ecosystem services perspective. The focal ecosystem services were clean water, water storage, and greenspace for recreation. The EPA model results were not used directly for decision making but were used to guide the development of a stressor matrix tool (See Section 2.7.3) to prioritize identified stressor-service links for future conservation investment.

1.3.2. Pacific Northwest and Puget Sound Case Studies

The Pacific Northwest (PNW) / Puget Sound case studies address the growing issue of balancing forestry ecosystem services with sustainability of aquatic/estuarine habitat for endangered salmon species. Intensive forest management in the PNW has emphasized clearcutting on short harvest intervals (40 years). This highly profitable practice has converted the region's vast pre-settlement old-growth forests to young forest landscapes, fundamentally changing their capacity to sustainably provide essential ecosystem services for local and downstream communities. Provisioning of drinking water, flood protection, fish and wildlife habitat, and recreational and cultural opportunities have been significantly degraded across the region. Indicative of these changes, PNW salmon populations have declined sharply from historic levels. In Puget Sound, for example, 22 of the estimated 37 stream-reach specific Chinook populations are now extinct, and many other indigenous fish populations are listed as endangered. In response, communities, tribes, and state agencies have formed cross-jurisdictional partnerships throughout the region to implement salmon recovery plans (www.psp.wa.gov/salmon-recovery-overview.php) to restore hydrological and ecological processes critical to salmon recovery, and more broadly, to the functioning of entire watersheds and ecosystem services upon which human health and well-being depend. Case studies in this region have focused on transfer of EPA watershed modeling tools (e.g., Visualizing Ecosystem Land Management Assessments, VELMA model) to assist such salmon recovery planning partnerships in achieving their environmental and community goals.

> *"Guided by sophisticated new modeling from EPA ORD's Western Ecology Division in Corvallis, combined with modeling used by the Nisqually Tribe for salmon recovery, the community forest's management team will selectively thin the property's timber stands to encourage old-growth forest characteristics and increase stream flow during the fall spawning season."*
> – Nisqually Land Trust Executive Director Joe Kane

Following NCF's successful implementation of VELMA, other groups requested technical assistance to inform other PNW salmon recovery planning efforts. Case study partnerships with Puget Sound's Snoqualmie Tribe and the State of Oregon Department of Fish and Wildlife (ODFW) are furthest along. A forthcoming report co-produced by EPA and the Snoqualmie Tribe describes the use of VELMA and Penumbra – a new stream temperature model – to identify best management practices for restoring salmon habitat in the Snoqualmie-Tolt River floodplain in Puget Sound. For a project in Oregon, we provided training for ODFW staff to use VELMA in support of their Oregon Coast Coho Conservation Plan (https://www.dfw.state.or.us/fish/crp/coastal_coho_conservation_plan.asp). The ODFW has produced a report (ODFW 2022) describing their applications of VELMA to assess potential impacts of climate change scenarios on streamflow and other fish habitat variables within 21 coastal Oregon watersheds, together totaling >10,000 square miles and supporting 56 distinct populations of the Oregon Coast Coho salmon.

The Nisqually Community Forest, Snoqualmie Tribe, and Oregon Department of Fish and Wildlife case study stories have prompted other new modeling partnerships with other PNW tribes, NGOs, and state and federal partners, and increased effort by EPA to streamline our tech transfer and training process.

1.3.3. San Juan Puerto Rico Case Study

The **San Juan Bay** Estuary Program (SJBEP), Puerto Rico was established in 1992 as part of the United States National Estuary Program under the Clean Water Act (US Estuaries and Clean Waters Act of 2000). The SJBEP seeks to address threats of degradation to the estuarine system (SJBEP 2000), including urbanization, aquatic debris, habitat loss, stormwater runoff, sewage discharges, and changing climate. Watershed management decisions, such as dredging areas of impacted hydrological flow, sewage discharge interventions, and mangrove restoration, have been developed as part of a comprehensive management plan and are being implemented to target these threats, and improve the condition of the estuary.

The estuary is one of the most heavily urbanized in the United States, with a large proportion of island residents living within its watershed. Socio-economic conditions vary widely across the watershed (Azar and Rain 2007), with some neighborhoods subjected to frequent flooding events that exacerbate human contact with wastewater discharges, including untreated sewage and stormwater runoff (Korfmacher et al., 2015). In consideration of this, management objectives of the SJBEP include improving multiple aspects of community well-being for people living in the watershed, including economic opportunities, cultural heritage, human health, education, public safety, social engagement, and good governance, in addition to more typical ecological goals of improving water quality and habitat. However, being able to predict the potential benefits of environmental management decisions is complicated by lack of data, uncertainty in relationships between environmental condition and human well-being, and widely varying socio-economic conditions throughout the watershed (Azar and Rain 2007).

The aim of the San Juan Puerto Rico case study was to develop scientific information to support and communicate benefits of estuarine management decisions as they are implemented, including estuarine condition and potential social, economic, and ecological benefits to people living in the estuary watershed, including:

- Understanding the impacts of land development and urbanization on the ability of mangroves to sequester carbon and regulate greenhouse gas emissions (Martin et al. 2020);
- Understanding the contributions of urban runoff, sewage runoff, and reductions in hydrological flow to nitrogen processing and water quality in the estuary (Oczkowski et al. 2019; Oczkowski et al. 2020);
- Applying ecological production functions (EPFs) to quantify ecosystem services production and material and energy flows throughout the estuary watershed (Balogh et al. 2021);
- Developing ecological benefits functions (EBFs) to link ecosystem services, such as flood-risk mitigation and water quality, to human health benefits, including vector-borne illness (e.g., Zika

virus; de Jesus Crespo et al. 2019a) and water-borne gastrointestinal disease (de Jesus-Crespo et al. 2019b);
- Conducting field work to link flooding and water quality to impacts on asthma-causing mold and bacteria (Betancourt et al. 2019) and vector-borne illnesses (Yee et al. 2019); and
- Quantifying spatial variability and disparities in social and economic indicators of human well-being throughout the estuary watershed, including connection to nature, cultural fulfillment, education, health, leisure time, living standards, safety and security, and social cohesion (Yee et al. 2020), and evaluating the degree to which ecosystem services such as green infrastructure and water quality may impact well-being (Yee 2020).

The case study directly engaged local partners, including the estuary program, community groups, local universities, and even local residents, in research efforts, which was essential for better understanding of local concerns, access to field sites, and informal communication and learning opportunities. More recently, in the aftermath of Hurricane Maria in 2017, community and conservation leaders in Puerto Rico are increasingly considering how green infrastructure solutions can reduce flood risk, improve livability, and support resilience of the island to future risks (Santiago et al. 2020).

Although the San Juan Puerto Rico case study research is specific to this sub-tropical urbanized location, and the overarching goals and management aspects of the SJBEP are unique, ecosystem services and human well-being are often underlying or even overtly stated goals of environmental management. As such case study research, including relationships between ecological condition and ecosystem services, and relationships between ecosystem services and human health and well-being, are broadly transferable to help monitor long-term degradation or improvement over time and to better communicate the potential benefits of ecosystem restoration or resource management.

1.3.4. Oklahoma Small Community Case Study

The Oklahoma small community case study was conducted in south-central Oklahoma, a region that encompasses approximately 10 counties. This area is centered around the Arbuckle Mountains, an ancient, eroded mountain range traversing approximately 70 miles across the region. There are numerous lakes and rivers that traverse this landscape and provide water resources and recreation opportunities. The Arbuckle-Simpson Aquifer underlies more than 500 mi.^{2} of south-central Oklahoma and is a vital groundwater source of the communities and the principal water source for approximately 40,000 people in the region. Dotted throughout this landscape are numerous springs that emanate from the Arbuckle-Simpson Aquifer, supporting not only base flow for rivers but also in some cases the primary water source for cities (Christenson et al. 2009). One of the springs, Byrd's Mill Spring, is the primary drinking water source for the city of Ada Oklahoma. Ada is in Pontotoc County and serves as the county seat. The Chickasaw Nation, a federally recognized Native American Nation, also has its nation headquarters located in Ada. The Chickasaw Nation and the city of Ada work collaboratively to ensure the sustainability and resiliency of the

Arbuckle-Simpson Aquifer and the water resources provided by this aquifer. Like all communities located in south-central Oklahoma, the Chickasaw Nation and the city of Ada recognize the ecosystem service value of the water resources provided by the aquifer and many of the supplemental impoundments in south-central Oklahoma. There is an ongoing collaborative effort between the city of Ada, the Chickasaw nation, various state agencies and other communities in south-central Oklahoma to both understand the hydrology and functioning of the aquifer and learn how to protect and utilize the resources provided by this aquifer across all of south-central Oklahoma.

In south-central Oklahoma many communities utilize both surface water and groundwater to sustain and better their communities. They recognize that the water resources in this region are the underpinning for much of the ecosystem goods and services that are provided in this landscape. They also recognize that protecting and preserving the overlying landscape features help sustain and improve numerous ecosystem goods and services, such as drinking water supply, flood control, recreational activities, wildlife habitat, and irrigation opportunities. There are many challenges that potentially impact the ability of the system to provide these ecosystem goods and services that these communities have come to rely on but in many cases take for granted. Like all communities there is an emphasis on promoting economic growth and providing desired services to the community. This growth, while good for the community, has impacts on the surrounding landscape area and the potential provisioning of ecosystem goods and services that communities rely on to sustain this growth. Southern plains communities in general experience protracted periods of drought, interspersed with periodic flooding events. There is a recognition that these challenges are shared by all the communities in the south-central Oklahoma region that they must collaborate to help solve these challenges equitably for all communities in south-central Oklahoma.

The Oklahoma Small Community case study is in south-central Oklahoma and worked across two lines of effort, one with the city of Ada focused on addressing the needs of the city and surrounding community and the second more broadly with the Chickasaw Nation focusing on the broader Arbuckle-Simpson Aquifer. While these efforts were handled separately, they are not mutually exclusive as there is much overlap between the two efforts. Both efforts were focused on using the EPA developed SDM approach Decision Analysis for a Sustainable Environment, Economy, and Society (DASEES, Dyson *et al*. 2019) to gather information on objectives of the project, develop measures appropriate for tracking these objectives, and develop alternatives that could be implemented to achieve the overall goals desired by the stakeholders in the communities.

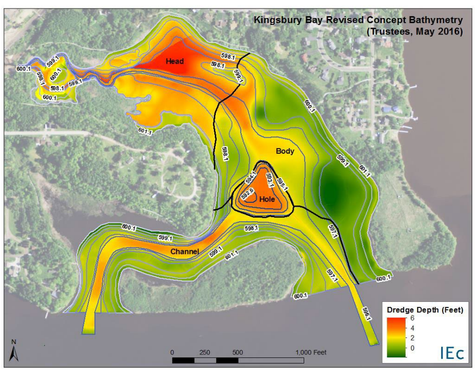
For the city of Ada effort, the focus was helping them gather the information in support of a water resources plan titled "Ada's Water Supply-The Path forward." The primary management question facing the city of Ada was how to develop a reliable and affordable source of water to meet the economic and social needs of the city of Ada and their surrounding communities. For the Chickasaw Nation effort, the focus was helping them gather information and support of efforts outlined in the plan titled "Arbuckle-Simpson Aquifer Drought Contingency Plan". The primary management question facing the broader Chickasaw Nation was how to sustain the water resources of the Arbuckle-Simpson Aquifer and the Blue River.

For both these efforts the decisional authority resides in part with either the city of Ada City Manager and the Ada City Council (city of Ada effort), the Chickasaw Nation tribal leadership, and state entities like the Oklahoma Water Resources Board (OWRB). There are decisions that can be made at the city of Ada level or the Chickasaw Nation level for each project without the involvement of State of Oklahoma regulatory agencies. But ultimately these local decisions must be within the bounds of the state regulatory constraints. That is why both these efforts included representatives from the state of Oklahoma regulatory agencies, like the OWRB, as part of their stakeholder engagement.

Both City of Ada and Chickasaw Nation efforts have completed workshops with the stakeholder group where the first phases of the SDM elicitation of objectives and associated measures were completed. The smaller decision-making groups for both efforts are now reviewing the identified objectives and measures to determine if the objectives listed are still current and relevant to the overall decisions that need to be made and if the associated measures for each objective are correctly assigned. The DASEES SDM process is flexible and iterative in nature and allows the decision makers and stakeholders to revise aspects of each of the steps as needed or appropriate. It is necessary to have the objectives and measures component of the process fully in place before moving to the alternative's development phase of the process. The work with both of these groups is ongoing (as of 9/30/22) and soon will be moving into the alternatives development phase of the project.

1.3.5. St. Louis River Case Study

The **St. Louis River (SLR)** case study was focused on a U.S. Environmental Protection Agency (EPA)-led health impact assessment (HIA; US EPA 2021) associated with a 200-acre habitat restoration project being implemented by the Minnesota Department of Natural Resources (MNDNR) at Kingsbury Bay and Grassy Point, which are adjacent to the City of Duluth on the Minnesota side of the St. Louis River. The HIA examined the potential public health implications of the restoration projects, including the intended restoration outcomes and how people will access and use the project sites following restoration. It also examined potential natural area improvements at both sites by the City of Duluth through the additions of trails, boardwalks, interpretative signage, fishing piers, birdwatching platforms, boat launches, and other amenities.



The 288-km long St. Louis River (9,412 km^2 watershed) flows through northern Minnesota into Lake Superior's western end. The mean annual discharge is 73.1 $m^3\ s^{-1}$ (USGS Gage # 04024000, Scanlon, MN). The lower river is bordered by the port cities of Duluth, MN, and Superior, WI. The river's outflow is constricted by a natural sand bar that limits exchange to two inlets, one located in each city. Periodic seiches (7.9-h duration) and weak semi-diurnal tides change the water height in the lower river by an average of 12.6 cm daily (Trebitz 2006). Seiche-driven inflows reverse river flow direction up to the first dam (Stortz and Sydor 1980), which is 38 km from the river mouth. The Duluth–Superior area developed rapidly during the late 1800s and early 1900s. Industrial and urban development resulted in uncontrolled discharges of sewage, industrial waste, organic contaminants (e.g., polychlorinated biphenyls, polyaromatic hydrocarbons, and dioxins), and heavy metals into the lower river (Dole and Wesbrook, 1907; MPCA and WDNR, 1992). Early water quality surveys reported sediment contamination from sawmill waste, tar substances, and organic matter, and episodic water column anoxia during summer (MSBH et al., 1929). These conditions virtually eliminated aquatic life in some areas of the lower river. Although water quality has improved dramatically since the 1970s (Bellinger et al., 2016), contaminated sediments remain widely distributed throughout the lower river, contributing to fish consumption advisories and causing concerns regarding ecological health (Hoffman et al. 2020, Janssen et al. 2021).

At Kingsbury Bay, the restoration goals were to restore open water habitat, improve vegetation quality, and restore the lower Kingsbury Creek channel, all of which have been impacted by extensive sedimentation that over time filled in a large portion of Kingsbury Bay. Amenities that were considered included trails, boardwalks, interpretative signage, a stormwater demonstration project, fishing piers, a kayak launch, and a swimming beach. At Grassy Point, the restoration goals were to restore sheltered bay habitat and improve both sediment and vegetation quality, all of which had been impacted by extensive wood debris that had been left by two sawmills that formerly occupied the site. Amenities that were considered included trails, boardwalks, bridges connecting created islands, interpretative signage, birdwatching platforms, fishing piers, and a kayak launch.

In this case study, the HIA was used to address two sets of questions, which each generated a separate analysis. First, the HIA addressed the different health outcomes associated with three different versions of the project design which varied in geographic extent. These were formal designs (that is, there were defined project areas and associated scopes of work) brought forward by a state agency for consideration. Essentially, the three proposals ranged from addressing only the most impacted portions of the sites (lowest extent) to addressing all impacted portions of the site (greatest extent). Second, the HIA addressed health mitigation and health promotion by providing stakeholders the opportunity to recommend design or implementation changes that would limit or mitigate negative health impacts or improve positive health impacts. These informal alternatives were brought to the decision-makers for their consideration in a format that explicitly linked the health impact being addressed (e.g., increased traffic from trucking out sediment by road through the neighborhood) and the associated recommendation (e.g., move the sediment by barge over water to prevent increased traffic).

The underlying environmental management goals are to address beneficial use impairments in the lower St. Louis River through the Great Lakes Area of Concern (AOC) program, which is under the auspices of the United States-Canada Great Lakes Water Quality Agreement (GLWQA; epa.gov/grtlakes/glwqa/). The GLWQA designated 43 Great Lakes communities as AOCs, which are locations that have highly degraded chemical, physical, or biological attributes (referred to as beneficial use impairments, or BUIs). Nine BUIs were identified for the St. Louis River AOC: restrictions on fish and wildlife consumption; degraded fish and wildlife populations; fish tumors and other deformities; degradation of benthos; restrictions on dredging; excessive loading of sediment and nutrients to Lake Superior; beach closings/body contact; degradation of aesthetics; and loss of fish and wildlife habitat (MPCA and WDNR, 1992; MPCA, 2013). To remove BUIs and delist an AOC, the U.S. Environmental Protection Agency (EPA) requires that delisting targets and corresponding management actions such as specific remediation or restoration projects be established by local advisory groups through a remedial action plan (RAP; US Policy Committee, 2001).

In addition to the environmental management goals, as part of the St. Louis River Corridor Initiative, the City of Duluth has been enhancing recreational amenities and enhancing public access along the St. Louis River. Kingsbury Bay sits at the mouth of Kingsbury Creek, downstream from the Lake Superior Zoo and neighboring Fairmount Park, one of the City of Duluth's targets for renewal as part of the St. Louis Corridor Initiative. Kingsbury Bay is public land that connects three important public facilities – the Lake Superior Zoo, Indian Point Campground, and the Western Waterfront Trail (now known as

Waabizheshikana or "The Marten Trail"). Kingsbury Bay is located about one mile upriver from Grassy Point. Grassy Point is a natural area with amenities to support outdoor recreation at the northern end of an extended Western Waterfront Trail and the only public river access in the Irving Neighborhood of Duluth.

The HIA was conducted to provide voluntary, evidence-based recommendations to MNDNR and the City of Duluth to address disproportionate health impacts (i.e., unequal sharing of health burdens and benefits), mitigate potential adverse health impacts, and enhance potential health benefits of the projects. MNDNR was responsible for ecological restoration design and implementation on public lands and waters. They also could support a limited amount of trail and boardwalk construction post-restoration. The City of Duluth is responsible for park planning, operations, and maintenance at Grassy Point, Kingsbury Bay, and adjacent Indian Point Campground (a public facility and natural area), as well as the riverfront trails connecting these two natural areas. The partners for the HIA were MNDNR and City of Duluth, who were also the decision-makers. At the first workshop held for community members (i.e., individual citizens), twenty-seven (27) community members attended. Most of the individuals represented themselves; however, a few also represented other interests, including neighborhood organizations, local business, parks-related interest organizations, and environmental organizations. Twenty-two (22) individuals attended the first workshop held for stakeholders (i.e., municipal, county, state, federal, and tribal agencies, as well as recreational interest groups).

Seven health pathways were examined: Water Habitat and Quality; Equipment, Operation, Traffic, and Transport; Air Quality; Noise and Light Pollution; Crime and Personal Safety; Recreation, Aesthetics, and Engagement with Nature; and Social and Cultural. Through these health pathway analyses, both positive and negative health impacts associated with ecological restoration and park improvement were identified. Negative health impacts were generally short-term and associated with construction activities or temporary park closures during construction. Positive health impacts were generally long-term and associated with future activity within the park areas, experiencing a restored riparian, wetland, and riverine habitats.

A final set of seventy-three (73) evidence-based recommendations were provided by the HIA. Adoption of any of these recommendations by the decision makers is voluntary. The HIA Project Team identified recommendations to maximize the potential positive health impacts (e.g., improved water habitat and quality, as well as opportunities for outdoor recreation, social interaction, and cultural resources), minimize or avoid the potential negative health impacts (e.g., air, noise, and light pollution related to construction, as well as impacts to residents and recreational users), and offer decision alternatives and health supportive measures (e.g., cultural and social resources, as well as communication and informational signage). At the time of the HIA (2018), the City of Duluth indicated they would consider recommendations directed towards park construction, operation, and maintenance as part of their park planning process, which would occur after the restoration construction period was complete. Forty-six (46) of the recommendations identified MNDNR as a responsible party for implementation. As of April 2019, twenty-two (22) of the 46 recommendations had been adopted in design and MNDNR was interested in implementing 5 of those 22 recommendations further as the habitat restoration work progressed (See Appendix B for details). In addition, MNDNR was also interested in adopting another 23 of the HIA recommendations in the future (data not shown). That is, as of the design process, the MNDNR had adopted nearly half of the recommendations, all of which were intended to improve the health outcome of the project, and many of which were also intended to improve the ecological outcome, as well.

1.3.6. Tillamook Bay Case Study

The Tillamook Estuaries Partnership (TEP) is an organization within EPA's National Estuary Program whose mission is to protect and restore the health of five estuaries and their watersheds on the northern Oregon coast (including Tillamook Bay) while supporting economic and recreational activities (TEP 2021). Through their direct efforts and partnerships with Federal, State, and County agencies, businesses, residents, and non-governmental organizations, TEP serves as a coordinator for addressing major issues facing coastal communities: loss of key fish and wildlife, declining water quality, increased erosion, and increasing flooding. Whereas shellfish are an important natural resource for the estuaries, TEP shares concerns with Oregon Departments of Fish and Wildlife (ODFW), Agriculture (ODA), and Environmental Quality (DEQ) to ensure the sustainable production of oysters and bay clams, to improve water quality, and to minimize the risk of consumption of bacteria-contaminated bivalves. Those issues are articulated in TEP's Comprehensive Conservation and Management Plans under their Key Habitat Action Plan and their Water Quality Action Plan Goals (TBNEP 1999). In this case study, we partnered with TEP, ODFW, ODA, and DEQ to identify and address knowledge gaps (i.e., locations of suitable habitat for bay clams within Tillamook Bay; spatial and seasonal environmental drivers of elevated concentrations of fecal bacteria within Tillamook Bay) that could improve sustainability of the shellfisheries and improve the shellfish harvest closure decisions. The primary tools for this cases study research were quantitative models that align shellfish abundance with habitat characteristics and that predict fecal contamination of shellfish habitat based on land use and hydrology. Both models were designed to inform decision making about shellfish harvesting.

Source: Used by Permission, Don Best Photography.com.

Tillamook Bay is the second largest estuary in Oregon, with an area of 34 km^2 and an average depth of 2 m. Subject to semi-diurnal tides, approximately half of the estuary is drained twice daily. Numerous intertwined tidal channels bisect extensive sand and mud flats, most of which are navigable only by shallow-draft boats. Five rivers (Tillamook, Trask, Wilson, Kilchis, and Miami Rivers) drain into the bay from the surrounding 1546 km^2 watersheds (TBNEP 1999). Most of the watersheds are undeveloped, temperate rainforest, but the lowlands surrounding the bay supports three towns (Tillamook, Bay Center, Garibaldi), rural homes, and extensive dairy agriculture (ca. 100 km^2; TBNEP 1999). The economy of the Tillamook basin is based on dairy farming, forestry, tourism, and shellfisheries, including oyster aquaculture and commercial harvest of bay clams. Tourism, shellfisheries, and residential real estate are heavily dependent on the condition of Tillamook Bay estuary for the production of ecosystem goods and services (TBNEP 1999):

- finfish, crabs and clams for recreational and commercial fishing;
- wildlife and scenic waterscapes for viewing by hikers, homeowners, and passers-by; and
- clean water that supports the production of clams, oysters, crabs, fish, and wildlife; and facilitates safe contact with the water by boaters, anglers, and shellfish harvesters.

The case study was primarily focused on the Tillamook Bay estuary where oyster aquaculture and commercial and recreational clam harvesting occur. That is the area in which our research was conducted. However, the secondary geographic scope of the study includes surrounding watersheds that are the predominant sources of bacterial contamination that trigger closures of shellfish harvesting. Oysters produced via aquaculture and naturally occurring bay clams are important resources for the commercial fisheries, recreational harvest, and tourism of communities along the Oregon coast, including around Tillamook Bay. Sustaining the production of these shellfish species depends on the availability of suitable habitat and water quality conditions favored by the bivalves. Sustaining their harvest depends in part on low risk to consumers for developing gastrointestinal illness caused by pathogenic microorganisms in shellfish tissues. Urban and rural residential development, farms, pets and wildlife contribute fecal bacterial contamination to Tillamook Bay via runoff into the bay's tributaries or non-point discharge directly into the estuary. As summarized in TBNEP (1999), Tillamook Bay has experienced bacterial pollution problems for decades which led to a federally mandated, Oregon state shellfish management plan adopted in 1991. The plan regulates shellfish harvest closures in response to actual or expected elevated concentrations of fecal bacteria in the bay.

The case study research culminated in two peer-reviewed, scientific journal articles that described new methods for (1) modeling and mapping suitable habitats for five species of bay clams harvested commercially and recreationally in Tillamook Bay (Lewis et al. 2019) and (b) identifying the relative and combined contributions of key environmental factors (i.e., tides, wind, precipitation, river flow) to seasonal and spatial (i.e., regions of the Bay) differences in fecal bacteria concentration (Zimmer-Faust et al. 2018). The latter study also developed a statistical model that estimated concentrations of fecal bacteria based on measurements of those key environmental factors. The articles were well received by TEP and the Oregon State agencies but have yet to be put into practice due to lack of resources within the agencies.

1.4 Structure of this report

This report is organized so to provide comparative entry points for the SDM cycle and the 17 practical strategies for community-based decision support. For this reason, we will not walk through each case study independently but work through the SDM cycle looking at the case studies for common ground related to their characteristics. This approach will allow readers working in other communities to see how the approaches used in these case studies may inform their use elsewhere. Section 1 is an introduction and gives background on the six case studies considered here (Table 1.1). Section 2 is organized around the six steps in the SDM cycle and in each step the case studies will be examined for how they approached that step, strengths and weaknesses of the step and common ground across the case studies that may allow for transference of an approach to novel sites. The common themes across the six steps are transferability and utility of an approach. In Section 3 we return to the subject of entry points as a guide for the transferability of approach by directly examining what makes an approach transferable across sites and between issues. This Section includes an examination of data gaps and future work to maximize utility of FEGS and the SDM process for community-level decision making. Finally, Section 4 contains supplementary information for the six case studies that will be useful to readers interested in application of FEGS and SDM at a novel location.

1.5 Quality assurance and quality control

This report contains qualitative environmental data collected from decision making tools with the

Table 1.1 Summary table of case study sites indicating important case study properties for the decision process.

Case study site	Primary decision point of contact	Decision context	Decision Scale (USGS watershed boundaries)	Focal natural capital	Major stakeholder groups	Critical FEGS	Decision trade-offs	Action taken/evaluated
1.3.1 Mobile Bay, AL	Mobile Bay National Estuary Program	Watershed restoration (water quality)	HUC12 (partial)	Stream habitat quality	Residents of Mobile and Baldwin Co.	Recreational access, wildlife abundance and diversity	Priority setting among multiple sub watersheds	Stream restoration activities implemented
1.3.2 Pacific northwest	Nisqually Community Forest (NCF); Oregon Department of Fish and Wildlife (ODFW)	Restoration trade-offs: fishing, forest products; tribal communities	HUC10	salmon, forest products; drinking water	Nisqually Tribe; Nisqually Valley communities; fishers; boaters; forest industry & shareholders	Harvestable resources, traditional lifestyle, recreational opportunities	Sustainable forest harvest; Fishing and fish habitat; wellbeing benefits to local tribe & communities	NCF is 3 years into implementing VELMA model-informed forestry practices for long-term forest and salmon habitat improvements
1.3.3 San Juan, PR	San Juan Estuary Program	Impacts of Urbanization	HUC10	Flood protection	Residents of the San Juan Metropolitan area	Natural flood protection, wildlife abundance and diversity, clean water	Urban development and health and well-being benefits of the estuary	Flood mitigation and nutrient reduction activities
1.3.4 Ok small community	City of Ada, OK; Chickasaw Nation	Water conservation planning	HUC10 to HUC12	Surface and aquifer water	Resident of Ada, OK and surrounding communities. Residents of Chickasaw Nation.	Useable Water Supply (quality and quantity)	Supply of water for economic development, recreation, and environmental conservation-in-stream flow	TBD multi-user water plan based on DASEES analysis

Case study site	Primary decision point of contact	Decision context	Decision Scale (USGS watershed boundaries)	Focal natural capital	Major stakeholder groups	Critical FEGS	Decision trade-offs	Action taken/evaluated
1.3.5 St. Louis River, MN	State of Minnesota	Urban estuary restoration and neighborhood revitalization	HUC12	Coastal wetland and riparian habitat quality	Residents living in adjacent neighborhoods, as well as surrounding communities (Duluth, MN; Superior, WI; Fond du Lac Band).	recreational fishing, birding, cultural value, public health, biodiversity, viewscapes	Design options for habitat restoration and associated shoreline amenities	Shoreline restoration option chosen and implemented; trail, fishing pier, and boardwalk design chosen and implemented
1.3.6 Tillamook Bay, OR	Tillamook Estuaries Partnership (TEP)	Water quality (bacteria) effects on bivalve fisheries	HUC10	Fishery species and habitat quality	Shellfish growers and harvesters; state natural resource management and environmental quality agencies	Harvestable resources, recreational opportunities, water quality	Whether to use new model to inform shellfish harvest closures; whether to use habitat suitability models to identify location of shellfish populations	New model developed for estimating probability of bacterial water quality exceedances in wet and dry seasons. Suitable habitat identified for multiple bivalve species.

intended purpose of assisting community stakeholders in their decision making and applying structured decision-making approach for proof of concept. The development and application of the decision support tools was done consistent with the requirements outlines in the Quality Assurance Project Plan (QAPP) for *Coordinated Case Study Synthesis Report,* J-GEMMD-0030992-QP-1-1(approved March 10, 2020). Data quality objectives were described in the QAPP. Any calculations or results generated with the decision support tools were for demonstration purposes only.

Peer reviews were completed and discussed for all research described herein. The conclusion of the QA and peer review process is that results presented in this report accurately reflect the course of the research and are scientifically valid and defensible.

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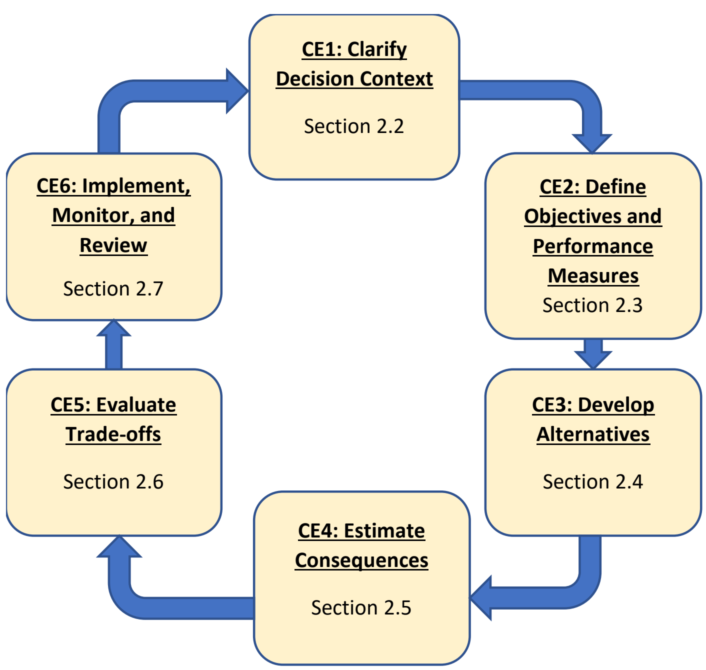


Figure 2.1 Structured decision-making cycle indicating identification of Critical Elements (CE) and report section links for each one.

Section 2. Case study common elements for the decision framework

2.1 Introduction to Section

This Section describes the application of practical strategies for decision support (Yee et al. 2017) in six community case studies within the US and its territories. The six case studies were selected to provide a variety of decision contexts, decision authorities, stakeholder composition and involvement, and geographic location. While each case study is unique, they each contain common elements (CE) that provide a basis for comparison and a standard for assessment of transferability. These common elements are organized around the six steps of SDM (Figure 2.1), as advocated in our practical strategies approach, such that each case study:

1. Applied approaches to clarify the decision context (CE1),
2. Identified relevant objectives and performance measures (CE2),
3. Developed or identified decision alternatives (CE3),
4. Developed scientific information and models to estimate consequences (CE4),
5. Communicated potential tradeoffs and other information to support decision-makers in making a decision (CE5), and
6. Evaluated outcomes and supported adaptive learning as decisions were made (CE6).

Case studies often approached each of the elements differently; however, through comparison of the different approaches and identification of similarities, this Section seeks to identify common themes that emerge. Each common element is addressed in a sub-section with an overall theme of addressing transferability and utility of approaches used across the case studies. Details are provided on each case study in Section 1.3. More detail on outcomes is available in the published works specific to each case study, which are described in Appendix A.

2.2 Clarify Decision Context (CE1)

The EPA case studies take an approach of using the SDM framework to demonstrate how inclusion of final ecosystem good and service (FEGS) thinking can improve social and environmental outcomes of research, management, and decision-making processes (Yee et al. 2017). The first step in any SDM process is clarifying the decision context. The decision context is "the question or problem that is being addressed" and "the scope and bounds" of the decision (Gregory et al 2012). This initial step in SDM is highly influential on the direction of the rest of the decision-making process. Even if this step is not taken in a deliberate fashion, every decision begins with a context that informs subsequent decision maker actions. If the decision context is not defined deliberately, the assumptions made about the context can lead to a less effective decision-making process with less appropriate results. For example, beginning a flood mitigation project with the question of "Where should levees be placed?" leads to a very different set of options and solutions than the question of "What flood mitigation projects should be considered?". When defining the decision context is overlooked, the decision process begins with assumptions about goals rather than a deliberate articulation. "Asking the right questions to define context at the beginning of the decision-making process is essential to correctly defining the problem and avoiding surprises" (http://dssresources.com/faq/).

Clarifying the decision context is critical because it allows for all aspects of the decision to be made visible so that the work has the appropriate focus. This can decrease the likelihood of unintended social, economic, or environmental outcomes (Bradley et al. 2015). Properly defining the decision context can also help in identifying the needed resources and information and ensure important values and participants in the process are not overlooked (Carriger and Benson 2012, Yee et al. 2017). The more holistic and comprehensive approach up front also includes the expansion of the viewpoints and values being considered.

Choosing a decision context has many aspects, and the relative importance of those aspects will shift from decision to decision. Defining the end goals, however, is always a critical aspect of defining the decision context because the end goals are particularly informative for determining what other aspects are needed. To return to the flood mitigation project example, if the end goal is to assess all flood mitigation options, defining the decision context will require substantially more information on a variety of topics than it would if the end goal is to construct levees.

The number and complexity of decision context aspects means that defining the decision context can be challenging. Gregory et al. (2012) gives a straight forward description of the decision context (the question being addressed and its scope and bounds), but in application this covers an innumerable range of components, both within and beyond control of the decision makers, including considerations such as decision drivers, policy objectives, temporal and spatial scales, who needs to be involved, how they need to be involved, roles and responsibilities of the decision team, and the financial and regulatory aspects of the decision (http://www.structureddecisionmaking.org, http://dssresources.com/faq/). There are, however, several key aspects that should always be examined to achieve a better understanding of the overlapping factors that influence decision options and outcomes (Table 2.1). In this Section we will examine how these key aspects were addressed in the six case study examples, how these key aspects led to the case study decision contexts, and how these examples can help establish decision context in other similar situations.

Take Home: Every decision begins with a context that informs subsequent decision maker actions. Explicit upfront efforts to clarify the decision context increase transparency and help clarify what other common elements are needed for a project.

2.2.1 Big picture drivers

Projects and decisions often have multiple drivers, but a big picture driver sets the stage for the decision process. The big picture drivers may be programs, plans, or some other guidance that provides general direction that guides the context. This is important because being clear about the big picture drivers can help ensure specific decisions meet policy goals and are context relevant. Clearly articulating the overarching drivers behind the project helps set the bounds for the additional aspects of the decision context that need to be clarified.

Table 2.1 Key aspects of the decision context.

What else governs decisions?	Explanation
Big picture drivers	This is the big "why" this decision is important
Intermediate drivers	Might be similar to big picture drivers, but might be on a different time/spatial scale
Secondary or tangential drivers	The additional or co-occurring benefits of the decision, but not the primary focus
Scale	Temporal and spatial boundaries
Scope	The boundaries of the decision
Resources	Financial, technical, personal resources
Authorities	Decision makers and implementation bodies
Regulatory frameworks	Necessary permits or processes to be followed

Our case studies provide several different examples of big picture drivers. Three of the case studies are situated in National Estuary Program (NEP) sites (Mobile, Tillamook, and San Juan; https://www.epa.gov/nep/overview-national-estuary-program). The NEPs develop Comprehensive Conservation and Management Plans (CCMP) to articulate their priorities and vision for the estuaries. The St. Louis River case study is part of the Areas of Concern program, and that work is centered on restoring beneficial use in identified Areas of Concern. Less formal partnerships include local agreements such as the Civic-Tribal agreements on decision making in the Southern Plains case study. In all these case studies, the work must fit within the larger goals of these programs. The most straight-forward big picture drivers are adherence to state/federal laws governing use of natural resources, such as shellfish harvest rules for Tillamook Bay, or salmon management in Puget Sound, WA. Explicitly identifying this is the first step in defining the decision context.

Take Home: Explicitly identifying big-picture drivers, the first step in defining the decision context, helps set the boundaries of a decision involving an environment or FEGS component.

2.2.2. Intermediate drivers

The intermediate drivers of the project may be similar or the same as the big picture drivers, but on a different temporal or spatial scale. Where big picture drivers may work on a timescale of decades (i.e., the time it takes to implement a comprehensive plan), intermediate drivers may represent one project or component of a comprehensive plan. Intermediate drivers can be explained as the "why right now" for your decision context, as these often represent the urgent or timely need. For example, the big picture driver in the St. Louis River AOC is to restore the beneficial uses of the ecosystem. To implement this big picture driver, there are many individual projects remediate legacy sediment contamination and habitat to restore habitat for fish and wildlife, improve aesthetics, ensure clean drinking water, and address sediment or nutrient loading. More specifically, the habitat restoration at Grassy Point and Kingsbury Bay along the St. Louis River is an example of an individual project that improved water and sediment quality, improved ecological value and aesthetics, and will provide amenities for human use. Clearly identifying the intermediate drivers of a decision, especially if they differ from the big picture drivers, will help identify aspects of the decision context that need to be clarified up front. The goal of habitat restoration, for example, would point to different information needs than a goal of sediment remediation. Parsing out intermediate from big picture driver is important as the tendency is to move directly to things like specifics of site restoration, but this needs to be linked to the big picture to have the most impact. The NEP-focused case studies included both big picture and intermediate drivers in the development of the CCMP, to capture both long and short-term goals for management. In the Oklahoma small community case study formal tools (DASEES; Dyson et al. 2019) were used to fully parse out drivers of water use in the community through focused stakeholder discussion and the development of an objective hierarchy that seperated fundamental objectives (e.g., provide water to all users) from means objectives (e.g., create a water use plan).

Take Home: Intermediate drivers of a decision are usually the easiest to identify. Clearly identifying where they differ from big-picture drivers, helps identify aspects of the decision context that need to be clarified up front and is especially helpful for complex decisions involving an environment or FEGS component.

2.2.3 Secondary or tangential drivers

Many environmental projects provide benefits that could be considered by-products of the original decision. Those benefits help to explain how society and the economy benefits from environmental projects. For example, community and ecological revitalization after environmental clean-up could be considered a benefit to communities. One example of these benefits would be the bike and walking trails that have been constructed next to waterways where sediments have been remediated and habitat has been restored as identified in the St. Louis River case study (Williams and Hoffman 2021).

The community case studies used different approaches to identify the secondary or tangential benefits that would result from environmental projects. One of the lessons from the case studies is that the benefits can best be part of project planning if stakeholders are aware of the possibilities. For example, SDM tools like DASEES or HIA explore all the potential drivers of a decision as a way of engaging stakeholders in the decision. In other case studies exploration of secondary outcomes, such as health impacts (San Juan Puerto Rico), economic revitalization (St. Louis River), or improvement of wildlife habitat (Mobile Bay, Tillamook Bay, Puget Sound) were specifically included in data collection or models to inform decisions even when the decisions have well-defined primary drivers .

Being clear about secondary or tangential drivers allows more stakeholders to be deliberately included in the decision process, while not necessarily letting them pull focus from the primary drivers of the work. There is a balance to be struck between maximizing stakeholder inclusion and minimizing decisional complexity. Using the right tools can help strike that balance while demonstrating targets of opportunity for increasing the benefits from a decision.

Take Home: Being clear about secondary or tangential drivers allows more stakeholders to be deliberately included in the decision process, while not necessarily letting them pull focus from the intermediate drivers of the work and increases opportunities for environmental benefits to be identified.

2.2.4 Scale

It is critical to be clear about both the temporal and spatial scales of the project. This includes the scales on which the project itself is operating, as well as the ideal scales for the work in question. Clarity about project lengths can help garner support for long-term projects (Wilson, 2016; Yee et al. 2017). It is critical to acknowledge how much time and in what space is needed to achieve desired outcomes, as well as any limitations of the work that can be done within the existing project scale. This clarification is especially necessary when trying to match landscape-scale processes with more limited project scales. For example, planning for water use in Oklahoma small communities means operating on two different timescales. First, communities need to implement community-level infrastructure projects to manage water use and accommodate economic development to serve their immediate needs. At the same time, the communities have been engaged in long-term planning with other communities that draw on the Arbuckle-Simpson aquifer to ensure water for future use. Similarly, the San Juan Puerto Rico case study involves the integration of watershed-scale management and restoration activities with smaller-scale health and environmental justice issues in individual neighborhoods prone to flooding. Defining the decision contexed means deciding on the appropriate scale as a necessary boundary for the decision.

Take Home: It is critical to be clear about both temporal and spatial scales of a project involving environmental benefits, including the scales on which a project itself is operating, and the ideal scales for the work in question.

2.2.5 Scope

It is important to clarify what decision factors fall within the scope of the project. Another way to think about the scope of the project is the project boundaries. In this context, boundaries may be programmatic or geographic. Much like scale, scope is often defined in practice by decision makers. Examples from the case studies would indicate that this is one of the decision factors over which decision makers have more control and provide insight for how to collaboratively determine the project scope. For example, the scope for the habitat restoration and park improvements in the Kingsbury Bay-Grassy Point (St. Louis River case study) habitat restoration provide an illustration of how project scopes may appear to overlap. The project scope for the Minnesota DNR was the habitat restoration in the project area including dredging, sediment transportation, capping, and island construction. After the completion of the habitat restoration, the City of Duluth will undertake projects to provide access to the newly restored habitat including constructing trails, fishing piers, and parking. There is no one best way in practice to clarify project scopes. One case study described a process of workshops, phone calls, and emails to organize projects. Another case study explained community members made decisions for their own communities but were respectful to the collectively defined regional goals. One theme that emerged from the case studies is that the decision makers often define the scope, and it is often closely related to authority invested in the project or the decision makers. Scope should be clarified during the decision process as it demonstrates areas for collaboration and integration of effort. Regulatory decision making may have a rigidly defined scope, but it can be expanded through partnerships. A good example of this is the NEP system active in three of the case studies, and the cooperative agreement that formed the AOI focus in the St. Louis river case study.

Take Home: It is important to clarify what decision factors fall within the scope of a project, ideally done during the decision process, to identify boundaries (e.g., programmatic, geographic, environmental benefit) and clearly identify areas for collaboration and integration of effort among stakeholders.

2.2.6 Resources

Having a full understanding of the resources (i.e., financial, personnel, in kind, etc.) that are needed and available is necessary to develop a realistic universe of project objectives and decision alternatives. Resources may be closely related to other decision factors including scope, intermediate drivers, and stakeholders. Resources are not only financial, and context should include any resource that may be limiting and therefore can affect the context of the outcomes, such as technical, personnel, and in-kind contributions.

The most often cited resources in the case studies include:

- Financial resources. Financial resources were mostly of two kinds – funds to plan and funds to implement projects
- Technical resources included required data, contractors, modelling outputs
- Partnerships are also a resource and include governmental partners, universities, nongovernmental organizations. They often provide in-kind resources such as meeting space, administrative support, and supplies.

Understanding available resources helps to organize decision processes as they encapsulate what you can and cannot do, but they are also important opportunities for engaging others and creating collective decisions.

Take Home: Understanding available resources helps to organize decision processes as they encapsulate what you can and cannot do, but they are also important opportunities for engaging others and creating collective decisions. Defining this aspect of the decision context sets the stage for making sure that the alternatives being assessed, and the tradeoffs being explored later in the decision process are transparent and well accepted.

2.2.7 Authorities

Authorities in a decision context are about power and responsibility – the individuals or organizations with the authority to implement or interfere with any aspect of the project. This includes those involved in the project team, as well as those who are not. Defining authorities can be complicated because many environmental decisions face overlapping authority structures. In our case studies, authorities included state agencies, local governments (i.e., city and county), USEPA Regional Offices, tribal governments, and USEPA programs. Many of the case studies experienced overlapping authorities with jurisdiction in the spaces they were working. For example, in the San Juan case study, NEP activities are conducted in partnership and coordination with the government of Puerto Rico, local community groups, USEPA Region 2, and the US Army Corps of Engineers (USACE); often with different groups responsible for or leading different aspects of a decision. A comprehensive understanding of authority will include both who will make the decision, the roles of different authorities in the decision process, as well as who can influence the decision.

Take Home: Defining a comprehensive look at authorities includes articulating who makes the decision, who can influence the decision, and the roles of different authorities in the decision process.

2.2.8 Regulatory framework

Authorities and regulatory frameworks are closely related. It is important to have an understanding of any regulatory frameworks that will need to be navigated during the life of the project, especially those that could limit actions taken. One of the most common interfaces with regulatory programs a decision will face is permitting. Some questions to ask are 1) are there regulations to follow and 2) will the project need permits. For example, the Tillamook Bay Estuary Partnership (TEP) is a non-profit organization for the NEP. All NEP activities are directed toward attainment or maintenance of water quality, which assures protection of public water and propagation of shellfish, fish, and wildlife, and allows recreational activities (US Code 1987). A regulatory framework may not be the only authority for a decision, but it usually is the most obvious element and therefore represents a good starting place.

Take Home: It is important to understand any regulatory frameworks that need to be navigated during the life of a project, especially those that could limit options or actions.

2.2.9 Stakeholders

Stakeholders are crucial to the process of defining the decision context because they may be collaborators, provide resources, or have technical or local knowledge. Alternatively, stakeholders can oppose decisions. Involving as many stakeholders as possible ensures that decisions represent diverse perspectives. For example, the three case studies associated with NEPs (Tillamook Bay, Mobile Bay, and San Juan) prioritized stakeholder engagement from the beginning to better understand stakeholder needs and concerns and to better communicate outcome value to the public. This approach of leveraging partnerships for stakeholder engagement can be helpful to regulatory authorities who may not have the resources to fully engage the public on their own. In a similar manner the Health Impacts Assessment used in the St. Louis River case study and the DASEES tool used in the Oklahoma Small Community case study both maximize stakeholder input and inclusion. Stakeholder identification and the level of stakeholder involvement suitable for a particular decision context is always case specific, yet all six case studies here formally engaged the public as part of efforts to support decision-making, which suggests this is an important and useful element.

Take Home: Stakeholders are important in decisions and involving as many stakeholders as possible ensures decisions represent diverse perspectives, including providing technical and local environmental knowledge. The level of stakeholder involvement suitable for a particular decision context is always case specific.

2.2.10 Conclusions

There are a variety of approaches for defining the decision context ranging from informal *ad hoc* scoping discussions to methods and tools designed specifically for the task. No matter the approach, conceptual models can help visualize cause and effect and other types of connections between aspects of the decision, as well as helping decision makers visualize those elements holistically. Web-based tools such as the EPA developed DASEES tool provide users with a suite of approaches for navigating the SDM process beginning with scoping out the decision context (Yee et al. 2017). When formal tools are not used or available, taking an iterative approach or collecting decision context information directly through surveys or formal committees can be an effective way to ensure a broad perspective is being taken at this step. The Mobile Bay Case Study used information from surveys and panel discussions to develop its decision context and the St. Louis River Case Study developed a series of conceptual pathways that were then verified by research teams assigned to each pathway. These tools are all highly transferable between sites and issues so that they can be applied at other sites. Whatever approach decision makers take, developing the decision context in a deliberate fashion at the beginning lays a solid foundation for the next steps in the implementation of a project. Once the decision context is defined, the next steps in the decision framework are to define objectives within the decision context and identify useful metrics connected to these decision objectives.

Cypress stand near Monroe, LA. Photo credit – Tom Malmay.

2.3 Identify Objectives and Performance Measures (CE2)

Support for local decision making is most effective if the decision context is associated with clear achievable objectives. For simple decisions, such as whether to build levees in a flood prone community, the objective is self-evident (e.g., increase public safety). However, for more complicated, multi-faceted decisions, objectives may cover a myriad of issues and have multi-faceted, even conflicting objectives. The SDM process prioritizes defining clear, unambiguous objectives prior to assessment in a transparent and inclusive manner (Yee et al. 2017). These objectives are broken into types starting with fundamental objectives, but also including means, process, and strategic objectives. Taking the time to figure out "what do we care about?", rather than jumping straight into "what should we do?" can be more time-consuming but has the advantage of the decision options being dictated by the objectives rather than the other way around. The SDM process also separates fundamental and the types of intermediate objectives with the former linked directly to achieving broader community goals (e.g., increasing public safety) and the latter being mechanistic mid-points that best measure if a particular action was successfully implemented (e.g., levee reduces flooding). A structured stakeholder engagement process is not always feasible and other options for defining objectives that should also be considered (Table 2.2). Three ways we can evaluate options for defining objectives are inclusiveness of the process to stakeholders, portability of the process across communities and issues, and objective effectiveness to positively impact the community .

Table 2.2 Description of three categories for development of objectives and performance measures in community case studies.

Objective process	Description	Stakeholder engagement	Professional engagement	Example case studies
Stakeholder derived	Structured stakeholder engagement process beginning with agreement on objectives	Central element involving a cross-section of stakeholders affected by targeted decisions	Variable and generally treated like stakeholders	St. Louis River (HIA) Ok Small Comm. (DASEES)
Expert derived	Engagement process involving a focus on decisional experts (e.g., water quality – state environmental scientists)	Experts are the stakeholders	Structured engagement process of experts for specific decision context	Mobile Bay San Juan St. Louis River
Policy derived	Objectives set in internal policy discussions typically associated with legal standards (e.g., Clean water act)	Experts consulted on implementation of policy	Stakeholder involvement limited (e.g., public comment)	Tillamook Bay Puget Sound

Like objectives, performance measures (PM) are an important element of the decision process. Performance measures are most often used for assessment after decision implementation. Yet, any decision (e.g., commitment of limited funds) that involves trade-offs can be informed with an accepted measure of likely return on investment. The SDM process involves the development of PM directly from established fundamental objectives (Yee et al. 2017). These PM can in turn be integrated into an assessment as response variables for modeling or empirical data gathering. Well-selected PM are measurable representations of objectives and effective in communicating change in an unambiguous way. PM can also be inherited from the past, derived from assessment techniques, or simply chosen based on the likelihood of changing in response to the action at hand, if they are representative of fundamental objectives.

Generally, performance measures can effectively measure one of three things that can be referred to as three Tiers of success for any decision. First Tier is that the decision was successfully implemented. In the case of building levees, this might be a minimum length of levee wall constructed. Second Tier is that the system responded adequately to the decision, such as number of flood events per year in levee-protected areas is lower. The third Tier is that stated fundamental objectives for the decision were met, such as number of claims for private flood insurance is lower. All three Tiers are meaningful measures of change, but only the final Tier is tied to fundamental objectives and therefore can inform decision making. The second Tier is the most common assessment tool and is frequently linked to means objectives. The third Tier performance measures are necessary and important to outcome assessment and useful for tying a decision to the fundamental objectives, and as a result are an important piece of the overall SDM process for decision support.

This report covers use of the SDM-based decision support cycle with a focus on ecosystem services as an assessment tool. This approach was described in detail in the Practical Strategies Report on ecosystem services (Yee et al. 2017) and here we focus on objectives and PM used in six case study examples, but with an SDM focus we are primarily interested in Tier 3 performance measures as they best inform decision making. Three broad approaches were used for setting objectives and PM across the five case studies (Table 2.2). First were stakeholder derived objectives established through some form of stakeholder engagement. This approach is most aligned with the SDM process. Second, were expert derived objectives and PM, which also require engagement, but limits input primarily to managers, policy makers, and other experts on the focal issue. Finally, there was policy-derived objectives, which requires limited direct public engagement but is dependent on legal requirements and/or previous experience with similar issues in other places. The latter approach tends to be more PM based with objectives being defined by values for chosen PM. All three approaches have strengths and weaknesses, and this report will focus on the three standards of inclusiveness, transferability, and outcome for community benefit.

Take Home: Objectives and performance measures should be linked and informative for predicting outcomes. Different approaches for setting project objectives and performance measures, each having strengths and weaknesses, may be used in decisions involving environment or ecosystem services components.

2.3.1 Stakeholder-derived objectives and performance measures

Stakeholder engagement to determine objectives and performance measures refers to an open process that deliberately seeks a diverse suite of opinions and minimizes pre-conceived boundaries for outcomes. This level of engagement can be time-consuming and usually involves specific effort to achieve, independent of implementation or assessment. We have two examples of this approach in our case studies. In the Oklahoma small community case study, the DASEES tool (Dyson et al. 2019) was used to facilitate stakeholder engagement, which included a determination and prioritization of objectives and associated PM. In the St. Louis River case study, a HIA (EPA 2021) was used to gather community opinion of project objectives. In the latter case PM were derived largely from expert opinion, but stakeholder objectives were used to determine project endpoints most likely to promote community health.

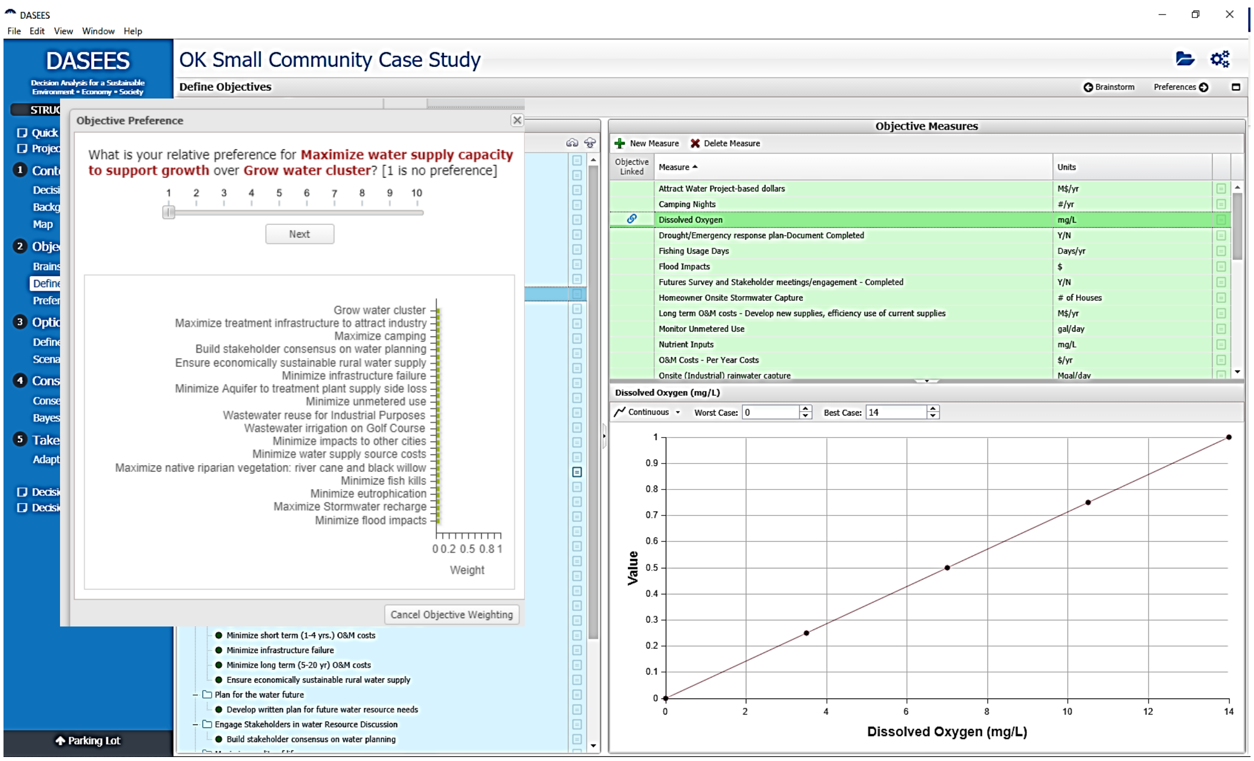


Figure 2.2 DASEES screenshot showing definition of performance measures from stated objectives. Insert shows method for defining changes in performance measures. Taken from DASEES tool.

The DASEES tool was designed to implement structured decision making (Gregory et al. 2012) in an open format that allows for both development and application of community objectives in the same exercise. Stakeholders are guided through the discovery process to establish and prioritize their objectives, define performance measures, and develop trade-off scenarios that allow for a PM-based comparison of the scenarios. The focus was balancing multiple user groups for managed reservoirs including drinking water consumers, recreation, and support for regional groundwater used for irrigation. Application of the DASEES tool resulted in a list of objectives (Table 2.3) and these objectives will be prioritized with the preference weighting tool available in DASEES (Figure 2.2). All these steps were completed in a workshop format with participants from multiple stakeholder groups. Participant diversity is a key feature of this approach as a wide diversity of interests needs to be represented. Facilitation of this approach is also an important feature as development of objectives can be open-ended without some guidance. Facilitators are familiar with the SDM process but also skilled in leading discussion and maximizing stakeholder participation. In the Oklahoma Small Community case study, the effort occurred in steps with personnel trained to use DASEES available at the beginning during the scoping phase. This is the phase when objectives and performance measures are identified so these items were well fleshed out. Later phases of the DASEES process involve quantifying PM and setting priorities, which might be achievable with less facilitation. The DASEES approach is highly inclusive and has potential to provide a higher level of benefit to the community assuming the results are integrated into the decision/assessment process.

Table 2.3 Objectives and associated performance measures as determined from stakeholder engagement with the DASEES tool in the Oklahoma Small Community case study

Objectives	Measures
Root Objective: Sufficient, safe, secure, reliable and affordable source of water	
1. Ensure effective stormwater management	
1.1. Minimize flood impacts	Flood Impacts on housing, loss of property, emergency response ($; # families temporarily displaced; # people permanently relocated)
1.2. Maximize stormwater re-use	Homeowner Onsite Stormwater Capture (# of Houses)
1.3. Maximize stormwater recharge	Stormwater recharge collection Areas (# of Collection Areas)
2. Maximize lake water quality	
2.1. Maximize clarity	Secchi depth (inches/feet)
2.2. Minimize eutrophication	Nutrient Inputs (mg/L)
2.3. Minimize sediment loading	Total Suspended Solids inputs mg/L
2.4. Minimize fish kills	Dissolved Oxygen (mg/L)
3. Meet tribal concerns	
3.1. Maximize large scale sustainability (22 counties in SE OK)	Rationing duration (# of days); Rationing events (#/yr)
3.2. Maximize native riparian vegetation: river cane and black willow	Riparian Vegetation (# of miles)
4. Maximize sustainable water supply	
4.1. Maximize water system revenues	
4.1.1. Maximize water revenues	Water Revenues from customers (M$/year
4.1.2. Minimize water supply source costs	Water Supply costs ($/1000g)
4.2. Meet minimal stream flow	Pumped volume of water from Aquifer (Mgal/day)
4.3. Minimize impacts to other cities	Water Flow from Aquifer (Flow trigger) (gal/day-7-day average)

Objectives	Measures
4.4. Develop drought & emergency response plan	Drought/Emergency response plan-Document Completed (Y/N)
4.5. Maximize wastewater reuse	
4.5.1. Meet golf course watering needs	
4.5.1.1. Wastewater irrigation on Golf Course	Wastewater Reuse (Mgal/day)
4.5.1.2. Onsite Rainwater capture for use on Golf Course	Storm Water Capture on Golf Course (Mgal/day)
4.5.2. Maximize industrial reuse	
4.5.2.1. Wastewater reuse for Industrial Purposes	Wastewater reuse substitution for Treated Water (Mgal/day)
4.5.2.2. Industrial Onsite rainwater Usage	Onsite (Industrial) rainwater capture (Mgal/day)
5. Minimize cost	
5.1. Minimize water loss	
5.1.1. Minimize unmetered use	Monitor Unmetered Use (gal/day)
5.1.2. Minimize post treatment side distributional loss	Post Treatment system Leakage (Mgal/day)
5.1.3. Minimize Aquifer to treatment plant supply side loss	Supply side transport leakage (Mgal/day)
5.2. Minimize short term (1-4 yrs) O&M costs	O&M Costs - Per Year Costs ($)
5.3. Minimize infrastructure failure	Water line Integrity Evaluation (miles/yr)
5.4. Minimize long term (5-20 yr) O&M costs	Long term O&M costs - Develop new supplies, efficiency use of current supplies (M$/yr)
5.5. Ensure economically sustainable rural water supply	Rural water opportunity cost ($)
6. Develop a plan for the water future	Water Resource Development Plan - Document Completed (Y/N)
7. Build stakeholder consensus on water planning	Futures Survey and Stakeholder meetings/engagement - Completed (Y/N)
8. Maximize quality of life	
8.1. Meet residential watering needs	Residential Watering Opportunities (hrs./day)
8.2. Meet recreational water use	
8.2.1. Maximize camping	Camping Nights (#/yr)
8.2.2. Maximize fishing	Fishing Usage Days (days/yr)
9. Maximize economic opportunity	
9.1. Maximize treatment infrastructure to attract industry	Unused water treatment capacity available (Mgal/day)
9.2. Maximize water supply capacity to support growth	Unused Water Supply (Mgal/day)
9.3. Grow water cluster	Attract Water Project-based dollars (M$/yr)

Take Home: Stakeholder derived performance measures, developed in a facilitated workshop setting, can reflect community thinking about potential trade-offs among beneficiary groups.

Another example of a structured tool for SDM is the Health Impacts Assessment (NRC 2011). The HIA focuses specifically on objectives tied to health outcomes but like the DASEES tool allows for a structured form of stakeholder engagement. In the St. Louis River case study, the HIA was used to compliment an expert-derived opinion approach for setting objectives to broaden the scope of alternative comparisons to consider health impacts on stakeholders. The case study concerns clean up and restoration of impaired sites along the St. Louis River and the HIA was used to develop a causative framework for health impacts that can be used to compare proposed alternative approaches to site restoration that varied according to endpoint design of the restoration effort. Focal objectives considered in the HIA were recreational access, aesthetics, and cultural use endpoints and the restoration alternatives were ultimately evaluated based on the PM impacts of differences in the restoration process and the amount of woody debris left at the site. These PM are in addition to other more intermediate PM developed using expert judgement and reviewed in the next sub-section (2.3.3. Expert-derived Objectives). The outcome distinction between HIA metrics and more traditional metrics is that woody debris left at the site had less impact on the intermediate metrics than it did on HIA metrics, particularly for aesthetics and recreational use (EPA 2021, Appendix D). The application of a hybrid approach to development of objectives and PM is an example of how means and fundamental objectives can be effectively combined for decision assessment, particularly in cases where established PM are used and new, broader PM are being proposed (i.e., HIA). The HIA involved multiple stakeholder engagement exercises combined with literature review and weight of evidence evaluation of pathways from proposed restoration plans to impact on human health. Health objectives were identified, as well as proposed evaluation tools that could be used as performance measures for health impacts. Health related PM are both more complicated to measure and take longer to show a response to restoration improvements. For example, the HIA identified multiple health objectives of improvements in water quality including reductions in consumption risk of fish caught in the St. Louis River. The PMs for this objective are changes in toxicity levels in fish tissue, a reduction in fish consumption advisories, and improved angler perception of fish quality (EPA 2021). All three of which might take multiple years post restoration to show a measurable change. These PM are Tier 3 indicators, and this case study is a good example of mixing longer term PM from the HIA with shorter term Tier 1 and 2 measures adapted from existing expert judgement (Table 2.4). This hybrid approach is both inclusive and portable given the resources to conduct an HIA. Potential benefit to stakeholders is also high but dependent on the use of results later in the decision cycle .

Table 2.4 Example table of Tier 1 and 2 performance measures used for the St. Louis River case study.

Details include current condition value, a minimum reference threshold value, and the associated Beneficial Use Impairment (BUI; BUI 4 is Degradation of Benthos, BUI 9 is Loss of Fish and Wildlife Habitat). Metrics cover vegetation status (aquatic macrophyte coverage, floristic quality, acres with invasive narrowleaf cattail and Phragmites), benthic organism condition (benthic index, species richness, pore water quality (ammonia, biological oxygen demand [BOD]), shoreline condition (riparian connectivity), sawmill waste removal (wood waste acres overall and wood waste left in open waters), and sediment quality (numeric sediment quality targets [SQT], including level 1 (provides high level of protection for benthic organisms) and level 2 (provides moderate level of protection for benthic organisms).

BUI Metric	Existing Condition	Reference Value Threshold	Primary BUI Association
Macrophyte coverage, %	34	60 - 80	4, 9
Floristic Quality Index	1.1	>7.0	4, 9
Narrowleaf cattail monoculture, acres	36.8	13.4	9
Non-native Phragmites monoculture, acres	1.3	0	9
Benthic index	0.51	0.44	4
Benthic species richness	18	17	4
Pore water Ammonia, mg/L	5.2-8.3	<1.9	4, 9
Pore water BOD, mg/L	166	<45	4, 9
Riparian connectivity, %	~30	>84	9
Wood waste, acres	~60	<5 in open water	4, 9
Mill waste within impaired area sediment, %	>80	<25	4, 9
>SQT 1 - < SQT 2 surficial, acres (0-50 cm; mercury, PAHs)	118	Cover	4
Area >SQT 2 surficial, acres (0-50 cm; lead, dioxins)	8.1	Cover	4

Take Home: Stakeholder-derived objectives and performance measures are generally more inclusive but require more effort and engagement to focus and organize the results. Engagement tools such as DASEES and HIA provide the best approach for stakeholder engagement on complex environmental decisions. Use of these tools can be combined with existing expert- or policy derived objectives and performance measures to make maximum use of existing information .

2.3.3 Expert-derived objectives

Expert-derived objectives and performance measures are chosen primarily based on the more problem-focused perspective of those directly engaged in the decision-making process. The pool of experts will certainly contain stakeholders but will not necessarily include the full suite of interests within the community. In some cases, expert-derived objectives may reflect stakeholder engagement in the past, but the ‘filter’ of expert opinion tends to result in a streamlined set of objectives. Expert opinion also tends to be PM focused. Three examples of an expert-derived suite of objectives were identified in our case study sites. In Mobile Bay and San Juan Bay the influence of the National Estuary Programs was observed to create a suite of objectives in-line with each program's Comprehensive Coastal Management Plan (CCMP, e.g., www.tbnep.org/comprehensive-conservation-and-management-plan.php). In both cases, solicitation of expert opinion resembled an SDM-type stakeholder engagement process but did not target the full community. Rather, the management community was strongly engaged through the NEP hierarchy.

Take Home: Expert-derived objectives and performance measures may not necessarily include a full suite of interests within a community but are helpful in deriving streamlined of objectives and performance measures for a decision. Solicitation of opinions from experts on the environment or ecosystem services improve the potential for capturing human benefits.

Expert opinion in two of the case studies originated from the National Estuary Program effort to engage local experts. In the Mobile Bay case study objectives were derived from both the Mobile Bay CCMP (MBNEP 2019) and the D'Olive WMP (Figure 2.3). From the CCMP, stated objectives were to improve watershed stream quality, restore ecosystem function, and improve human connections to the

Monitored site	Average discharge (cfs[1])	Average discharge duration (minutes)	Average turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	Maximum TSS (mg/L)	Estimated suspended sediment load		
							lbs/min	t/yr	t/mi²/yr
JB1—Pre	4.8	115	166	369	719	5,850	5.7[4]		
JB1—Post	9.5	725	262	948	536	1,350	7.2	53.6[5]	
JB6—Pre	13.6	165[1]	4,292	6,280	93,276	341,000	1,840		
JB6—Post	6.4	n/a[2]	349	863	370	805	51[6]	34.7	
JB7—Pre	4.9	n/a[3]	797	3,640	4,061	20,000		18,236	82,890[7]
JB7—Post	2.4	n/a[3]	150	490	263	747		1,034	4,700

[1]Discharge at site JB6 was intermittent during the pre-restoration monitoring period
[2]Discharge at site JB6 was perennial during the post-restoration monitoring period
[3]Discharge at site JB7 was perennial during the pre- and post-restoration monitoring periods
[4]pounds per minute
[5]tons per year
[6]Sediment load estimated for discharge greater than base flow
[7]tons per square mile per year

Figure 2.3 Summary of performance measures for restoration work in Mobile Bay case study site – D'Olive creek. Reproduced from D'Olive restoration report https://www.mobilebaynep.com/watersheds/dolive-watershed

watershed. Performance metrics for these objectives included legal standards like delisting of streams from 303d impaired status under the Clean Water Act (US Estuaries and Clean Water Act of 2000), but generally lacked specifically for ecosystem function and human connections. The D'Olive WMP objectives included improved water quality in targeted streams, increased naturalness of streams, and reduced stormwater impacts, such as bank erosion and turbidity from heavy stormwater flow. As with the CCMP objectives, the clearest PM were water quality parameters taken from existing metrics (e.g., turbidity), while PM for naturalness and stormwater impacts were more qualitative, such as flow calming effects during storm events as measured by flow gauges put in place specifically for restoration assessment (www.mobilebaynep.com/assets/pdf/DOlive-Final-Report-Full.pdf). Model-based assessments were included post-restoration to include ecosystem services related to the latter two objectives, such as ground water storage capacity and carbon and nitrogen sequestration (Fulford et al. 2022). The intent was to apply alternative techniques to post-restoration data gathering to broaden the available PM to include all stated objectives. NEP objective development was through a committee structure of local expert stakeholders combined with contract consultants working on the specific restoration projects. Primary PM were developed as a part of the project development process. Secondary PM based on ecosystem services were developed during the model development process but reflected NEP objectives to improve stakeholder awareness of project benefits. Models increase portability of the outcomes between sites because they come from work in other watersheds (Russell et al. 2015) .

The NEP organization of experts was also important in the San Juan Puerto Rico case study. The SJNEP CCMP (estuario.org/plan-integral-de-manejo-y-conservacion-del-estuario-de-la-bahia-de-san-juan-ccmp/) includes developed objectives and PM for protecting the integrity of the San Juan Bay estuary. Case study researchers initially developed objective hierarchies (Figure 2.4) based on reviewing objectives as described in the San Juan Bay Estuary CCMP. Additional objectives were derived from other existing management and planning documents, using a Driver-Pressure-State-Impact-Response (DPSIR) framework (Bradley et al. 2015) to help identify means objectives as Responses (R) to modify Drivers (D) or alleviate Pressures (P) and fundamental objectives as important components of ecosystem state (S) or Impacts (I) to human health and well-being. Because the origins of the objectives in this case study were existing management documents, we classify this effort as being based on expert opinion.

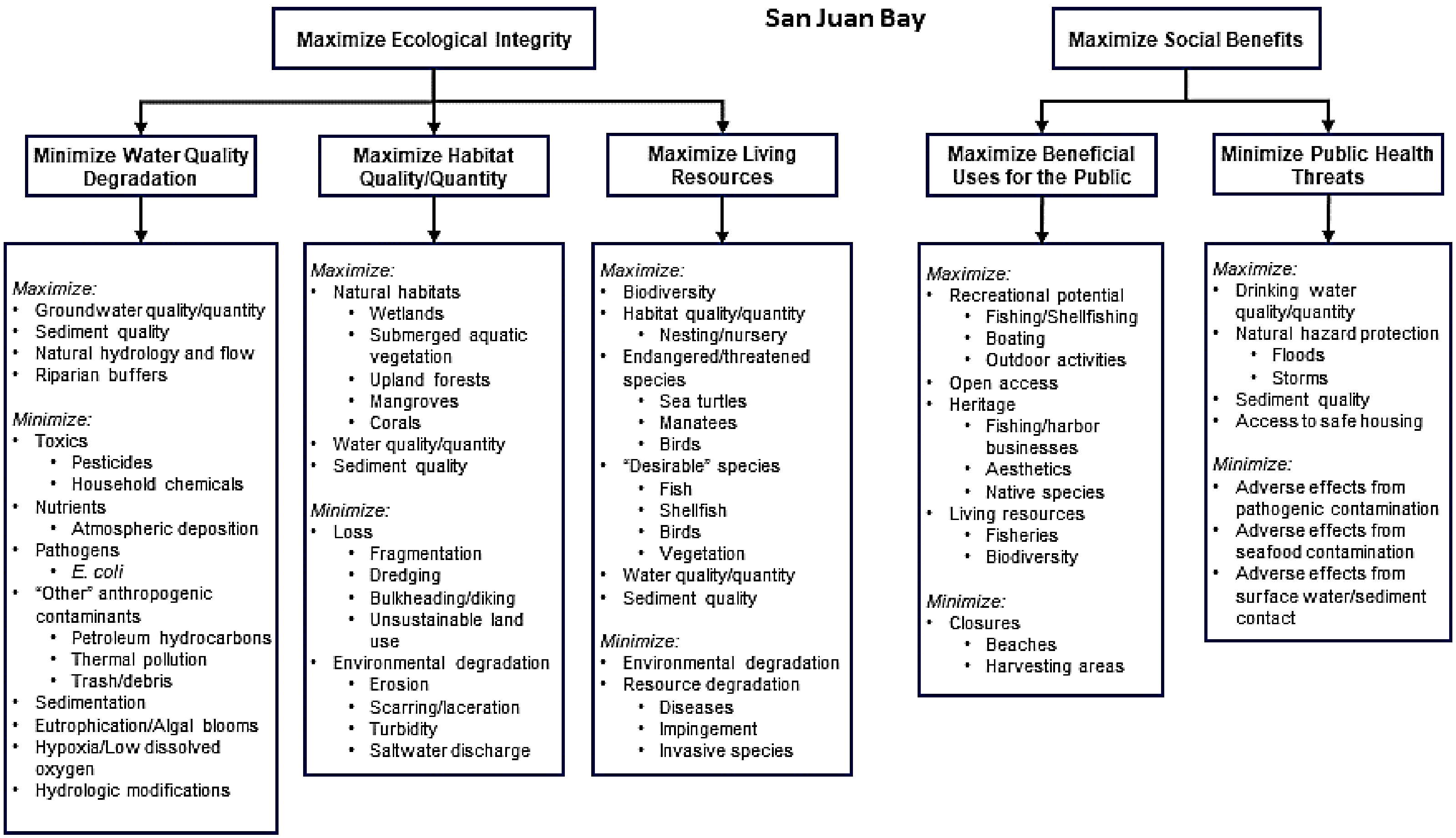
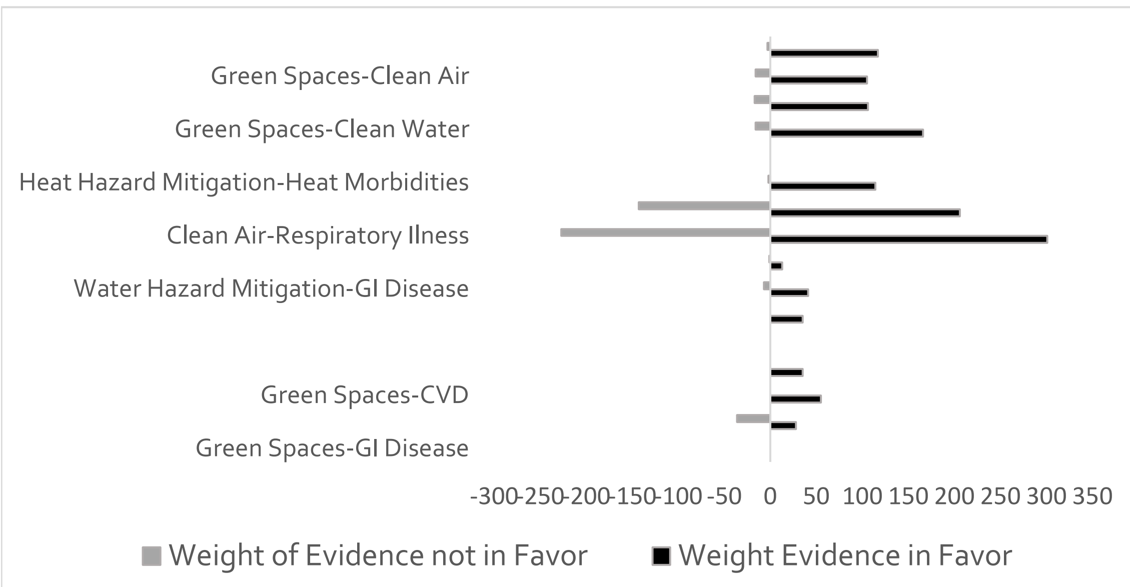


Figure 2.4 Objective hierarchy developed by case study researchers based on reviewing the SJBE CCMP for San Juan Bay, Puerto Rico. Only Ecological and Social objectives shown for example.

Performance measures in the San Juan case study were identified by leveraging expert opinion on measurable components of ecosystem state and identifying measurable impacts to ecosystem services and human well-being. Example sources for metrics were the Human Well-being Index (HWBI; Smith et al. 2013), the FEGS Classification System (Boyd et al. 2016), and the EPA' Eco-Health Relationship Browser (http://www.epa.gov/enviroatlas). Weight of evidence approaches were used to identify linkages between environmental and human health endpoints, and to prioritize which health-related objectives were most likely to respond to environmental decisions or where more information was needed to reduce uncertainty in relationships (de Jesus-Crespo and Fulford 2018; e.g., Box 2.1). This case study involved a general comparison of FEGS across NEP sites (Yee et al. 2019) and metrics of human well-being across the United States (Orlando et al. 2016), so has a large potential for transferability.

Box 2. 1. Causal criteria analysis (de Jesus-Crespo and Fulford 2018) is a weight of evidence method for combining scientific evidence for EGS-health links when direct study is too complicated to provide a clear picture. The figure shows weight of evidence both for and against a given EGS-health link with greater weight placed on designed studies. This can be viewed as formalized expert opinion in the prioritization of objectives and performance measures. (Image taken from de Jesus-Crespo and Fulford 2018)



In St. Louis River case study, expert opinion was derived through existing restoration authority and the state DNR. As mentioned above, this site also employed a stakeholder engagement process to support the expert-derived process, but this was secondary, so the St. Louis River objectives and PM are considered to be primarily expert-derived and related to adherence to legislative standards such as the Clean Water Act (Table 2.4). The state of Minnesota has developed two multimetric indices used in this case study: The macroinvertebrate index of biotic integrity (MPCA 2014 a&b), and the floristic index (Bourdaghs et al. 2006). Together these indices measure habitat quality based on biotic response to change which is a structural/functional approach to measuring outcomes. In the short term they both reflect structural changes in the restored system, but over time these indices reflect functional improvement through diversity and abundance of preferred species. The development of these indices was a statewide effort based on spatial differences in aquatic habitat (Bourdaghs et al. 2006; MPCA 2014 a&b). As such they represent a nominal PM for aquatic habitat statewide to meet designated use criteria under the Clean Water Act and more importantly have clear management thresholds that can be used in an SDM framework to guide decision making .

Take Home: A suite of objectives taken from management plans can be used to generate pre-project performance measures related to addressing regulatory and programmatic goals. These objectives can be supplemented with the use of expert opinion. Once a comprehensive list of relevant performance measures is identified, various approaches (e.g., individual analyses; weight-of-evidence analyses) and efforts are needed to predict measurable impacts of a project to ecosystem services and human well-being. This is a process of converting Tier 1 and 2 PM into Tier 3 PM for the purpose of informing decision making .

2.3.4 Policy-derived objectives

There is no clear line regarding policy and solicitation of expert opinion, however in many cases objectives are well-established, even codified to the point that further adaptation is not a part of current analysis of trade-offs. Examples of this situation often involve heavily managed activities such as resource extraction and/or trade-offs among such activities. Well-defined policy objectives are the result of extensive study and there is benefit in stability as it allows for a focus on comparing alternatives as opposed to defining objectives. The best-case study examples of this approach are the Tillamook Bay and Puget Sound cases studies, which focused on balance between watershed forestry management and habitat quality for aquatic resources (e.g., salmon and shellfish) within the target waterbody. Overall objectives were to maximize shellfish and salmon population sustainability while allowing for watershed development that impacts aquatic habitat through nutrient and sediment delivery into the Bays. Objectives in both cases come directly from state resource management plans. Additional input was also derived from relevant partners, such as the Tillamook Bay NEP, for overall estuary health, but the focus of both case studies was a model-based assessment centered on existing management objectives. The combination of policy derived objectives with model-based estimates of associated performance measures is a well-developed tool for informing decisions.

A good example of combining policy objectives with model-based estimates comes from a habitat suitability analysis in Tillamook Bay. The key ecosystem service examined here was fishery sustainability for harvested crab species, such as *Cancer magister*, and clam species, such as *Clinocardium nuttallii* (Lewis et al. 2019, Lewis et al. 2020). The Tillamook estuary is a known nursery ground, so protection and restoration of crab nursery habitat is a key objective in this system. Subobjectives include maximizing vegetative coverage and reducing water quality impairment caused by excess nutrients and *E. coli* (Zimmer-Faust et al. 2018) entering from the landscape. Predetermined PM for these objectives were easily identified as measures of vegetative coverage, as well as nutrient and *E. coli* concentrations particularly associated with storm events. Policy derived objectives and PM make this element of SDM straight forward and the focus of this case study was on the estimation phase discussed in Section 2.3.

A more complicated example of combining policy-derived objectives with model-based PM can be found in Puget Sound, where the focus is a management trade-off between two extractive ecosystem services: forest harvest and salmon production. Both services include the objective of maximizing sustainability of production. The PM for this linked decision were straightforward and well-defined involving salmon habitat quality and amount of forest products produced. A more complex model was needed to estimate outcomes as links between forest practice and salmon production had to be examined in a way that made them comparable (McKane et al. 2020). Policy-derived objectives and associated performance measures are easy to understand, but also limited to Tier 1 or 2 as defined at the beginning of Section 2.3 so not as useful for guiding a decision without the addition of predictive tools such as models. This will be addressed in detail in Section 2.5 .

Take Home: Well-defined and established policy objectives have a benefit in terms of creating stability, allowing for a focus on comparing alternatives as opposed to defining objectives, and can be relevant in examining environmental management tradeoffs in heavily managed activities. Policy-based objectives and performance measures require historical data or model-based predictions to inform decisions. Optimally, policy-based thresholds for PM are also defined to better characterize change in the context of the decision.

2.3.5 Conclusions

Development of objectives and corresponding PM are the link between decision context and assessment of decisional consequences. All three approaches described here are valid and capitalize on existing needs and resources. In cases where stakeholder engagement is possible this represents the most comprehensive method for objective development. Expert derived objectives are the most common choice and often parallel stakeholder priorities. Yet expert opinion tends to focus on the big picture and may miss important ancillary interests among stakeholders. Policy derived objectives are the most focused on the problem at hand (e.g., forestry impacts on shellfish) and are more useful for a technical analysis of the issue. They also are the least flexible and most likely to overlook objectives not directly related to the analysis at hand (e.g., aesthetics, coastal recreation). Even if a policy- or expert-derived approach is used, a stakeholder engagement exercise can help increase transparency and inclusiveness by allowing for an open discussion of why particular objectives were used. A stakeholder engagement process for development of objectives is also highly portable as demonstrated using SDM in multiple case studies.

Performance measures should be associated with objectives and not be chosen based on convenience. Three levels of PM exist for any issue and most restoration projects focus on reporting measures of completion (Tier 1) and measures of response (Tier 2), while limiting use of PM measuring achievement of fundamental objectives (Tier 3). This is a natural result of a focus on assessment rather than decision making and not having clear fundamental objectives at the onset of the action. It is important to remember that PM tied to fundamental objectives (Tier 3) can be used for assessment post-action but can also inform decisions which is a central element of the SDM process. Whether or not monitoring extends long enough to measure achievement of fundamental objectives, they should have defined PM to support decision making. Finally, Tier 3 performance measures are highly transferable among locations and issues as the associated fundamental objectives (e.g., increase public safety) tend to be more consistent through time and space than more specific issue-associated objectives (e.g., reduce turbidity).

Photo: This spot on a small estuary in Rhode Island is popular with boaters and recreational anglers but is especially popular with kayakers and standup paddleboarders. Define objectives and performance measures based on beneficial use. (Photo credit: W. Berry).

2.4 Developing decision alternatives (CE3)

Decision alternatives are an important part of decision making and allow for multiple points of view. Alternatives must be clearly stated and connected to O&PM to be effective. The basic alternative for any decision is whether to act or not, but more complex considerations are frequently at least implicitly considered. Formal stakeholder engagement often leads to a suite of alternatives for comparison that may consider multiple points of view about the final objectives. For example, flood protection for a river community will often involve building levees, however a closer examination might yield multiple alternatives for levy design that vary in terms of recreational access to the river or use of land adjacent to the levy. Multiple potential alternatives can be compared simultaneously based on how they are predicted to change selected performance measures. A key consideration for the development of useful alternatives is the process by which those alternatives are developed, especially with regards to the project objectives and stakeholder input. In this Section, the development of alternatives in the six case studies will be examined with a focus on how they were developed and the transferability of these alternatives to other sites and issues.

2.4.1 Methods for choosing alternatives

Four of the case studies conducted either a formal or informal analysis of alternatives (Table 2.5). An alternative can refer to a project design, a decision about where to conduct management activities, or a set of management actions. By formal alternatives analysis, we mean that distinct, competing (albeit not necessarily mutually exclusive) proposals were developed and compared prior to any decision. The comparison among alternatives was made using the same set of criteria to evaluate trade-offs between adopting one alternative compared to another. By informal alternatives analysis, we mean that additions or subtractions to an existing proposal were considered by decision-makers at one or more times during the decision-making process. These informal alternatives were not necessarily considered as competing proposals or subject to the same criteria. For example, in the Mobile Bay case study, as part of the Comprehensive Conservation and Management Plan (CCMP) development, the scientific advisory committee in consultation with stakeholders made determinations of priority watersheds and the sequencing of work among watersheds. These decisions were revisited intermittently as work progressed. Such a process informally evaluates the options as the program progresses. In the Tillamook Bay case study, the goal was to improve bivalve stock assessment methodology by considering spatial additions or subtractions to the design as informal alternatives. In contrast, in the St. Louis River case study, during the design phase, three competing restoration designs were formally considered based on common criteria relating to overall ecological impact and ecosystem services to be provided. A final design was chosen based on the trade-off analysis that was conducted. Also, the two approaches can be combined. For example, in the St. Louis River case study, at the same time the three formal alternatives were being evaluated, stakeholders and community members were offering project recommendations to add or subtract elements. Note that the agency that was undertaking the restoration was involved in both alternative analyses and integrated the two analyses through the project design.

Table 2.5 Description of alternative form, approach for identifying, comparing alternatives, and stakeholder engagement for five* case studies.

Case Study	Alternative Form	Alternatives Considered	Approach for Identifying Alternatives	Approach for Comparing Alternatives	Stakeholder Engagement
Mobile Bay	Informal	Which watershed to conduct work	Consultation with CCMP scientific advisory committee and stakeholders	CCMP deliberations, project scheduling, bid process	Engagement conducted with city and county officials, academic partners; held public meetings
Oklahoma small community	Formal	Management scenarios (groups of management options)	Consultation with stakeholders	Decision Analysis for a Sustainable Environment, Economy, and Society (DASEES)	Representative group of stakeholders participating in decision-support process (via DASEES)
Tillamook Bay	Informal	Determine most suitable locations for shellfish culture and harvest	Consultation with state management agencies	Ecological models (Habitat suitability)	Model development and analysis with state management agencies
Puget Sound	Informal	Alternative forest watershed management plans	Consultation with state, tribal, and community partners	Ecological model (VELMA)	Model development and analysis with state, tribal, and community partners
St. Louis River	Formal	Competing wetland restoration designs	Introduced by management agencies	Health Impact Assessment (HIA)	Stage agency participating as a partner in the HIA
St. Louis River	Informal	Recommendations to add or subtract actions to the project	Consultation with stakeholders and community partners	Health Impact Assessment (HIA)	Stakeholders and community members participating in decision-support process (via HIA)

***San Juan case study did not include the formal development of decision alternatives, but instead looked more generally at understanding relationships between means objectives (e.g., reducing urban runoff, changing land use/landcover) and fundamental objectives (e.g., ecosystem services and human well-being) that inform decision alternatives.**

The alternatives were identified through diverse approaches, ranging from direct consultation to the application of formal decision-support tools (Table 2.5). In the Tillamook Bay case study, alternatives were developed in direct consultation with state management agencies to meet their needs for information about shellfish habitat. Similarly, in the Puget Sound case study, alternatives were developed in direct consultation with state, tribal, and community partners, and the alternatives development was informed through research with an existing ecological model. In the Mobile Bay case study, alternatives were developed as part of the CCMP writing process involving stakeholder committees. In the St. Louis River case study, the formal alternatives were developed by state agencies through direct consultation whereas the informal alternatives were developed by stakeholders and community members through an associated HIA (EPA 2021). The Oklahoma Small Community case study also used a formal SDM approach, DASEES, to consider and develop alternatives. All case study leads agreed that these processes were readily transferred to other similar settings and primarily differed by what type of stakeholders and how many were consulted.

Take Home: Choosing decision alternatives should follow a deliberate process. The use of formal, informal, or mixed approaches to defining alternatives, whether decision support models and tools are used or not, is relevant across a range of decision contexts for projects involving decisions with environment benefits. Alternatives considered should be well-aligned with stated objectives for the decision.

2.4.2 Approaches to prioritizing or ranking alternatives

As with the development of alternatives, the ranking or prioritizing of alternatives was completed using a diversity of approaches (Table 2.5). In the Mobile Bay case study, the informal alternatives were prioritized through deliberations among the management partners, considering both management objectives and logistical considerations such as project scheduling and bid process. In the Puget Sound case study, alternatives were compared using the ecological model (VELMA) and prioritized based on comparing the model outputs to management goals (e.g., improved habitat, water quality, cultural benefits). In the St. Louis River case study, the HIA was used to evaluate and rank both formal and informal alternatives, which meant that all alternatives were evaluated using similar information and criteria. The ranking of formal alternatives was completed by the technical team leading the HIA and occurred by comparing the overall health outcomes of each restoration design. Within the approach, the connection between ecological change and health was made through application of ecosystem service models, which can be used to contrast anticipated future state of the system based on the alternative (e.g., Table 2.6). In contrast, the ranking of informal alternatives (which were identified as "recommendations" within the HIA) was completed by both stakeholders and community members and was done by voting for preferred actions. In the Oklahoma Small Community case study, DASEES was chosen as the approach for evaluating and ranking alternatives. Here, alternatives are a collection of options grouped into management scenarios. A consequence table is developed that shows a visual comparison of the outcomes of the management scenarios with respect to the management objectives. Preference weighting of the management objectives is then used to rank or prioritize the management scenarios. More detail on comparing alternatives is provided in Section 2.6.

Among the case studies, several factors were considered important to success during the identification and evaluation of alternatives. For the Tillamook Bay case study, having existing, widely supported management plans (e.g., a CCMP) and good relationships with partners, especially partners with a strong comprehension of the decision-context, were deemed important by project participants. For the Puget Sound case study, technology transfer was important for success because it was at times necessary that partner agencies or stakeholders have the information and skills to operate the ecological model used to identify and evaluate alternatives. In the Oklahoma case study, success was dependent on organizing a representative group of stakeholders to increase the diversity and creativity of alternatives. Similarly, broad stakeholder and community engagement was important in the St. Louis River case study to meet the principles of HIA, which are designed to achieve trust, transparency, equity, and knowledge exchange within the community.

Table 2.6 Example of trade off analysis associated with the St. Louis River case study, (modified from Hoffman and Angradi 2019). The trade-off analysis compares the status quo (Alt 1) to three different project alternatives, including retaining a railroad causeway through the restoration site, converting the rails use to a trail (rail to trail), or removing the causeway. The analysis is based on ecosystem services providing areas or ecosystem service proxies. The cells are color coded to help indicate relative change from current condition among alternatives: yellow = less than a 30% change from current conditions; blue = at least a 30% increase from current conditions; red = at least a 30% decrease from current conditions.

Ecosystem Service (units)	Current Condition (Alt 1)	Retain Rail, North Opening, Bay Mouth Bar (Alt 2)	Rail to Trail, North Opening, Bay Mouth Bar (Alt 3)	Remove Causeway, North Opening, Bay Mouth Bar (Alt 4)
Highly-sheltered bay (acres)	23.4	30.9	30.9	9.8
Fill in public waters (lineal feet)	4894	4782	4782	3067
Protected shoreline (lineal feet)	4379	4107	4107	1302
High density submerged aquatic vegetation (acres)	75.9	79.3	79.3	73.3
>50% likelihood of floating leaf vegetation occurrence (acres)	42.2	57.9	57.9	2.9
Power boating (acres)	75.9	75.9	75.9	110.9
Human-power boating (acres)	129.7	129.7	173.4	184.0
Gamefish spawning (acres)	75.7	78.9	78.9	72.9
Designated shore fishing (acres)	0.0	0.0	1.0	1.2
Boat/ice fishing (acres)	144.6	149.2	149.2	160.6

Choosing and ranking alternatives is tied to accepted objectives, and alternatives can be broad or proscribed according to the diversity of these objectives. All cases studies began with the simple alternative to act or not within the chosen decision context, and the range of approaches in the case studies for expanding the list of alternatives reflects the range of methods used to define objectives. The utility of an approach for defining alternatives will be maximized if it matches the diversity of objectives under consideration. Offering insight into how an approach for defining alternatives is chosen so that it aligns with project objectives should be a high priority for transferring these techniques to other similar sites.

Photo of community meeting gathering community feedback on proposed alternatives via participatory mapping (credit EPA)

2.4.3 Stakeholder and community engagement

Stakeholders can be informed of decision alternatives, consulted in their development, and even engaged to assess and prioritize. In the cases studies, the form and breadth of stakeholder and community engagement was related to the approach chosen for identifying and evaluating alternatives (Table 2.5). Two of the case studies used decision-support tools that relied on extensive engagement (Oklahoma Small Community case study – DASEES, St. Louis River case study -HIA), including working through the entire decision-making process with a diverse group of stakeholders and partner management agency representatives. Both these tools emphasize two-way communication with stakeholders, and so require additional communication support both to document stakeholder input and share the documentation with stakeholders to ensure accuracy. To develop trust with the community, in the Mobile Bay case study, engagement included interactions with city and county officials and academic partners, as well as conducting open public meetings to discuss and present management objectives, alternatives, and priorities. The other two case studies relied on consultation with stakeholders and management agencies that were already engaged in the management plan (as with a CCMP) or decision-making process. The former involves standing, long-term engagement activities and the latter is more short-term engagement focused on a particular decision .

Take Home: Identifying and ranking decision alternatives is an effective way to engage stakeholders and communicate reasons for decision outcomes. The form and breadth of stakeholder and community engagement is strongly related to the approach chosen for identifying and evaluating alternatives. Emphasizing two-way communication with stakeholders involves additional investment in effort and helps develop trust with the community.

2.4.4 Conclusions

Decision alternatives can be simple or detailed according to the specific needs of the action under consideration. Similarly, how alternatives are ranked and compared can be formal or informal based on need and resources. The six case studies spanned the range of options including Tillamook Bay which addressed the pre-determined alternative of status quo vs. the use of models to inform shellfish management. At the other end of the spectrum, there were case studies that used a formal development process for alternatives usually involving application of a formal tool like DASEES to guide the process. Several consistent outcomes of alternative development were evident across the case studies. First, stakeholder engagement is an important element in alternative development. Any action has the implicit alternatives of “act” or “don’t act” and stakeholder input will be a valuable tool for moving beyond this binary question to consider the most beneficial way to invest valuable resources. Second is that connecting alternatives to the full list of stated objectives is important for remaining consistent to the SDM process. It is easy to develop a set of objectives but then focus on only a few in defining alternatives, which leads to predetermined outcomes and disenfranchised stakeholders. It is optimal to be comprehensive at this stage and leave evaluation to the trade-off process described in section 2.6. Finally, the alternatives must be measurable to be comparable so make sure performance measures are chosen that align with all the alternatives (quantitative and qualitative) as in Table 2.6. The most transferable approach will be the formal process included in tools like DASEES that also maximize stakeholder engagement, but the most useful approach for any new site will be the case study most closely matched to this new issue or context. Once alternatives are agreed upon, the next step is the process of determining outcomes for evaluation. This involves the chosen performance measures and some formal process of considering success in meeting objectives under each alternative. The information needed for this process is obtained through the evaluation of consequences for each alternative and is the subject of the next section.

Arbuckle aquifer, Ada Oklahoma (photo credit Tim Canfield)

2.5 Estimating Consequences (CE4)

Once objectives, PM, and decision alternatives have been defined for a case study, the next step is to develop estimates of decision consequences so that the proposed alternatives can be effectively compared. As with the prior steps, the approach and complexity of estimating consequences should be tailored to the circumstances and the objective at hand. This section describes the processes of estimating and reporting consequences of case study decision alternatives outlined in Section 2.4. Consequences as direct estimable outcomes of defined decision alternatives are the primary focus. Methods used to estimate consequences varied across the six case studies, owing to the wide range of environmental, social, and economic conditions and stakeholder priorities encountered. We discuss cross-site commonalities and differences in the context of informing the decision process.

2.5.1 Estimated consequences for decision alternatives

Consequences are changes in the value of PMs associated with identified decision alternatives. This definition makes the process of estimating decision consequences a linked step of each study's SDM process, whereby consequences estimated needed to align with stakeholder-defined priorities for the decision context (Section 2.2), objectives and PMs (Section 2.3), and decision alternatives (Section 2.4).

For example, all six case studies – St. Louis River, Mobile Bay, San Juan, Oklahoma Small Community, Puget Sound, Tillamook – used this process to estimate consequences of local and regional concern for decision alternatives affecting water quality and/or quantity. The nature of those concerns varied across study sites, reflecting place-based cultural, economic, and human health priorities. For Tillamook and Puget Sound, water resource concerns included potential impacts of land management on specific biota of economic and cultural importance – shellfish and salmon, respectively. For San Juan, St. Louis River, and Oklahoma, primary objectives were to estimate consequences of decisions affecting the connection between water quality and/or quantity and community health and wellbeing. Priorities included remediation of polluted urban floodwaters (San Juan); reducing estuarine sources of toxic chemicals that bioaccumulate in freshwater gamefish (St. Louis River); and protection of surface water and groundwater sources necessary for sustaining drinking water supplies for communities (Oklahoma).

In turn, the response of PMs for targeted environmental and human health consequences were estimated for each decision alternative under consideration. For instance, expert- and policy-derived water quality objectives (Section 2.3) were connected to performance measures for shellfish habitat, as in the Tillamook Bay case study that estimated specific consequences for shellfish harvest trends assuming water qualtiy impacts on habitat. This can be contrasted with stakeholder-derived performance measures, as for the St. Louis River case study that considered a qualitative set of consequences across a suite of factors, or the Puget Sound case study that used process-based models to estimate quantitative performance measures based on land use decision alternatives. All these examples underscore the necessity of linking an approach for estimating consequences to the performance measures and decision objectives for any given location and community (see Section 2.3 for a discussion of performance measure selection) .

Take Home: Estimated consequences of decision alternatives should be communicated with established PM for the decision. Effective application of SDM concepts in decisions involving ecosystem services needs to have consequence estimation align with stakeholder-defined objectives and performance measures provide the link for this alignment.

2.5.2 Approaches and tools used to estimate decision consequences

The tools and approaches used to estimate consequences varied across case studies, largely as a function of differences in stakeholder objectives and associated PM requirements. The comprehensive SDM tools (DASEES, HIA) described in preceding sections provide stakeholder-oriented platforms for estimating consequences for alternative decision options. For example, for the Oklahoma Small Community case study DASEES was used to integrate water quality data, stakeholder preferences, and other information to generate consequence charts for identified decision alternatives aimed at protecting and sustaining limited drinking water supplies. The DASEES tool combines stakeholder input on decision consequences with visual comparison tools that clearly demonstrate trade-offs among alternatives affecting multiple stakeholders.

The Mobile Bay and Puget Sound case studies used quantitative models like EPA's VELMA ecohydrological model (McKane et al. 2014) to estimate consequences of stakeholder-identified priorities – land use and restoration options for improving suburban water quality and quantity in Mobile Bay, and forest management options for restoring in-stream habitat for endangered salmonid populations in Puget Sound (McKane et al. 2018; 2020; and in review; Fulford et al. 2022). These quantitative tools directly compare different decision options and provide visualization capabilities for communicating results and associated PMs to stakeholders (Section 2.5.3). Because implementation of tools like VELMA requires some GIS and modeling skills, the EPA case study teams generally implemented the tools and interpreted the results for stakeholders. The Puget Sound community forest stakeholder group was an exception, and with a modest amount of training (1-2 weeks in-person or online, plus 1-2 months practice) were able to independently develop and apply their own watershed management scenarios and interpret the results. For the Mobile Bay case study, the optimal entry point was a hybrid approach that considered more traditional monitoring of simple water quality criteria while also exploring broader model-based assessments.

The St. Louis River and San Juan case studies used combinations of quantitative and qualitative tools to estimate human health consequences of estuarine restoration. The Great Lakes study applied a Health Impacts Assessment (HIA) framework combined with restoration monitoring data for the St. Louis River estuary to statistically estimate potential human health consequences for alternative cleanup scenarios (Williams and Hoffman 2020). HIA emphasizes stakeholder input and provided a comprehensive comparison of restoration outcomes in the St. Louis river that were easily communicated to stakeholders using both maps, figures, and other visualization tools (EPA 2021).

The San Juan case study used the HWBI (Smith et al. 2013) and EPA's Eco-Health Relationship Browser in combination with empirical data gathering to develop a methodology that communities can use to estimate consequences of decision alternatives on San Juan Bay water quality, ecosystem services and human well-being (Yee et al. 2017, 2020). Such ‘weight of evidence’ approaches are useful tools for making full use of best available information for estimating consequences where data are limited locally (de Jesus-Crespo and Fulford 2018).

Such human health and well-being assessments could in principle have been applied to the Puget Sound, Tillamook Bay, and Mobile Bay case studies. However, the decision contexts, geographic scales, and modeling infrastructure required for such assessments were beyond the scope of these case studies. Nonetheless, work to date can potentially provide a foundation for larger scale coastal zone assessments including health impacts. For example, scalable multi-model decision support frameworks such as ENVISION (http://envision.bioe.orst.edu/) are designed for integrated evaluations of ecological, economic, social, and health consequences of stakeholder-defined ecosystem management decision alternatives (e.g., Bradley et al. 2016, Jaeger et al. 2017). It is also feasible to develop tool-specific “plugins” for ENVISION, including VELMA and other EPA modeling tools designed for coastal ecosystem services assessments (McKane et al. 2020).

2.5.3 Communicating estimated consequences to stakeholders

As described in Section 2.5.2, stakeholders provided community-based preferences and supporting information that EPA team members then analyzed using appropriate tools (e.g., VELMA, HIA, HSI) to generate estimated consequences with appropriate performance measures for identified decision alternatives. Communication of results back to stakeholders was generally designed to provide clearly framed, intuitive views of likely consequences for alternative decision scenarios. Some examples follow.

For the Oklahoma Small Community, Mobile Bay and Puget Sound case studies, EPA team members used DASEES (Oklahoma) or VELMA and associated tools (Puget Sound, Mobile Bay) to synthesize stakeholder preferences and supporting data inputs to estimate water quality/quantity consequences of decision alternatives. Modeled results from these tools can be voluminous (gigabytes in some cases), posing significant analytical and communication challenges. VELMA and supporting data analysis tools were specifically designed to facilitate communication of large, complex model outputs to stakeholders via data visualization methods (McKane et al. 2015).

Figure 2.5 is one example of a Puget Sound case study visualization found to be effective for communicating complex model results to community forest stakeholders seeking to evaluate potential long-term consequences of alternative forest management scenarios. As shown in this figure, the technique of normalizing disparate PMs for a range of objectives enabled stakeholders to quickly evaluate co-benefits and tradeoffs associated with each forest management scenario. In turn, stakeholders have used similar visualizations to communicate their preferred management objectives to state and federal agencies responsible for land-water management and policy decisions.

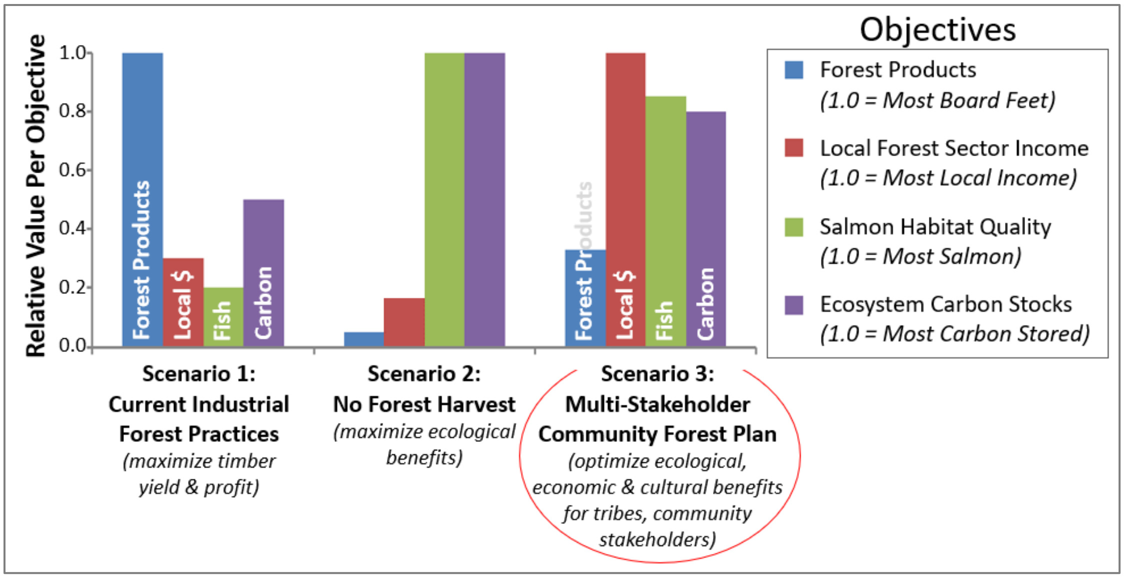


Figure 2.5 Example visualization of model-based Puget Sound case study results found to be effective for communicating potential long-term consequences of alternative forest management decision scenarios defined by community forest stakeholders.

Performance measures for each management objective (see legend) were normalized (0-1, y axis) with respect to the maximum value of a particular objective across three decision scenarios. (McKane et al. 2018). The objective is to present data in a format optimized for comparing alternatives to each other in the context of establish performance measures as opposed to a simple presentation of data which may not inform the decision process.

Similarly, the DASEES tool incorporates various features to help stakeholders visualize and sort through complicated multi-objective environmental issues in an objective way. DASEES is designed to accomplish this interactively, for example, during workshops in which stakeholders are engaged in exploring how specified decision alternatives produce different consequences (Figure 2.6).

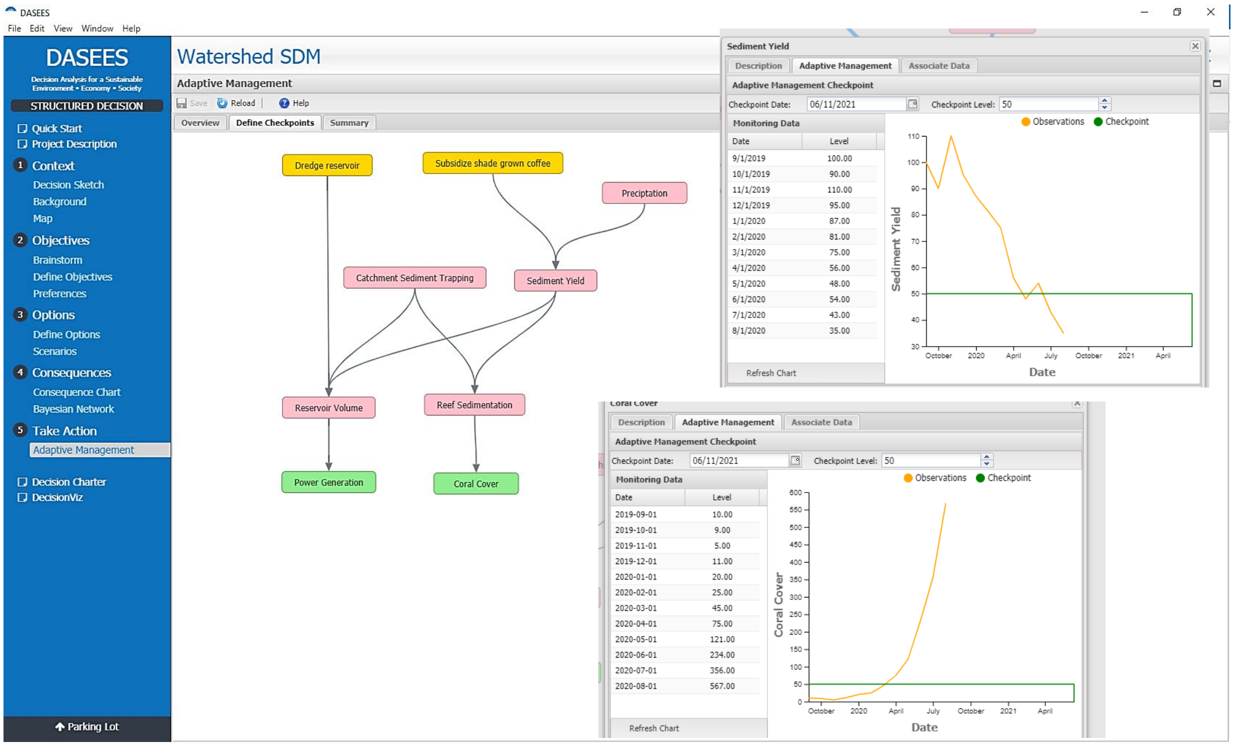


Figure 2.6 DASEES screenshot showing estimated consequences of proposed actions under consideration.

Main figure is the determined flow chart from actions to outcomes and the inserts show estimated change in performance measures combined with checkpoint values for evaluation.

In summary, stakeholders across all case studies were keenly interested in the process of estimating consequences for all decision alternatives, positive or negative, and how those aligned with their preferred objectives. Trust is a necessary prerequisite when complex data are presented in this way to compare proposed actions, and this is best accomplished through stakeholder involvement in all steps in the process. Knowledge of outcomes associated with different decision alternatives – for example, business-as-usual versus conservation-based management options – provided context for understanding tradeoffs and scientific backing for stakeholders seeking to implement and/or advocate for changes in environmental management and policy. The case studies varied in how they communicated consequences, but they all demonstrate the importance of the effort (Table 2.7).

Take Home: Consequences of decision alternatives should be estimated as a part of the decision process based on the best information available. Whether the decision context is data rich or data-poor, consequence estimation should make use of best available information and engage stakeholders. Transparent consequence estimation is optimal for evaluating and communicating tradeoffs and to advocate for changes in environmental management and policy.

Table 2.7 Examples of communicating case study consequences that have led or may lead to changes in community planning, a policy, or other action.

Case Study	Communication of estimated consequences to stakeholders
San Juan	San Juan Bay Estuary Program and Martin Peña neighborhood community organization are using empirical results to communicate potential benefits of management actions to local communities, and to advocate for the dredging of the Martin Peña canal (pending). For example, a *Zika* vector-borne illness study was used to advocate for environmentally safe clean-up solutions over traditional pesticide spraying.
Mobile Bay	Modeled consequences of alternative suburban stream restoration scenarios were reported to National Estuary staff for them to evaluate new priorities for meeting NEP goals. Consequences were reported as changes in ecosystem services value, as well as changes in water storage across the watershed with an emphasis on restoration sites.
St. Louis River	The HIA Project Team identified and summarized four scenarios for St. Louis River Estuary revitalization, which were reported to decision makers as maps with PM narratives in support. Adoption of these recommendations is at the discretion of Minnesota DNR and City of Duluth case study partners.
Oklahoma Small Community	DASEES structured decision-making workshops were used to generate visual consequence charts for identified decision alternatives aimed at protecting and sustaining scarce drinking water supplies.
Tillamook Bay	The Oregon Department of Agriculture is considering whether to pursue further development of the fecal bacteria environmental-drivers model to help inform shellfish harvest closure decisions in this National Estuary.
Puget Sound and PNW	Modeled visualizations of consequences of alternative forest management practices and/or climate change were communicated to, and in some instances codeveloped with, stakeholders including the NCF, Snoqualmie Indian Tribe (SIT), and ODFW. These stakeholders have in turn communicated this information forward to successfully advocate for state funding to purchase new community forest lands for the protection of endangered salmonid species (NCF); identify optimal habitat management practices for salmon recovery on ancestral tribal lands (SIT); and prepare a public report describing projected climate impacts on Oregon Coast coho salmon stream habitat (ODFW 2022).

2.5.4 Transferability of approaches and tools used to estimate consequences

All tools and methods for estimating consequences described in this report are transferable, though to varying degrees that depend upon the scale and complexity of decision contexts encountered, and expertise of the research team. Table 2.8 summarizes the primary tools used for each of the case studies, and the primary factors affecting their transferability for estimating consequence in new locations.

Table 2.8. Case study methods and tools and their transferability to new locations.

Case Study	Methods and tools used	Transferability to new locations
San Juan	HWBI framework, Eco-Health Browser, I-Tree, Invest, and EPA H2O models provided inputs for statistical analysis of environmental variables affecting estuarine water quality and human health.	The modeling frameworks and ecosystem production function (EPFs) used have been demonstrated to be transferable. But whether the statistical results for this case study are transferable is unclear. Probably qualitatively but maybe not quantitatively – there are unique technical challenges with this sub-tropical environment.
Mobile Bay	H_2O model and VELMA watershed analysis to identify suburban restoration options for improving estuarine water quality	EPA H_2O model is transferable as demonstrated by its transfer from Tampa, FL to the Mobile Bay watershed. Details on transfer can be found in Russell et al. 2013. VELMA model: See Puget Sound, below
St. Louis River	Health Impact Assessment (HIA) and statistical analysis connecting improvements in estuarine water quality and human health	These tools and methods have been demonstrated to be transferable and have been used at other locations. The main factors that could limit transferability are availability of water quality and health impacts data, and technical expertise.
Oklahoma Small Community	DASEES-guided structure decision making is being used to assist community stakeholders formulate sustainable management of limited water supplies in Southern Plains dryland landscapes	DASEES is designed to be generally applicable for any decision-making context and is increasingly being used nationally to assist diverse community groups facing difficult planning decisions. The only limitation encountered is an initial reluctance to try a new approach, which can often be overcome as familiarity builds.
Pacific Northwest: Tillamook Bay	Statistical analysis of environmental conditions favoring estuarine fecal bacteria outbreaks necessitating shellfish bed closures	The approaches used to develop the shellfish habitat suitability and fecal bacteria environmental models are transferable. Similarly, the advantages that could flow from using the two models are likely to be useful in other estuaries in the PNW and around the country. Factors that would limit the estimation of consequences center on whether data exist to develop site-specific models.
Pacific Northwest: Puget Sound	VELMA watershed analysis to identify forest management best practices for salmon recovery	VELMA is applicable to any terrestrial ecosystem and has been successfully applied across various inland and coastal watersheds, including six National Estuary locations. The model can be set up and run based only on publicly available data. Technical expertise in ecohydrological modeling is the only limitation to its use, but stakeholders and case study teams have gained this through workshops and prepared tutorials.

2.5.5 Conclusions

Estimating consequences is a critical step linking established decision priorities to a formal trade-off analysis described in the next section. The six coordinated case studies successfully implemented tools and methods that were responsive to the unique environmental, economic, social, and health needs and preferences of stakeholders encountered at each site. Of all the steps in the SDM process, estimating consequences varies the most across case study sites. This cross-site diversity required flexibility in the choice of methods used to estimate consequences of identified stakeholder decision alternatives. This was facilitated by the transferability of essentially all the tools and methods used in this study, as evidenced in part by this study (Table 2.8) and by previous studies by other researchers working in other locations (per references cited). A key driver of which method to use will be the level of stakeholder involvement in estimating consequences and how the outcome will be communicated. In the examples highlighted in this section, the choice of method was largely based on access to resources and technical knowledge, and the consent of important stakeholder groups. These issues represent good starting points for choosing a method and fit well into the overall SDM approach to decision making. The examples of case study consequences that have led or may lead to changes in community planning, policies, or other actions demonstrate the effectiveness of the overall SDM approach and the tools and methods used across the case studies.

Skyline bordering estuary near San Juan, Puerto Rico. (Credit – San Juan Estuary Program)

2.6. Evaluate Tradeoffs (CE5)

Communities and community leaders make complex decisions every day. Some of these decisions may be simple and can be made implicitly while others are more complicated and require decision makers to explicitly detail how they arrived at the decision they chose to implement. Typically, environmental management decisions faced by communities are complicated and have multiple facets that are not easily addressed without some form of formal explicit evaluation. Multiple competing interests from stakeholders, limited resources to apply to community problems, and outcomes that may have varying effects on economic, social and environmental aspects of the community all need to be considered. This necessitates having a process where established alternatives can be compared and chosen to ultimately achieve community goals. This is the process of making trade-offs.

All decisions involve trade-offs even if it is simply the cost of acting or not. Once the decision context is clearly defined and articulated, the objectives and performance measures have been clearly identified, a range of decision alternatives have been identified, and the consequences of implementing the decision alternatives are estimated, it is time to look at trade-offs between the different approaches to achieve the community goals as identified by the objectives. Selecting among options characterized by multiple objective consequences is not always straightforward and necessitates methods and approaches for evaluating trade-offs in terms of objective gains and reductions across the options. There are a wide range of approaches and techniques ranging from intuitive heuristics to rational quantitative methods. There is no one universally accepted approach or right way to evaluate trade-offs. Some methods may be more effective and explicit, but the goal is to make trade-offs that make sense to the stakeholders and achieve the objectives that the community is trying to achieve. To better understand some of these methods, Hammond et al., (1999) and Gregory et al., (2012) provide an overview of methods, suggested processes to utilize them, and example applications.

Trade-off analysis is part science and part art and involves judgments on how much of one objective can be reduced to gain in another objective (Gregory et al., 2012). Reasonable and defensible decisions are justified based on accepted amounts of potential gains and reductions among objectives. It is critically important that both decision-makers and stakeholders understand why certain reductions in the achievement of some objectives are related to the gains realized in other objectives and what the rationale was for making the decisions to go one way versus the other. It has been said that the only bad trade-offs are the ones made unknowingly or without fully appreciating their implications (Gregory et al. 2012). Here we take a comparative approach among the six case studies to examine how trade-offs were defined, measured, and applied to the decisional process.

2.6.1 Case Study Approach to Trade-offs

Every case study had some form of trade-off approach, whether it was visibly recognized or not. In order to implement any decisions when looking at environmental issues, the fact that there are multiple desired objectives but limited resources to allocate across all these objectives inherently requires trade-offs and how the objectives are pursued and implemented. Trade-offs will ultimately be made either formally or informally. Formal trade-off analysis involves a deliberate comparison of pre-defined alternatives usually involving comparison tools (e.g., DASEES), while an informal approach is not defined or structured, may primarily involve ad hoc discussions among experts, and may occur after the decision has been made. Across the six case studies considered for this report, three (Puerto Rico, Mobile Bay, Puget Sound) employed an informal trade-off process, one case study (Oklahoma) employed a formal trade-off process, and one case study (St. Louis River) utilized both a formal and informal trade-off process based on how they split the stakeholder groups up. (Table 2.9) The final case study (Tillamook) did not execute a trade-off comparison process but involved tools to inform examination of

Tradeoffs occur when benefits from ecosystem services like resource extraction come with costs such as need for roads through a natural areas and habitat loss. Decisions should be informed by a clear understanding of trade-offs involved in decision options under consideration. (Photo credit: Ted DeWitt EPA).

Table 2.9. Description of Trade-offs approach, comparing trade-off options, and stakeholder engagement for six case studies. Note that 'NA' indicates trade off analysis was not documented for the Tillamook Bay case study which ended prior to formal decision making.

Case Study	Trade-off Form	Information Considered for Trade-offs	Tools or approaches Used for Trade-offs	Trade-off Analysis Used for Choosing Options to Implement	Stakeholder Engagement for Trade-off Process
San Juan Puerto Rico	Informal	Ecosystem services and health impacts	Graphical comparisons with charts, HWBI information	No formal tradeoff analysis. Decisions paths already set.	Stakeholder engagement primarily through information briefings
Mobile Bay	Informal	CCMP goals and 303d status and water quality criteria	Ad hoc approach with NEP staff using CCMP end points as end goals	No formal trade-off analysis, committee deliberations.	Interviews and surveys. Decision made by committee of experts.
Oklahoma Small Community	Formal	Environmental, social, economic. water quantity and quality, recreational, future costs	SDM approach with stakeholder participation using EPA DASEES tool.	Decision Analysis for a Sustainable Environment, Economy, and Society (DASEES)	Representative group of stakeholders from city, tribal, county, and local businesses participating in decision-support process (via DASEES)
Tillamook Bay	NA	NA	NA	NA	NA
Puget Sound	Informal	Water quality, salmon, sustainable forestry, tourism, health and recreational	Ecological model (VELMA) to support stakeholder group deliberations	Ecological model Visualizing Ecosystem Land Management Assessments (VELMA)	Stakeholder groups generally made trade-off assessments individually. Trade-off assessments typically informal
St. Louis River	Formal	Health pathways: water habitat and quality, social and transportation issues	Health pathway analysis (part of HIA) to guide decisions of decision makers	Health Impact Assessment (HIA)	Stage agency participating as a partner in the HIA
St. Louis River	Informal	Same as formal	Qualitative consultation with stakeholders and community partners.	Health Impact Assessment (HIA)	Stakeholders and community members participating in decision-support process (via HIA)

trade-offs by other authorities. The decision to examine trade-offs with a formal or informal process, and whether that process is implicit or explicit is up to the stakeholders and decision-makers in each case study. The subsequent discussion of trade-offs will focus on and provide information from the San Juan, Mobile Bay, Oklahoma Small Community, Puget Sound and St. Louis River case studies.

The importance of including trade-off analysis varied across the case studies. In the case of San Juan Puerto Rico many of ecosystem services or health impacts were looked at separately, and not really considered simultaneously. In the case of Mobile Bay, no formal trade-off analysis was completed. The development of an annual NEP workplan included trade-offs regarding where to invest restoration resources with that plan being developed by NEP staff in consultation with expert committees. The Oklahoma Small Community case study was designed from the beginning to follow an SDM approach where trade-offs analysis and process would be integral in determining what decisions were implemented to achieve objectives. The Puget Sound trade-off analysis was used where all of the stakeholders (community, tribal, state, federal decision-makers) were interested in knowing how different watershed management alternatives resulted in different outcomes, specifically what are the trade-offs for management options X, Y, and Z example, and this was informed by model-based analysis In the St. Louis River, a formal trade-off analysis was critical to agency agreement regarding the scope of the project the informal trade-off process typically conducted by non-agency or non-expert stakeholders was used for improving project design and construction with respect to health outcomes.

Information used in the case studies to conduct trade-offs and do trade-off analysis included information from environmental, social, economic and health aspects that were important for the communities in the final decisions that would be made. The San Juan case study considered impacts of urban runoff, vegetative cover, urbanization, and other factors on multiple ecosystem services such as air quality, carbon sequestration, nitrogen removal, and urban heat islands and the potential linkages to multiple metrics of human health and well-being. In Mobile Bay, CCMP goals like level of impairment of individual candidate sites, such as 303d (US Estuaries and Clean Water Act of 2000) status, water quality criteria, and fish and wildlife habitat quality metrics were used as part of the trade-off analysis information. No economic or social criteria were used overtly for decision-making; however, priority is typically given to sites with social or economic importance in committee deliberations. The Oklahoma Small Community case study was designed to integrate aspects of environmental, social, and economic considerations into the trade-off analysis through an organized stakeholder engagement process. This effort is primarily about water sustainability and resiliency. Thus, most of the options are directed at protecting water supplies, minimizing waste of this water through leakage in the system, providing sufficient quantities and quality of water for domestic and economic usage and creating recreational opportunities for the local community. The SDM process applied in the Oklahoma Small Community case study includes formal trade-off analysis as a key step in maximizing benefits to as many stakeholders as possible. Puget Sound case study included multiple aspects of environmental, economic, and social considerations for their trade-off process. Environmental considerations were restored salmon habitat, clean drinking water, flood protection, and climate regulation, which included aspects of carbon sequestration. The economic information used in sustainable forest products and associated local job opportunities included local and regional tourism dollars associated with restored salmon populations. Social aspects included cultural benefits of healthy salmon populations, health, and recreational benefits of clean water supplies. Information used in the St. Louis River case study was collected through a formal Health Impacts Assessment (HIA; EPA 2021). This information included benefits of the project such as water habitat and quality, recreation, aesthetics, and engagement with nature both social and cultural; but also, costs associated with project implementation, such as equipment operation, traffic and transport, noise and light pollution, air quality, crime and safety.

Take Home: Multiple competing interests from stakeholders and limited resources to apply to community problems require trade-offs. Comparison of identified alternatives in a trade-off analysis adds transparency to a decision and increases acceptance. Case study details in Table 2.9 can help start a trade-off analysis in a new location.

2.6.2. Stakeholder Engagement and Tools Used for Trade-off Analysis

The use of stakeholders and stakeholder engagement varied across the case studies. Most of the Case studies had some form of stakeholder engagement involved to look at alternatives or scenarios that were under consideration for implementation. The only case study that examined trade-offs but indicated stakeholders were not engaged in the trade-off process was the San Juan case study. For the most part decisions were already underway and analysis from the case study was used to provide additional support in terms of expanding knowledge of potential benefits of those decisions. Results from these discussions were provided back to stakeholders through briefings, conference calls, and sharing of journal articles that were published with this information. The Mobile Bay case study was similar in that established CCMP goals guided the trade-off analysis, but trade-off decisions were made by committees comprised of federal, state, county, civic, and private experts. These committees were made up of the representative stakeholders in the process and the work of these committees represent the contribution of the stakeholders to the trade-off assessment.

Two of the case studies used formal stakeholder engagement, which extended to trade-off analysis. For the Oklahoma Small Community case study, the entire process is stakeholder informed from the very start with the stakeholders providing the objectives and criteria as the basis for the study. This tight integration between steps led smoothly to the analysis of trade-offs based on a direct comparison of scenarios. This engagement is aided by visualization tools that display alternatives in terms of their collective impact on PMs. While it is understood that those empowered as the decision-makers will ultimately choose the final approach to implement, the process will be conducted in an open and transparent manner that includes the stakeholders so they will have ownership in the final decisions. The second case study with formal engagement on trade-offs was St. Louis River. The St. Louis River case study engaged stakeholders in a formal and informal trade-off analysis process. The informal process involved an informal alternatives process (making recommendations) that included all stakeholders and community members. After this informal process a formal trade-off analysis occurred through agencies like the Minnesota DNR and the Minnesota Pollution Control Agency (MPCA) where the alternatives developed and informed through the informal process were compared and final trade-off decisions were made.

The final two case studies applied a free-form type of stakeholder engagement for analysis of trade-offs, but the analysis was based on model-based outcomes, so it was more data-driven than in the other case studies. In the Tillamook Bay case study, quantitative habitat assessments were developed to consider trade-offs for management, but stakeholders were simply provided with the data to include or not in their assessment. In the Puget Sound case study, the different stakeholder groups looked at the model output for specific scenarios amongst their groups and separate from the other groups. Stakeholders generally made their own assessment of economic and social trade-offs/benefits associated with projected environmental outcomes for different watershed management options. Trade-off assessments by communities and tribes were often informal, reflecting their social, economic, and cultural values. Assessments by state land management agencies were more quantitative, but generally still focused on environmental endpoints rather than economic and social impacts as they tended to be risk-averse to entering into public controversies

Quantitative and qualitative tools help to organize and visualize data in a way that is specific to comparing trade-offs among decision alternatives. The approaches used to conduct and make trade-off analysis varied across the case studies and how this information was presented to those involved in the trade-off analysis varied by case study as well. In the San Juan Puerto Rico case study, differential impacts were compared graphically (i.e., bar charts, spider charts) or with maps (i.e., impacts of population loss on multiple ecosystem services; impacts of ecosystem services on multiple human well-being impacts) but no formal tradeoff analysis was conducted (e.g., swing-weighting or ranking). For the most part decisions were already underway, and the case study analysis only provided support in terms of providing knowledge specific to potential benefits of those decisions. The Mobile Bay case study decisions were made by committee in an ad hoc process that greatly benefited from a formal assessment of decision alternatives. For instance, Mobile Bay NEP staff are working with partners on the stressor matrix describing how key stressors are related to the CCMP endpoints. The matrix was intended to provide a formal process for committee decisions. It can and was most likely used to identify projects based on key stressors and to rank them by importance to facilitate decisions on what to implement and what to set aside. The Oklahoma Small Community case study use the DASEES tool to collect and organize data for the trade-off analysis. Assessed facts are evaluated, aggregated, and then visualized for comparison in the DASEES consequence chart . Stakeholders commented that the DASEES tool visuals are very effective for communicating consequences based on fundamental objectives, measures, options, and stated preferences of the stakeholders. The DASEES trade-off effort is designed to provide a balance across multiple stakeholder values and needs and facilitate the adoption and implementation of an agreed-upon approach to achieve the objectives identified by the stakeholders.

The most quantitative analysis of trade-offs occurred in the Puget Sound case study. In the Puget Sound case study, the VELMA tool was used to conduct the trade-off analysis. Results generated from the VELMA tool address most of the listed environmental trade-offs associated with different watershed management options (e.g., Figure 3 in McKane et al. 2020). For the Puget Sound case study, the VELMA tool facilitated comparisons between differing alternatives such as business as usual for history on private lands (forty-year harvest intervals) versus salmon friendly, ecosystem-based forest management (long harvest intervals coupled with thinning and riparian protections) allowing stakeholders the ability to assess the pros and cons of adopting one alternative over the other. The VELMA tool is optimized for visualization of alternative scenarios, but unlike the DASEES tool VELMA does not consider stakeholder-derived PM but rather is programmed for preset PM with a focus on land use and natural water movement. The St. Louis River case study utilized the health pathways analysis, which is part of the HIA tool. Formal trade-offs were analyzed both quantitatively (data visualization) and qualitatively (expert opinion). Informal alternatives were chosen to identify ways to improve either the project design or construction to improve health mitigation or health outcomes and lacked a formal trade-off analysis.

Take Home: Targeted stakeholder engagement, using formal and informal trade-off approaches, can be effective at examining alternatives or scenarios under consideration for implementation. Open and transparent approaches involving stakeholders during this step provides opportunities to examine stakeholder values and concerns over alternatives and ultimately improve ownership and support of final decisions.

2.6.3. Conclusions

The utility and transferability of approaches to trade-off analysis will be, as with other steps in the decision process, dependent on matching an approach to the needs in other, novel sites. The ad hoc process used in several case studies of developing information and passing it along to decision makers (i.e., San Juan and Tillamook Bay) is best suited to informing a formal policy decision process (e.g., fishing rules). In these cases, Information on differential responses of ecosystem services or human health outcomes to specific management actions will be provided to partners to support ongoing decisions and communication of potential benefits. In the Mobile Bay case study even though no formal trade-off analysis was conducted, tools are being developed to specifically address trade-offs (e.g., H2O model, stressor matrix) and the information provided to the committees and used in their deliberations was considered a useful part for allocating resources and ensuring public support for the planned work.

These informal approaches can be contrasted with the use of formal tools like DASEES or HIA, which require more resources but also generate more decision specific information. The Oklahoma Small Community case study has not reached the point where trade-off analysis has been conducted but when the stakeholders were given an overview of the DASEES process many said they were looking forward to the trade-off process to help them select better management approaches. In the St. Louis River case study, the stakeholders felt the overall HIA approach and the subsequent trade-off analysis portion of the HIA was very useful. In this case study the trade-offs were also visually communicated, which made the information more accessible even after the decision was implemented.

Combinations of multiple management questions generated more complex trade-offs and made optimal use of quantitative tools. The Puget Sound case study stakeholders felt the model-based trade-off process they used was very useful. For example, the Nisqually community forest has already adopted an ecosystem-based watershed management option that VELMA model results have shown to provide marked improvements in stream habitat favorable to restoration of salmon and other ecosystem services important to local and downstream communities.

Overall, partners in every case study felt the approach they used would be very transferable to other locations. There was a broad recognition that there may be some modifications and adjustments needed depending on where future community case studies might be cited. Thinking broadly, there is a balance to be struck between the complexity of the decisions on the table and the value of a formal trade-off analysis involving stakeholder engagement. In some cases, decisions are constrained to a limited set of options (example setting TMDL) that may not merit an extensive evaluation. However, it is increasingly common that options for investing limited resources can be varied, and in these cases a structured trade-off analysis (e.g., DASEES, HIA) can be valuable both for transparency and for informing a comparison of disparate decision options.

Counting Dungeness crabs in Tillamook estuary. (photo credit Ted DeWitt).

2.7 Implementation, Monitoring, and Learning (CE6)

Once potential benefits and tradeoffs among decision alternatives have been considered (Section 2.5), decision-makers should have the best available information to make a decision and to document the rationale for their choices. The ultimate decision may not be an ‘optimal’ solution or even represent a consensus among stakeholders, but through the SDM process decision-makers should have a better understanding of stakeholder willingness to accept tradeoffs that can help inform the ultimate choice of action (Gregory et al. 2012). Some decision alternatives may be quickly dismissed, for example because they have little or unacceptable effects on stakeholder objectives. Other alternatives may be put on a short-list as acceptable to stakeholders. If a clear winner cannot move forward, additional work may be needed to modify alternatives to make them more acceptable, or to even reconsider stated objectives or performance measures to better discern among alternatives. The bottom line is that in most cases a decision must be made based on Best Available Information (BAI) and an important objective of this final step is to improve both quality and availability of information going forward .

Take Home: In most cases, a decision must be made based on best available information (BAI) and an important objective of the implementation, monitoring, and learning step is to improve both quality and availability of information going forward. The goal is to improve BAI.

2.7.1. Implementation

Structured decision software platforms, such as DASEES (Decision Analysis for Sustainable, Economy, Environment, and Society; Dyson et al. 2019), not only provide guidance but can provide a virtual workspace to document the steps of a decision process and collect the information that informed the ultimate decision. The Oklahoma Small Community case study has been using the DASEES tool to document the decision process with stakeholders. Although the decision process in this case study is still ongoing, the process is well communicated and mapped out. DASEES can be used to produce a report

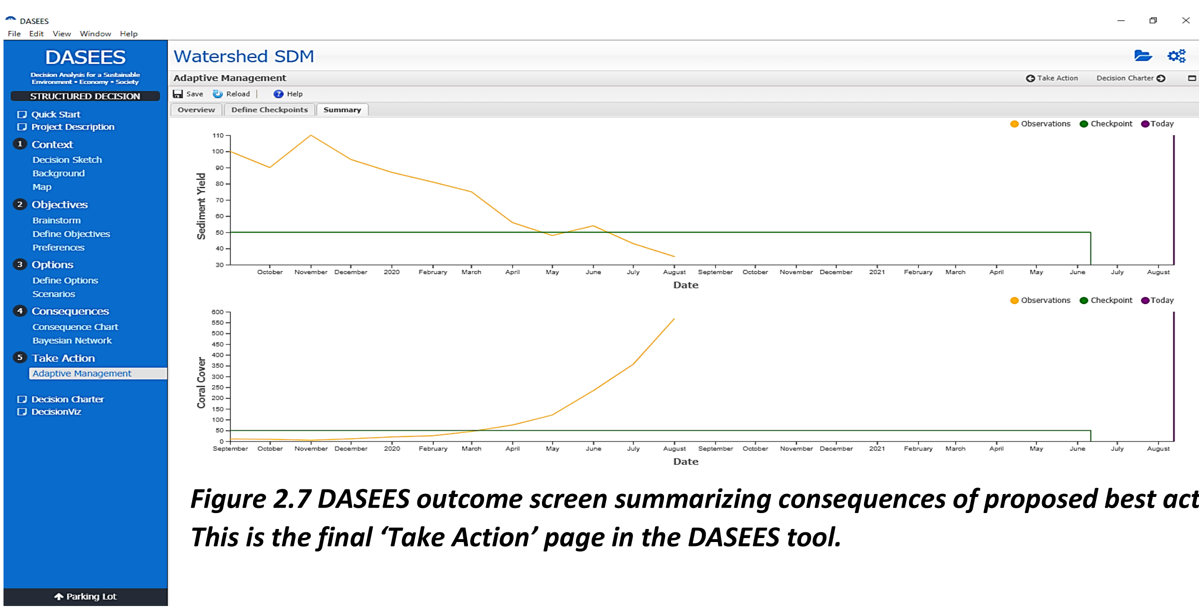


Figure 2.7 DASEES outcome screen summarizing consequences of proposed best action. This is the final ‘Take Action’ page in the DASEES tool.

that collects the information from the individual decision process steps and combines it into a comprehensive report. A part of this report includes the fifth and final step in DASEES: “Take Action & Adaptive Management” (Figure 2.7). This step documents the preferred decision to be implemented, and guides users through monitoring the success of that decision once it is implemented. The “Decision Charter” tool then compiles all the information gathered and developed as part of the DASEES project workspace and renders it into a file that can be edited and shared with stakeholders and decision-makers. It can also be used as a basis for a more detailed final report.

Even in the absence of a visualization/decision platform like DASEES, a structured decision process can help to organize the information that went into a decision in a transparent way. The St. Louis River Minnesota case study used Health Impact Assessment (HIA), which has SDM steps similar to DASEES, to organize and present findings and recommendations to the community, decision-makers, and stakeholders. The HIA results were organized as a presentation, with each of the seven impact pathways (e.g., noise & light pollution; water habitat & quality; air quality; traffic & transport; recreation & aesthetics; social & cultural; crime & personal safety) having a similarly formatted poster explaining the results and recommendations, on which community members and stakeholders had the opportunity to note which recommendations they considered a priority (Figure 2.8). The HIA process, findings, and recommendations were included in a final report available to the community (EPA 2021).

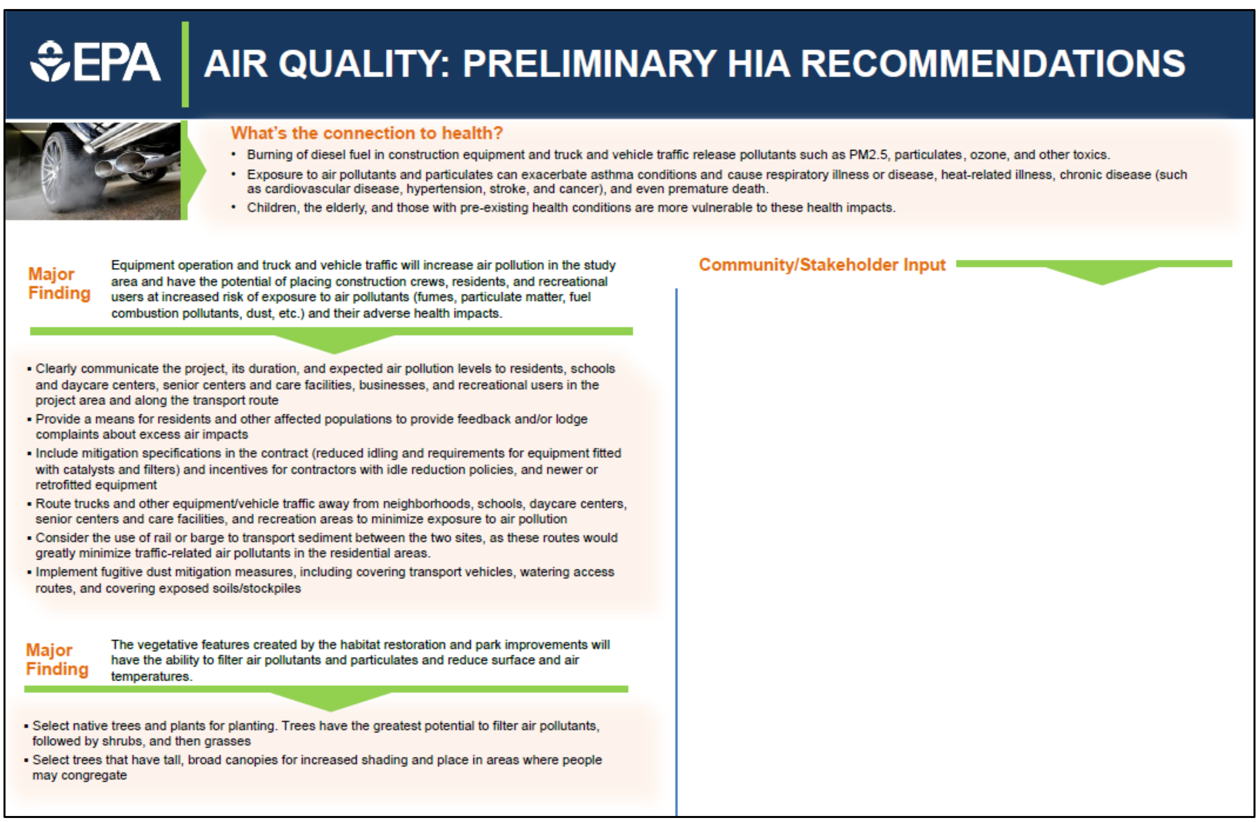


Figure 2.8 Example poster from St. Louis River Minnesota HIA final meeting giving participants opportunities to provide input on recommendations (Williams and Hoffman 2019).

For most of our case studies, presentations or reports summarizing scientific findings were the most common way to provide scientific results supporting decision-making to community members, stakeholders, or decision-makers (Appendix A). The Puget Sound Washington case study, for example, used a combination of written reports and presentations via project meetings and webinars with key partners to summarize model results and recommendations for optimizing ecosystem services of interest. The visualization tools, VELMA and VISTAS (McKane et al. 2014), were particularly useful in conveying the spatially explicit modeling results and to visually communicate main findings (McKane et al. 2018). The case studies also presented results at scientific conferences and documented research efforts through journal articles (Appendix A). Though more targeted for a scientific audience, journal articles and scientific conferences enhance the scientific credibility of the information being developed to support decision-making and provide opportunities for relationship building, particularly with scientific representatives from partner organizations. It is also important that such information is adapted to a public audience with summaries or visualizations such as those used in the St. Louis River, Puget Sound, and Oklahoma Small Community case studies. This will maximize its utility and transparency.

The information and scientific research developed by each case study was in some cases very directly used to make and implement a decision. For the St. Louis River Minnesota case study, based in part on the HIA, a decision was made to undertake the most extensive restoration project among three formal alternatives considered, with many of the informal recommendations also adopted in the project design. In the Puget Sound Washington case study, the ecosystem services analysis helped to inform the decision to adopt salmon-friendly forest management recommendations that include longer harvest intervals coupled with thinning of young stands to improve summer flows, salmon migration, and habitat quality.

For most of the other case studies, the decision process is still ongoing, but information on ecosystem services is being reported back to local partners to continue to advocate for decisions to be implemented, or in some cases to support or motivate urgent short-term decisions as they arise. In the San Juan Puerto Rico case study, for example, the dual crises of the Zika outbreak in 2016 and Hurricane Maria in 2017, highlighted the relationships between water quality, flooding, and human health, and the potential role of improved environmental conditions and ecosystem services (e.g., flood regulation, water retention, biological control of mosquito vectors) as a sustainable alternative to built infrastructure or pesticides (de Jesus-Crespo et al. 2016; de Jesus-Crespo et al. 2017). For other case studies, though existing plans are moving forward as is, ecosystem services research is being considered for incorporation into future planning or monitoring. In both the Mobile Bay and the Tillamook Bay case studies, new models and data based on ecosystem services are now available for inclusion into a recurring decision process that requires the new data be accepted as a portion of best available information for the decision. This acceptance process is aided by scientific support such as scientific peer-review and public support gathered through stakeholder engagement. The case studies demonstrate transferable methods for pursuing both at the same time.

Determining whether the chosen alternative was successful at meeting management objectives is challenging. For the Mobile Bay case study, the management activities are ongoing, and so determining if the chosen projects are meeting the stated management objectives is a continual and iterative process that feeds back on future decisions in a cyclical fashion. In the Puget Sound case study, management plans for the NCF are being implemented based on the model-based alternative evaluation process. The management goals being addressed are diverse (habitat, land acquisition strategy, increasing recreational and cultural opportunities, increase job, inform carbon trading strategies) and thus determining success will be multi-faceted and will take years or even decades to fully measure some goals. Similarly, for the St. Louis River case study, a wetland restoration project design was chosen and implemented. Owing to the large size of the restoration, it will take multiple years to complete, and it is anticipated that the ecological response and community benefits will also take years to manifest.

Take Home: Decision implementation is not the end but the next step in the SDM cycle. A key element of this step is communicating outcomes to stakeholders and investing in monitoring and learning.

2.7.2. Monitoring

By bringing together a diverse group of experts and stakeholders as part of a values-focused decision process (Gregory et al. 2012), the implemented action is anticipated to produce desirable end results. However, there is often uncertainty in the information that goes into making a decision and implemented actions may or may not achieved desired end goals. Also, decisions involving limited resources or other trade-offs need to be validated through the reporting of outcomes to stakeholders. As decisions are implemented, existing and accepted PM connected to stated objectives should be monitored over time to gauge whether the action has been successful in achieving these objectives, or whether new actions are needed. Monitoring can also help practitioners better understand what levels of ecosystem condition and function are needed to achieve desired levels of change, and then apply that knowledge to adapt future decisions and to reduce decision uncertainties (Yee et al. 2017). Ultimately monitoring is controlled by resource availability in the form of personnel and equipment needs for a monitoring plan, but we advocate a process that first considers outcomes (what is needed) prior to considering necessary resources (what is possible).

Monitoring can be used to evaluate whether implemented decisions are achieving desired objectives, including predicted ecosystem services benefits. Optimally, monitoring will be guided by PMs developed during the decision process (Section 2.3). For the Puget Sound, Washington case study, USGS stream gage streamflow data, including peak and low flows that affect salmon spawning and rearing habitat, are being monitored frequently to evaluate the success of implementation of salmon-friendly forest management recommendations. Ideally, soil moisture and stream temperature would also be collected to better validate model predictions and outcomes for salmon recovery. In the St. Louis River, Minnesota case study, the project plan identified a number of ecological PMs for pre- and post-construction monitoring, including water quality variability, benthic integrity indices, and species targets (EPA 2021), to evaluate outcomes as recommendations from the HIA are implemented. The addition of social monitoring in addition to ecological monitoring, specifically human health outcomes, is actively under consideration as well. The St. Louis River is part of the Great Lakes AOC program that uses an adaptive management framework, so monitoring is specifically designed, in part, to iteratively learn from past decisions to inform future decisions. The DASEES process, being used for the Oklahoma small community case study, includes a step "Take Action & Adaptive Management" (Figure 2.8) specifically designed to guide users through establishing an adaptive management strategy by identifying a series of decision points, known as triggers, where evaluations of process and success of implemented actions will be evaluated (Dyson et al. 2019). Proactively setting trigger points will ensure project success is evaluated in a timely manner to allow course corrections, if needed. As with the other steps, monitoring is greatly aided by use of the structured tool DASEES, as it provides a clear link between monitoring activities and the decision process. This can be contrasted with monitoring plans developed based on other priorities, such as historical monitoring or logistics, which may not directly inform stated objectives.

Monitoring protocols for the NEP have been written into specific project work plans, driven by the specific objectives of the workplan (e.g., turbidity, shellfish stock, fecal bacteria). The Tillamook Bay case study identified environmental conditions, such as strong winds and tidal extremes, which may influence fecal bacteria levels and risk to shellfish harvesting but are not currently being monitored in concert with river flow and precipitation to make harvest closure decisions (Zimmer-Faust et al. 2018). As a complement to ecological field monitoring, the Mobile Bay Alabama case study demonstrated how the use of modeling tools, such as EPA H_2O (Russell et al. 2015), can be used to quantify ecosystem services benefits of restoration, based on observed changes in landcover (Fulford et al. 2022). The potential ecosystem services impacts identified in these case studies are being discussed with partners to guide future monitoring plans.

Take Home: Monitoring, ideally guided by PM tied to decision objectives can be used to evaluate whether implemented decisions are achieving desired objectives, including predicted ecosystem services benefits, and help understand what levels of ecosystem condition and function are needed to achieve desired levels of change.

2.7.3. Learning

Monitoring the outcomes of a decision action is a direct example of how learning can be used to evaluate success or whether additional follow-up actions are needed. Learning, however, does not just take place after a decision is made (Gregory et al. 2012). Collaborative learning is important throughout the decision process, not only in informing the current decision through a shared understanding and common language, but also folding lessons learned into future decision activities through adaptive management (e.g., Williams et al. 2009). New information, even from monitoring, must be actively integrated into the decision process to be useful and this process is a form of learning. For example, the Mobile Bay case study currently involves the development of an ecosystem stressor matrix (Table 2.10) intended to link known stressors to high priority parts of the ecosystem in a way that is useful for both setting priorities and projecting impacts of decisions. The stressor matrix, when completed and available, will greatly aid in integrating new information into future decisions (MBNEP *personal communication*).

Table 2.10 Example stressor matrix under development by the Mobile Bay NEP to collect expert opinion on ecosystem services impacted by known stressors. Here a theoretical raw sewage spill in Perdido Bay is examined by connecting habitats to stressor effect through ecosystem services. Committee members complete the matrix together ending with projected effects (up/down; high, medium, low) in the red bordered cells. Only two potential habitats are shown here. The CCMP values are general MBNEP objectives listed in the CCMP.

			Raw Sewage Spill in Perdido Bay		
Impacted Habitats	**CCMP Values**	**Ecosystem Services**	**Event/Response**		
			Stressor	**Stressor**	**Stressor**
Estuaries	ACCESS				
Estuaries	WILDLIFE				
Estuaries	HERITAGE				
Estuaries	BEACHES				
Estuaries	RESILIENCE				
Shoreline	ACCESS				
Shoreline	WILDLIFE				
Shoreline	HERITAGE				
Shoreline	BEACHES				
Shoreline	RESILIENCE				

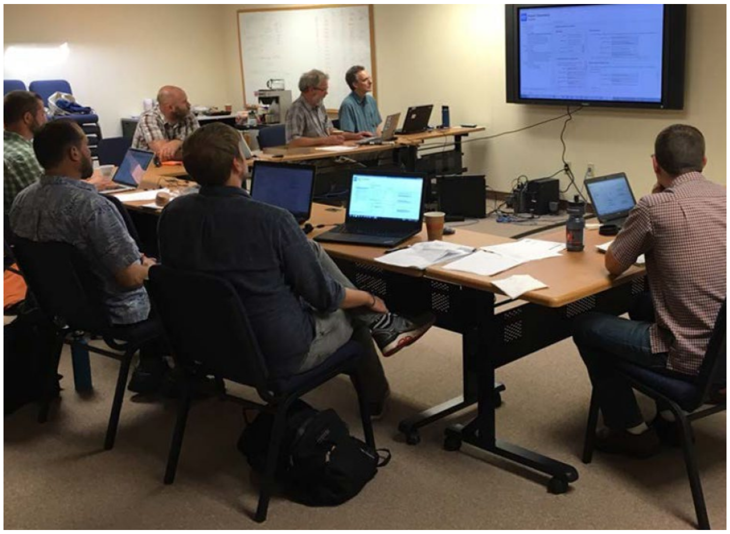
Improving scientific knowledge can help to reduce uncertainties and improve the effectiveness of future decisions. From an SDM perspective (Gregory et al. 2012), the most important sources of uncertainty are those that influence the ability of decision makers to make informed choices either because the choices are not clear, or the outcomes cannot be predicted. By conducting scientific research within the context of ongoing decisions, the case studies were able to identify key sources of uncertainty where more research is needed. For many of the case studies, though knowledge of potential economic and social outcomes of ecosystem services were desired, lack of data inhibited the ability to do economic, cultural, or public health evaluations. The case studies relied on model-based predictions, proxies, traditional ecological knowledge, or expert opinion to fill gaps, and are considering the potential value of including ecosystem services and health related metrics in future monitoring. All of these data sources should be considered when compiling BAI for a decision.

In the Puget Sound Washington case study, validation of VELMA modeling results (McKane et al. 2018) relies heavily on published empirical data, which is often at different spatial or temporal resolutions than model outcomes. VELMA results describing different streamflow outcomes for forest stands of different ages could not be directly validated at the stand-level, until the publication of recent empirical data on the effects of stand age on low summer flows (Perry and Jones 2017). This recent validation has led to increased interest in the use of VELMA for municipal watershed planners for evaluating drinking water supplies, especially in dry summer months. In the Mobile Bay case study, assessment of ecosystem services benefits is currently limited by the lack of a quantitative baseline for evaluating change in response to restoration. Empirical data on this subject is hard to acquire as it requires both social and ecological data however model-based assessment are being developed that inform decision making by setting a baseline relative to historic change in ecosystem services in the target watersheds. This approach is readily transferable to other sub-watersheds of Mobile Bay (Fulford et al. 2022).

Collaborative learning through the decision process can help participants gain new perspectives on what objectives matter about a decision, and to gain trust in resource managers and the credibility of information (Gregory et al. 2012). Joint fact-finding is one approach that encourages experts, stakeholders, and decision-makers to work closely together to gather information and leverage multiple sources of knowledge. The San Juan case study engaged local residents in research efforts to collect data for quantifying ecosystem services, such as flood regulation and water quality, with related human health outcomes, such as household mold or mosquito borne illness (Betancourt et al. 2019; Yee et al. 2019). The research was dependent on this local on-the-ground support from partners and homeowners, but additionally provided an opportunity for the public to become aware, personally invested, and highly engaged in the research outcomes.

For the Puget Sound Washington case study, a key priority is to the reduce the expert dependence of using scenario modeling via VELMA to develop information (McKane et al. 2018). The case study team has invested energy and time in training for stakeholders to be able to transfer the use of VELMA from model experts to decision-makers for incorporation into their own planning. Similarly, the positive reaction of stakeholders and decision-makers who participated in the St. Louis River case study HIA process shows their interest in using HIA in their own future project planning.

In addition to learning how to use tools, it is often the case that incorporation of ecosystem services into decision making is limited by stakeholder understanding of ecosystem service benefits (Boyd et al. 2016). Extractive services, such as harvesting natural resources, pose no conceptual challenge but other services, such as recreational access and clean water, are both harder to value and communicate to stakeholders.



VELMA training workshop (photo credit B. McKane).

Take Home: Learning is about making a more informed decision. Dedicated attention to learning can help evaluate success of the decision, identify whether additional follow-up actions are needed (i.e., adaptive management), and improve stakeholder awareness of ecosystem service benefits provided by the decision.

2.7.4. Conclusions

While partners and stakeholders in the case studies recognized and appreciated the value of considering ecosystem services, their successful inclusion of ecosystem services in implementation was variable. While two case studies implemented decisions directly based on the ecosystem services assessment, the majority of other case studies are continuing to consider how ecosystem services information might be incorporated in future planning. Data limitations, especially for social, economic, or health outcomes, can limit the ability to estimate potential benefits of decisions, and most case study partners recognized a need for collecting the kind of data needed for ecosystem services assessment. However, often multiple agencies, scientific advisory boards, internal approvals, or public review may be required to make changes to existing monitoring protocols, so it may be unrealistic to expect rapid implementation as new information becomes available. Furthermore, monitoring an ecological project for social and health outcomes is a relatively novel idea, and may be reported at different spatial or time scales than ecological data, for example to protect personal identities. Here we encounter again the notion of BAI and how new ideas and data become accepted and integrated as a part of BAI for a particular decision. All of the case studies should be viewed as cyclical in that some decisions, as well as the BAI used to make them, are revisited regularly. The most transferable and useful element of the case studies is a structured incremental process for incorporating ecosystem service concepts into BAI. This is not SDM itself, rather how new information is integrated into the SDM cycle over time. The structure of SDM makes this process both easier and more transparent.

Overall, the case studies highlight the importance of using a structured process to engage community members and stakeholders. This allows the establishment of clear expectations and timelines; facilitates communication among community members, experts, and decision-makers; and undertakes a process with transparency. Stakeholders in the St. Louis River case study appreciated that the decision process was flexible; connected an ecological project with social, safety, and human health concerns; followed a systematic process; and that facilitators continually followed-up with participants (EPA 2021). Community members may be more likely to accept the ultimate decision if they feel they have been heard and played a role in impacting the decision, even if they disagree with it (Gregory et al. 2012). Furthermore, a process that engages collaborative learning can set the foundation for more effective planning and implementation of future decisions.

2.8 Practical strategies and transferability

The ecosystem services practical strategies report (Yee et al. 2017) outlined the SDM approach to decision support that was applied here in the case studies, as well as a suite of practical strategies intended to be a guide for the transferability of this approach to other locations and issues. The goal for Yee et al. (2017) and this coordinated case study comparison is to demonstrate the value of an SDM approach based on ecosystem services, but also to facilitate its use elsewhere. In this coordinated case study comparison, not all the steps were fully implemented for all the case study sites. Further, the cases studies applied a range of tools best suited to the location, the issue at hand, and the organizational structure of the decision authority involved. All steps should be used, if possible, but each step can be approached differently if needed. Overall, a structured decision support tool like HIA or DASEES offers the best entry point as they include all steps in the process and follow a guided, logical path for stakeholders, but they require more time and technical investment to use. The SDM framework that was demonstrated is intended to be modular and flexible. Its primary elements are stakeholder engagement and the inclusion of ecosystem services as both objectives and as assessment tools. The next section builds on this theme of transferability by considering entry points for the SDM process as a guide for applying the SDM approach at new sites. These entry points along with the practical strategies represent key lessons learned during the case study project.

Take Home: All steps of structured decision making should be used, if possible, but each step can be approached differently for a specific decision context. This is a balance between the common elements and locally specific characteristics.

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Section 3. Transferability and entry points of the decisional framework

The practical strategies report (Yee et al. 2017) outlined a suite of steps based on SDM (Gregory et al. 2012) that can guide the inclusion of final ecosystem services (FEGS) into environmental decision making. This report has described a set of case study applications of these practical strategies with the objective of providing transferable tools and entry points (Table 3.1) for application in other locations to address a variety of important decisions. The goal is to make the application of FEGS in decision making more understandable and accessible. The case studies include a mix of decisions, decision authorities, and tools that should give interested readers some common ground no matter what their situation may be. However, any effort to include ecosystem services into decision making should consider the following base elements for success .

3.1 FEGS directly link a decision to human beneficiaries

The advantage of FEGS as a tool for informing decisions is that they link the decision outcome directly to human benefit in as comprehensive a manner as possible. For example, in the Oklahoma Small Community and St. Louis River case studies the primary effort at the beginning of the process was a scoping of potential human benefits that could be connected to the decision at hand. Such efforts are time consuming but highly beneficial as the end products are well and clearly aligned with how they benefit people. Less formal entry points for this include expert opinion approaches, such as the stressor matrix applied in the Mobile Bay case study or the human health links built in the San Juan case study. Identification of high priority FEGS in any context, as well as how to measure change in FEGS production, is an important step for decision support .

3.2 Structured tools as an entry point for decision framework

Expanding decision support to consider FEGS is a part of achieving BAI for a decision. That said the case studies demonstrate that doing so is not a simple straight path to inclusion of new information. Complex decisions often require organized approaches for the inclusion of new data. The structured decision tools, such as HIA or DASEES, represent the most inclusive application of SDM and offer clear entry points for new sites and decision contexts. They begin with clearly defining the decision and engaging stakeholders and progress to clear metrics, useful visuals for comparison of decision alternatives, and a framework for reporting the outcome in an understandable way. Tools like DASEES are complicated and require facilitation to use them well. They are also time and data intensive. For these reasons we consider adaptive endpoints as alternative entry points (Table 3.1) but recommend the use of structured tools whenever possible and practical.

3.3 Stakeholder engagement is a central, critical element of SDM

One of the central elements of incorporating FEGS into decision support is the connection to people. Some benefits of a decision are usually well understood, such as the sustainable harvest of shellfish in the Tillamook Bay case study. However, many less obvious benefits may exist and should be considered, and stakeholder engagement is a critical tool for increasing the inclusivity, transparency, and acceptance of a decision outcome. In the St. Louis River case study, stakeholder engagement in the form of workshops was used to broaden the scope of decision alternatives to consider not just environmental restoration metrics, but also human health endpoints. These new endpoints altered the discussion of alternatives beyond site clean up to consider the impact of restoration implementation on the neighborhood and to examine post restoration use of the site. These were novel objectives used to compare alternatives. In the Mobile Bay case study, existing stakeholder committees were given opportunity to steer decisions about how and where to make restoration investments. These represent examples of both formal (St. Louis River) and adaptive (Mobile Bay) methods for stakeholder engagement that can be applied in other situations (Table 3.1) .

3.4 New communities/same strategies

It is well accepted that every community has its own unique characteristics, history, and issues that will affect the decision process no matter what the issue at hand may be. That said, an examination of environmental decision making across the cases studies demonstrate a large amount of common ground that allows for transferable lessons and strategies as we have outlined here and in previous reports (Yee et al. 2017, Fulford et al. 2016). Further the SDM process and the approach for inclusion of FEGS into decision making are both designed to be flexible and transferable across locations and issues. The case studies demonstrate the idea of new communities/same strategies, and this report provides key entry points for those interested in adapting these strategies to a new decision context. The goal is for each new community to find the entry points that best fit their situation as a starting point with the end goal being a comprehensive inclusion of FEGS in decision support. This approach allows new FEGS practitioners to start small and build a good foundation as a long-term effort to improve not just the decision outcome but also the decision process.

Take Home: All steps of structured decision making should be used, if possible, but each step can be approached differently for a specific decision context. Existing research has demonstrated a suite of entry points whereby decision makers can most easily take advantage of these new concepts in environmental decision making.

3.5 The way forward

This case study research was aimed at establishing the utility and transferability of the FEGS decision framework between communities and across issues. The key to this approach is the 17 practical strategies that were 'lessons learned' across all the case studies (yee et al. 2017), as well as viable entry points for implementing these practical strategies (Table 3.1) with links to resources to make the practical strategies useful. New users of this FEGS decision framework can use this report to choose entry points for each practical strategy that suits their own situation and based on the work conducted in the six case study sites (Appendix A). Final ecosystem goods and services are an important tool for assessment of decisions based on how they benefit people. An adaptation of any environmental decision to better or more completely consider human benefit is a change for the better in that the decision will be clearly justifiable, accepted by stakeholders, and adaptable as priorities change or new information becomes available. Taken together and applied well, these practical strategies have high potential to improve economic, social, and environmental benefits of complex decisions.

Table 3.1 Example applications of practical strategies outlined in Yee et al. (2017) based on case study experiences.

Entry points represent approachable ways to start with each strategy both formally (Formal) and in an adaptive manner that builds on existing decision strategies (Adaptive). Representative case study examples are given for each entry point. Case studies are: Mobile Bay (MB), San Juan (SJ), Southern Oklahoma (SOK), St. Louis River (SLR), Puget Sound (PS), and Tillamook Bay (TB).

Practical strategy	SDM step (Section link)	Entry points
1. Apply FEGS concepts to explicitly connect EGS to people **The concept of FEGS explicitly connects ecosystem services to the people that benefit from them, leading to identifying biophysical metrics that are more meaningful to a community and what they care about.**	**Overall SDM element (2.1)** **Formal example case study (SLR; 1.3.5)** **Adaptive example case study (PS; 1.3.2)**	**Formal** – Use SDM tools such as DASEES, HIA, or DPSIR to identify important FEGS through stakeholder engagement. (Ex. SLR, SOK) **Adaptive** – Identify FEGS using expert opinion and existing objectives with opportunistic inclusion of non-target FEGS also impacted. (Ex. TB, PS)
2. Apply principles of SDM to emphasize flexible approaches to FEGS **Principles of SDM can provide a philosophy for integrating FEGS into decision making by emphasizing flexible approaches to develop creative alternatives that are responsive to what stakeholders care about.**	**Overall SDM element (2.1)** **Formal example case study (SOK; 1.3.4)** **Adaptive example case study (SJ; 1.3.3)**	**Formal** – Use SDM tools such as DASEES, HIA, or DPSIR for walking through the entire SDM decision cycle. (Ex. SLR, SOK, SJ) **Adaptive** – Identify SDM steps in existing decision process with an effort to expand and educate stakeholders. (Ex. MB, SJ, TB)
3. Incorporate FEGS concepts at any point in the decision process **Ecosystem services concepts can be integrated at multiple points in a decision process, whether that process is in early or late stages, or whether that process includes informal or formal decision analysis.**	**Overall SDM element (2.1)** **Formal example case study (SLR; 1.3.5)** **Adaptive example case study (MB; 1.3.1)**	**Formal** – Use SDM tools such as DASEES, HIA, or DPSIR to connect FEGS to objectives, performance metrics, and as an assessment tool in analyzing trade-offs. (Ex. SLR, SOK) **Adaptive** – Identify important FEGS and connect to an existing decision process based on expert opinion with an effort to educate stakeholders. (Ex. MB, SJ)
4. Use FEGS to identify beneficiaries as potential stakeholders	**Clarify Decision Context (2.2)**	**Formal** – Use SDM tools such as DASEES, HIA, or DPSIR to identify beneficiaries through inclusive

Practical strategy	SDM step (Section link)	Entry points
FEGS is a useful construct for ensuring potential benefits and costs of environmental impacts are under consideration and identifying beneficiaries to engage as stakeholders in the decision process.	**Formal example case study (SJ; 1.3.3)** **Adaptive example case study (PS; 1.3.2)**	stakeholder engagement. (Ex. SLR, SOK, SJ) **Adaptive** – Beneficiaries identified by expert opinion and existing stakeholder input process, such as committees. Process should be open to identification of new beneficiaries. (Ex. TB, MB, PS)
5. Use conceptual models as a scaffold to visualize cause and effect and relationships **Conceptual models can help visualize cause and effect between decisions, stressors, FEGS, and benefits. They help provide a common language, guide discussions, and elicit information, especially when built from a structured generic model as an underlying scaffold.**	**Clarify Decision Context (2.2)** **Formal example case study (SLR; 1.3.5)** **Adaptive example case study (MB; 1.3.1)**	**Formal** – SDM tools such as DASEES, HIA, or DPSIR can be used to build conceptual models of a given decision context. (Ex. SJ, SLR) **Adaptive** – Conceptual models can be developed as an ad hoc process to describe a decision, usually as a part of stakeholder deliberation or because of the inclusion of new data. (Ex. MB)
6. Use objectives hierarchies to define what is important about FEGS **Depending on the context, FEGS may be fundamental objectives or means to achieving other social or economic objectives, such as better health or more jobs. Objectives hierarchies can help clearly define what is important about ecosystem services (intermediate or final), and the means to achieve it.**	**Define objectives and performance measures (2.3)** **Formal example case study (SOK; 1.3.4)** **Adaptive example case study (MB; 1.3.1)**	**Formal** – SDM tools such as DASEES, HIA, or DPSIR can used to build an objective hierarchy to maximize inclusion of all objectives. (Ex. SJ, SOK, SLR) **Adaptive** – Listing of all objectives associated with a decision via expert stakeholder deliberations can result in an objective hierarchy, but the objectives need to be linked and ranked. (Ex. PS, TB, MB)
7. Use structured systems as a starting point to identify measurable objectives **Structured approaches to indicator development, such as the FEGS Classification System, Rapid Benefits Indicators, and the HWBI, can provide a starting point for clarifying objectives and how to measure them in ways that reduce ambiguity.**	**Define objectives and performance measures (2.3)** **Formal example case study (SOK; 1.3.4)** **Adaptive example case study (PS; 1.3.2)**	**Formal** – SDM tools such as DASEES, HIA, or DPSIR can used to convert a list of objectives into measurable performance indices. (Ex. SOK, SLR) **Adaptive** – Performance indices developed via regulation or through expert judgement can be linked to objectives and should allow for expansion of metrics if all objectives are not measured. (Ex. MB, PS)
8. Consider FEGS as means to achieve other objectives **Depending on the decision context, FEGS may be means to achieving other**	**Develop alternatives (2.4)** **Formal example case study (SLR; 1.3.5)**	**Formal** – SDM tools such as DASEES, HIA, or DPSIR are designed to consider all objectives identified through stakeholder engagement. (Ex. SOK, SLR, SJ)

Practical strategy	SDM step (Section link)	Entry points
economic, social, health, or general well-being objectives, and may provide an opportunity for developing creative alternatives alongside more typical social or economic initiatives.	**Adaptive example case study (MB; 1.3.5)**	**Adaptive** – Novel objectives can be identified through ad hoc consideration of ecosystem goods and services by considering impacts on stakeholders. (Ex. MB, PS)
9. Use structured paradigms to link FEGS alternatives to broader objectives **Structured paradigms, such as FEGS or the HWBI, can provide a starting point for identifying alternatives that leverage ecosystem services (intermediate or final) to achieve economic or well-being objectives.**	**Develop alternatives (2.4)** **Formal example case study (SLR; 1.3.5)** **Adaptive example case study (PS; 1.3.2)**	**Formal -** SDM tools such as DASEES and HIA are designed to identify formal decision alternatives and link them to performance measures to ease comparison. (Ex. SOK, SLR) **Adaptive** – Existing decision options can be evaluated with ecosystem services metrics identified by expert opinion or through stakeholder engagement. (Ex. MB, PS, SJ)
10. Prioritize information and analysis to what is actually needed **Information collection and application of tools should be prioritized to what is needed to estimate consequences of alternatives on measurable objectives, and to reflect the uncertainty decision makers are able to tolerate. Complex FEGS assessments or economic valuations may or may not be needed.**	**Estimate consequences (2.5)** **Formal example case study (SLR; 1.3.5)** **Adaptive example case study (TB; 1.3.6)**	**Formal -** SDM tools such as DASEES and HIA formally consider only those objectives identified as important through stakeholder engagement through an organized and facilitated process. (Ex. SOK, SLR) **Adaptive** – Adapting an existing decision process, such as resource management, to consider all needed information typically requires a stepwise process including a new data champion, review of new data, and expert discussion. (Ex. MB, PS, SJ, TB)
11. Use conceptual models to visualize relationships **Conceptual models allow for a clear understanding of assumptions being made in estimating consequences. Such visual models can be built as a part of a formal discussion or borrowed from existing information. Consensus on content of these models is important.**	**Estimate consequences (2.5)** **Formal example case study (SOK; 1.3.4)** **Adaptive example case study (MB; 1.3.5)**	**Formal –** SDM tools such as DASEES provide a framework for turning targeted discussions into a visual conceptual model (Ex. SOK). **Adaptive** – Conceptual models of relationships can be derived from informal discussion or existing documents as a part of estimating consequences and then confirmed with experts (Ex. MB, PS).
12. Quantify FEGS with EPFs **A number of mathematical modeling tools, ranging from fairly simple lookup tables to complex biophysical models, can quantify the effects of**	**Estimate consequences (2.5)** **Formal example case study (PS; 1.3.2)**	**Formal –** Develop new modeling tools specifically to quantify ecosystem services and compare decision scenarios defined by decision makers. (Ex. PS)

Practical strategy	SDM step (Section link)	Entry points
alternative scenarios on provisioning of ecosystem services through the use of EPFs.	**Adaptive example case study (TB; 1.3.6)**	**Adaptive** – Adapting an existing decision process with model-based information and projections can help improve BAI. Inclusion of new data is gradual. (Ex. TB, MB)
13. Let objectives drive choice of methods for FEGS benefits analyses **Choice of methods to estimate ecosystem services benefits (EBFs) should primarily be driven by 1) benefits endpoints under consideration and 2) the information required to make a decision.**	**Estimate consequences (2.5)** **Formal example case study (PS; 1.3.2)** **Adaptive example case study (TB; 1.3.6)**	**Formal** – SDM tools such as DASEES and HIA formally link objectives to benefits analysis. (Ex. PS, SOK, SLR) **Adaptive** – Gradual inclusion of FEGS benefit assessment into an existing decision process occurs by working backwards from known beneficiaries to FEGS to decision options. The monitoring cycle is important here for development. (Ex. MB, TB, SJ)
14. Use Decision Support Systems (DSS) to organize and link FEGS analyses **DSS can help engage stakeholders in a step-by-step process by organizing information and models linking decisions to ecosystem services (EPFs), to benefits (EBFs), and to facilitate estimation of consequences.**	**Estimate consequences (2.5)** **Formal example case study (SOK; 1.3.4)** **Adaptive example case study (SJ; 1.3.3)**	**Formal** – SDM tools such as DASEES, HIA, or integrated modeling tools such as Envision, VELMA, InVEST, and EPA H2O, can be applied from the beginning to guide a decision and engage stakeholders. (Ex. SOK, SLR) **Adaptive** – Gradual inclusion of DSS might include expansion of objectives, addition of stakeholder engagement, and development of conceptual models describing an issue. (Ex. MB, SJ)
15. Compare alternatives with consequence tables and trade-offs in FEGS benefits **Consequence tables are a useful tool to display effects of decision alternatives and understand trade-offs among decisions, particularly FEGS trade-offs, which are more directly relevant to beneficiaries .**	**Estimate consequences (2.5)** **Formal example case study (SLR; 1.3.4)** **Adaptive example case study (MB; 1.3.5)**	**Formal** – SDM tools such as DASEES and HIA include use of consequence tables and FEGS trade-offs. (Ex. SOK, SLR) **Adaptive** – Consequence tables and FEGS trade-off assessments can be developed independently as an entry point for existing decisions. (Ex. MB, SJ)
16. Consider trade-offs in FEGS benefits relative to other kinds of objectives **Trade-off analysis is a valuable step for considering how FEGS benefits, like human health, compare to more immediate benefits like achieving water quality goals.**	**Evaluate trade-offs (2.6)** **Formal example case study (SLR; 1.3.4)** **Adaptive example case study (SJ; 1.3.3)**	**Formal** – SDM tools such as DASEES and HIA use stakeholder input to organize all benefits of a decision. (Ex. SOK, SLR) **Adaptive** – Benefit outcomes of a decision can be identified by experts or data and results organized using ad hoc tools. (Ex. MB, SJ)

Practical strategy	SDM step (Section link)	Entry points
17. Monitor impacts to FEGS benefits after a decision to inform future decisions **FEGS objectives should have their own PMs and these PMs should be included in long-term monitoring to improve future decisions.**	**Implement, monitor, and learn (2.6)** **Formal example case study (SLR; 1.3.4)** **Adaptive example case study (SJ; 1.3.3)**	**Formal** – SDM tools such as DASEES and HIA provide the basis for monitoring and assessment by following the SDM cycle. (Ex. SOK, SLR) **Adaptive** – Planned monitoring and assessment can be adapted to a FEGS approach by considering additional PMs. (Ex. MB, SJ, PS)

Appendix A – Additional resources for more detail on research in the coordinated case studies

Table A.1 - Examples of dissemination of case study results through published journal articles, internal or public-facing reports, and book chapters. More details are available through EPA Science Inventory (www.epa.gov/si).

Case Study Citation	Type of Product
Great Lakes Areas of Concern	
Alsip, P., J. Hartig, G. Krantzberg, K. Williams, and J. Wondolleck. Evolving institutional arrangements for use of an ecosystem approach in restoring Great Lakes Areas of Concern . Sustainability. MDPI AG, Basel, SWITZERLAND,	Journal Article
Angradi , T., J. Launspach, D. Bolgrien , B. Bellinger, M. Starry, J. Hoffman , A. Trebitz , M. Sierszen , and T. Hollenhorst. Mapping ecosystem service indicators in a Great Lakes estuarine Area of Concern . JOURNAL OF GREAT LAKES RESEARCH. International Association for Great Lakes Research, Ann Arbor, MI, USA, 42(3): 717-727, (2016).	Journal Article
Angradi, T. A predictive model for floating leaf vegetation in the St. Louis River Estuary. US EPA Office of Research and Development, Washington, DC, USA, 2015.	Model
Angradi, T., J. Launspach, and R. Debbout. Determining preferences for ecosystem benefits in Great Lakes Areas of Concern from photographs posted to social media . JOURNAL OF GREAT LAKES RESEARCH. International Association for Great Lakes Research, Ann Arbor, MI, USA, 44(2): 340-351, (2018). https://doi.org/10.1016/j.jglr.2017.12.007	Journal Article
Angradi, T., K. Williams, J. Hoffman, and D. Bolgrien. Goals, beneficiaries, and indicators of waterfront revitalization in Great Lakes Areas of Concern and coastal communities . JOURNAL OF GREAT LAKES RESEARCH. International Association for Great Lakes Research, Ann Arbor, MI, USA, 45(5): 851-863, (2019). https://doi.org/10.1016/j.jglr.2019.07.001	Journal Article
Angradi, T., P. Ringold, and K. Hall. Water clarity measures as indicators of recreational benefits provided by U.S. lakes: Swimming and aesthetics . ECOLOGICAL INDICATORS. Elsevier Science Ltd, New York, NY, USA, 93: 1005-1019, (2018). https://doi.org/10.1016/j.ecolind.2018.06.001	Journal Article
Angradi, T., W. Bartsch, A. Trebitz, V. Brady, and J. Launspach. A depth-adjusted ambient distribution approach for setting numeric removal targets for a Great Lakes Area of Concern beneficial use impairment: Degraded benthos . JOURNAL OF GREAT LAKES RESEARCH. International Association for Great Lakes Research, Ann Arbor, MI, USA, 43(1): 108-120, (2017).	Journal Article
Bolgrien, D., T. Angradi, J. Bousquin, T. Canfield, T. DeWitt, R. Fulford, M. Harwell, J. Hoffman, T. Hollenhorst, J. Johnston, J. Launspach, J. Lovette, B. Mckane, T. Newcomer-Johnson, M. Russell, L. Sharpe, A. Tashie, K. Williams, and S. Yee. Ecosystem goods and services case studies and models support community decision making using the EnviroAtlas and the Eco-Health Relationship Browser. U.S. Environmental Protection Agency, Washington, DC, USA, 2018.	Report
Bracey, A., M. Etterson, F. Strand, S. Matteson, G. Niemi, F. Cuthbert, and J. Hoffman. Foraging ecology differentiates life stages and mercury exposure in common terns	Journal Article

Case Study Citation	Type of Product
(Sterna hirundo) . Integrated Environmental Assessment and Management. Allen Press, Inc., Lawrence, KS, USA,	
Hoffman, J., and T. Angradi. Mud Lake alternatives ecosystem services analysis. U.S. EPA Office of Research and Development, Washington, DC, USA, 2019.	Technical Fact Sheet
Hoffman, J., V. Blazer, H. Walsh, C. Shaw, R. Braham, and P. Mazik. Influence of demographics, exposure, and habitat use in an urban, coastal river on tumor prevalence in a demersal fish . SCIENCE OF THE TOTAL ENVIRONMENT. Elsevier BV, AMSTERDAM, NETHERLANDS, 712: 12 pg., (2020). https://doi.org/10.1016/j.scitotenv.2020.136512	Journal Article
Holifield, R., and K. Williams. Recruiting, integrating, and sustaining stakeholder participation in environmental management: A case study from the Great Lakes Areas of Concern . JOURNAL OF ENVIRONMENTAL MANAGEMENT. Elsevier Science Ltd, New York, NY, USA, 230: 422-433, (2019). https://doi.org/10.1016/j.jenvman.2018.09.081	Journal Article
Holifield, R., and K. Williams. Watershed or bank-to-bank? Scales of governance and the geographic definition of Great Lakes Areas of Concern . Environment and Planning E: Nature and Space. SAGE Publications, THOUSAND OAKS, CA, USA,	Journal Article
Lepak, R., J. Hoffman, S. Janssen, D. Krabbenhoft, J. Ogorek, J. DeWild, M. Tate, C. Babiarz, R. Yin, E. Murphy, D. Engstrom, and J. Hurley. Mercury source changes and food web shifts alter contamination signatures of predatory fish from Lake Michigan . PNAS (PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES). National Academy of Sciences, WASHINGTON, DC, USA, 116(47): 23600-23608, (2019). https://doi.org/10.1073/pnas.1907484116	Journal Article
Preiner, K., and K. Williams. Expanding the narrative of tribal health: The effects of wild rice water quality rule changes. Fond du Lac Band of Lake Superior Chippewa, MN, USA, 2018.	Summary
Sierszen, M., L. Schoen, J. Kosiara, J. Hoffman, M. Cooper, and D. Uzarski. Relative contributions of nearshore and wetland habitats to coastal food webs in the Great Lakes . JOURNAL OF GREAT LAKES RESEARCH. International Association for Great Lakes Research, Ann Arbor, MI, USA, 45(1): 129-137, (2019). https://doi.org/10.1016/j.jglr.2018.11.006	Journal Article
Steinman, A., B. Cardinale, W. Munns Jr, M. Ogdahl, D. Allan, T. Angradi, S. Bartlett, K. Brauman, M. Byappanahalli, M. Doss, D. Dupont, A. Johns, D. Kashian, F. Lupi, P. McIntyre, T. Miller, M. Moore, R.L. Muenich, R. Poudel, J. Price, B. Provencher, A. Rea, J. Read, S. Renzetti, B. Sohngen, and E. Washburn. Ecosystem services in the Great Lakes . JOURNAL OF GREAT LAKES RESEARCH. International Association for Great Lakes Research, Ann Arbor, MI, USA, 43(3): 161-168, (2017).	Journal Article
Williams, K. IFBRP Open House and Stakeholder Group Comment Analysis. U.S. Environmental Protection Agency, Washington, DC, USA, 2017.	Summary
Williams, K., and J. Hoffman. Mud Lake future alternatives community values and health impact analysis. U.S. EPA Office of Research and Development, Washington, DC, USA, 2019.	Summary
Williams, K., and J. Hoffman. Remediation to restoration to revitalization: Ecosystem based management to support community engagement at clean-up sites in the Laurentian Great Lakes. Chapter 7, Ecosystem-Based Management, Ecosystem Services	Book Chapter

Case Study Citation	Type of Product
and Aquatic Biodiversity: Theory, Tools and Applications. Springer, Heidelberg, GERMANY, 543-559, (2020). https://doi.org/10.1007/978-3-030-45843-0_27	
Williams, K., D. Bolgrien, and J. Hoffman. How the community value of ecosystem goods and services empowers communities to impact the outcomes of remediation, restoration, and revitalization projects. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC, 2018.	Report
Williams, K., E. Washburn, D. Augsburger, J. Hembd, S. Mahmud, G. Epping Overholt, J. Schomberg, and H. Sorensen. People and Places Forum Workshop Report. U.S. Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington, DC,	Internal Report
Williams, K., J. Carlson, and D. Bolgrien. Analysis of Health Comments from the City of Duluth Comprehensive Plan Kick-off Event. U.S. Environmental Protection Agency, Washington, DC, USA, 2017.	Report
Williams, K., J. Carlson, and D. Bolgrien. Analysis of the comments about fairness from the City of Duluth Comprehensive Planning kick-off event. U.S. Environmental Protection Agency, Washington, DC, USA.	Internal Report
Williams, K., J. Hoffman, and N. French. From remediation to restoration and community revitalization: The St. Louis River story. Chapter 10, J.H. Hartig, G. Krantzberg, J.C. Austin, and P. McIntyre How restoring polluted waters leads to rebirth of Great Lakes Communities. International Association for Great Lakes Research, Ann Arbor, MI, USA, 61-66, (2019).	Book Chapter
Mobile Bay and Gulf of Mexico	
Jackson, C., P. Schmutz, M. Harwell, and C. Littles. The ecosystem service of property protection and exposure to environmental stressors in the Gulf of Mexico . Ocean & Coastal Management. Elsevier, Shannon, IRELAND,	Journal Article
Lewis, M. Near-Coastal Ecosystem Vulnerability: Plant-Dominated Fringe Habitats, Anthropogenic Non-Nutrient Chemicals and Risk Assessment Considerations . AQUATIC BOTANY. Elsevier Science Ltd, New York, NY, USA,	Journal Article
Lewis, M., J.T. Kirschenfeld, and T. Goodhart. Environmental Quality of the Pensacola Bay System: Retrospective Review for Future Resource Management and Rehabilitation. U.S. Environmental Protection Agency, Washington, DC, USA, 2016.	Report
Yee, S., E. Paulukonis, C. Simmons, M. Russell, R. Fulford, L. Harwell, and L. Smith. Forecasting effects of land-use change on human well-being through changes in ecosystem services . ECOLOGICAL MODELLING. Elsevier Science BV, Amsterdam, NETHERLANDS,	Journal Article
Fulford, R., and M. Jackson. EPA H20: Assessing ecosystem services in D'Olive Watershed.	Technical Fact Sheet
Fulford, R., K. Houghton, J. James, and M. Russell. Habitat specific differences in nitrogen cycling in a Gulf of Mexico Estuary . SCIENCE OF THE TOTAL ENVIRONMENT. Elsevier BV, AMSTERDAM, NETHERLANDS,	Journal Article
Fulford, R., M. Russell, J. Hagy, and D. Breitburg. Managing estuaries for ecosystem function . Global Ecology and Conservation. Elsevier B.V., Amsterdam, NETHERLANDS, 21(e00892): 13, (2020). https://doi.org/10.1016/j.gecco.2019.e00892	Journal Article

Case Study Citation	Type of Product
San Juan Bay Estuary and Puerto Rico	
Balogh, S., J. Bousquin, T. Muñoz-Erickson, E. Meléndez-Ackerman, A. Lugo, G. García López, C. Ortiz García, M. Pérez Lugo, and P. Méndez-Lázaro. Ecosystem services and urban metabolism in shrinking cities: A case study of San Juan, Puerto Rico.	Journal Article
DeJesus-Crespo, R., J. Wu, M. Myer, S. Yee, and R. Fulford. Flood protection ecosystem services in the coast of Puerto Rico: Associations between extreme weather, flood hazard mitigation and gastrointestinal illness . SCIENCE OF THE TOTAL ENVIRONMENT. Elsevier BV, AMSTERDAM, NETHERLANDS, 676: 343-355, (2019). https://doi.org/10.1016/j.scitotenv.2019.04.287	Journal Article
DeJesus-Crespo, R., Yee, S., P. Mendez-Lazaro. Linking Wetland Ecosystem Services to Vector-borne Disease: Dengue Fever in the San Juan Bay Estuary, Puerto Rico . WETLANDS. The Society of Wetland Scientists, McLean, VA, USA, 39(6): 1281-1293, (2019). https://doi.org/10.1007/s13157-017-0990-5	Journal Article
Giri, C. Mapping and Monitoring of Mangrove Forests of the World Using Remote Sensing. 1st. Chapter 13, Lisamarie Windham-Myers, Stephen Crooks, Tiffany G. Troxler (ed.), A Blue Carbon Primer: The State of Coastal Wetland Carbon Science, Practice and Policy. CRC Press - Taylor & Francis Group, LLC, Boca Raton, FL, USA, 163-177, (2018).	Book Chapter
Huang, Y., S.L. Pimm, and C. Giri. Using metapopulation theory for practical conservation of mangrove endemic birds . CONSERVATION BIOLOGY. Blackwell Publishing, Malden, MA, USA, 34(1): 266-275, (2020). https://doi.org/10.1111/cobi.13364	Journal Article
Martin, R., C. Wigand, A. Oczkowski, A. Hanson, S. Balogh, B. Branoff, E. Santos, and E. Huertas. Greenhouse Gas Fluxes of Mangrove Soils and Adjacent Coastal Waters in an Urban, Subtropical Estuary . WETLANDS. The Society of Wetland Scientists, McLean, VA, USA, 40: 1469–1480, (2020). https://doi.org/10.1007/s13157-020-01300-w	Journal Article
Oczkowski, A., A. Hanson, and D. Katz. Science and Social Justice at the Caño Martín Peña Estuary in San Juan, Puerto Rico. In: CERF's Up!, Coastal & Estuarine Research Federation, Port Republic, MD, USA, issue}: 4-5, (2020).	Newsletter Article
Oczkowski, A., E. Santos, A. Gray, K. Miller, E. Huertas, A. Hanson, R. Martin, E. Watson, and C. Wigand. Tracking the Dynamic Ecological History of a Tropical Urban Estuary as it Responds to Human Pressures . ECOSYSTEMS. Springer, New York, NY, USA, 23: 231-245, (2020). https://doi.org/10.1007/s10021-019-00399-1	Journal Article
Oczkowski, A., E. Santos, R. Martin, A. Gray, A. Hanson, E. Watson, E. Huertas, and C. Wigand. Unexpected Nitrogen Sources in a Tropical Urban Estuary . Journal of Geophysical Research - Biogeosciences. American Geophysical Union, Washington, DC, USA, 125(3): e2019JG005502, (2020). https://doi.org/10.1029/2019JG005502	Journal Article
Orlando, J., S. Yee, L. Harwell, and L. Smith. Technical Guidance for Constructing a Human Well-Being Index (HWBI): A Puerto Rico Example. U.S. Environmental Protection Agency, Washington, DC, USA, 2017.	Report
Yee, D., R. DeJesus-Crespo, F. Hunter, and F. Bai. Assessing natural infection with Zika virus in the southern house mosquito, *Culex quinquefasciatus*, during 2016 in Puerto	Journal Article

Case Study Citation	Type of Product
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Yee, S. Contributions of Ecosystem Services to Human Well-being in Puerto Rico . Sustainability. MDPI AG, Basel, SWITZERLAND,	Journal Article
Yee, S., D. Yee, R. DeJesus-Crespo, A. Oczkowski, F. Bai, and S. Friedman. Linking Water Quality to *Aedes aegypti* and Zika in Flood-Prone Neighborhoods . EcoHealth. Springer, New York, NY, USA, 16: 191-209, (2019). https://doi.org/10.1007/s10393-019-01406-6	Journal Article
Yee, S., E. Paulukonis, and K. Buck. Downscaling a Human Well-Being Index for Environmental Management and Environmental Justice Applications in Puerto Rico . ECOLOGICAL INDICATORS. Elsevier Science Ltd, New York, NY, USA,	Journal Article
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Halama, J., B. Barnhart, R. Kennedy, B. Mckane, J. Graham, P. Pettus, A. Brookes, K. Djang, and R. Waschmann. Improved soil temperature modeling by using spatially explicit solar energy driver data . WATER. MDPI AG, Basel, SWITZERLAND, 10(10): 1398, (2018). https://doi.org/10.3390/w10101398	Journal Article
Kaldy , J., and T. MochonCollura. Zostera japonica mapping surveys in Skagit Bay and Port Susan, Puget Sound Washington, U.S.A.: Summary Report. U.S. Environmental Protection Agency, Washington, DC, USA, 2015.	Dataset
McKane, B., A. Brookes, K.S. Djang, J. Halama, P. Pettus, B. Barnhart, M. Russell, K.B. Vache, and J.P. Bolte. An Integrated Multi-Model Decision Support Framework for Evaluating Ecosystem Based Management Options for Coupled Human-Natural Systems . Ecosystem-Based Management, Ecosystem Services and Aquatic Biodiversity: Theory, Tools and Applications. Springer, Heidelberg, GERMANY, 255-274, (2020). https://doi.org/10.1007/978-3-030-45843-0_13	Book Chapter
Brown, C.A., T. Mochon Collura, and T. DeWitt. Accretion rates and carbon sequestration in Oregon salt marshes. U.S. Environmental Protection Agency, Washington, DC, USA, 2020.	Dataset
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Lewis, N., D. Young, C. Folger, and T. DeWitt. Assessing the Relative Importance of Estuarine Nursery Habitats – a Dungeness Crab (Cancer magister) Case Study . Estuaries and Coasts. Estuarine Research Federation, Port Republic, MD, USA, (2020).	Journal Article
Lewis, N., E. Fox, and T. DeWitt. Estimating the distribution of harvested estuarine bivalves with natural-history-based habitat suitability models. . ESTUARINE, COASTAL AND SHELF SCIENCE. Elsevier Science Ltd, New York, NY, USA, 219: 453-472, (2019). https://doi.org/10.1016/j.ecss.2019.02.009	Journal Article
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Case Study Citation	Type of Product
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Syntheses of Relevance Across Multiple Case Studies	
Fulford, R., I. Krauss, S. Yee, and M. Russell. A keyword approach to finding common ground in community-based definitions of human well-being . Human Ecology. Springer, New York, NY, USA, 45(6): 809-821, (2017). https://doi.org/10.1007/s10745-017-9940-3	Journal Article
Fulford, R., M. Russell, J. Harvey, and M. Harwell. Sustainability at the community level: Searching for common ground as a part of a national strategy for decision support. U.S. Environmental Protection Agency, Washington, DC, USA, 2016.	Report
Fulford, R., R. Bruins, T. Canfield, J. Handy, J. Johnston, P. Ringold, M. Russell, N. Seeteram, K. Winters, and S. Yee. Lessons learned in applying ecosystem goods and services to community decision making. U.S. Environmental Protection Agency, Washington, DC, USA, 2016.	Report
Yee, S., A. Sullivan, K. Williams, and K. Winters. Who Benefits from National Estuaries? Applying the FEGS Classification System to Identify Ecosystem Services and their Beneficiaries . International Journal of Environmental Research and Public Health. Molecular Diversity Preservation International, Basel, SWITZERLAND, 16(13): 2351, (2019). https://doi.org/10.3390/ijerph16132351	Journal Article
Yee, S., J. Bousquin, R. Bruins, T. Canfield, T. DeWitt, R. DeJesus-Crespo, B. Dyson, R. Fulford, M. Harwell, J. Hoffman, C. Littles, J. Johnston, B. Mckane, L. Ruiz-Green, M. Russell, L. Sharpe, N. Seeteram, A. Tashie, and K. Williams. Practical Strategies for Integrating Final Ecosystem Goods and Services into Community Decision-Making. U.S. Environmental Protection Agency, Washington, DC, USA, 2017.	Report

Appendix B – Example recommendations for action

Table B.1 - Recommendations provided by stakeholders to mitigate negative health impacts or improve positive health benefits of the Kingsbury Bay- Grassy Point restoration project within the St. Louis River case study.

Recommendations were associated with one more health pathways (e.g., Water Habitat and Quality), which were the causal pathways between restoration actions or park improvements and health outcomes. Recommendations were assigned to either of the decision-makers for the restoration work and associated park improvements, Minnesota Department of Natural Resources (MNDNR) or the City of Duluth. As of April 4, 2019, the restoration project was under contract; recommendations included in the design or contract by MNDNR are indicated. As of that date, the City of Duluth had not yet undertaken a review of the park plans, and so no action was yet possible (N/A).

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Water Habitat & Quality	Follow best practices for stormwater management, erosion and runoff, and equipment leaks during the construction phases and implement mitigations, as necessary	MNDNR, City of Duluth	MNDNR – adopted in design, included in EAW City of Duluth – N/A
Water Habitat & Quality	Develop habitat plans for marsh birds, wading birds, and migratory waterfowl	MNDNR, City of Duluth	MNDNR – adopted in design, included in EAW City of Duluth – N/A
Water Habitat & Quality	Develop a long-term, non-native species management plan for both Grassy Point and Kingsbury Bay	MNDNR, City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Water Habitat & Quality	Where compatible with project goals, protect existing high-quality aquatic plants at Kingsbury Bay	MNDNR	MNDNR – adopted in design, included in EAW
Water Habitat & Quality	Develop a sediment remediation target protective of human health based on surface-weighted area contaminant concentration, particularly for dioxins	MNDNR	MNDNR – adopted in design, included in EAW
Water Habitat & Quality	For a future project, cap or remove sediments to the east of the Grassy Point project area (currently outside the project area) to reduce bioavailability of dioxins	MNDNR	N/A
Water Habitat & Quality	Design the stormwater pond identified in the concept plan to intercept stormwater to maximize its ability to protect Kingsbury Bay water quality	City of Duluth	N/A
Water Habitat & Quality	Conduct creel surveys focused on fishing within the AOC, and include information on race, ethnicity, location of residence, age, and fish consumption habits	MNDNR	N/A
Water Habitat & Quality	Implement a fish monitoring program that includes mercury, dioxins, and PCBs, and targets both resident and migratory fish species	MNDNR, MDH	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Water Habitat & Quality	Provide ethnically-appropriate communication on consumption-related risk that addresses specific-contaminant risk as well as fish species and size	MNDNR, MDH	N/A
Water Habitat & Quality	Should contaminant concentrations of certain fish species or sizes at the project sites meet human health guidelines, promote the consumption of local fish due to its health benefits	MNDNR, MDH	N/A
Water Habitat & Quality	Identify upland habitats within the site suitable for trees, and develop goals for the upland plant community that take into account future changes in invasive species, water level, and climate, as well as crime prevention and safety guidelines (e.g., Crime Prevention through Environmental Design guidelines)	MNDNR, City of Duluth	N/A
Water Habitat & Quality	Identify regional stormwater outfalls or other sources of *Escherichia coli* and implement additional best management practices to improve water quality at the future swimming beach at Kingsbury Bay	City of Duluth	N/A
Water Habitat & Quality	To sustain the ecological integrity of the site, provide interpretative signage that provides information on wetland habitat types and the	City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
	benefits each habitat provides for fish, reptiles, birds, and people		
Water Habitat & Quality	Implement routine beach monitoring at the future Kingsbury Bay swimming beach	MDH	N/A
Equipment Operation, Traffic, and Transport **Air Quality** **Noise and Light Pollution**	Clearly communicate the project, its duration, project updates (including issues and concerns), and expected roadway and water traffic impacts, air pollution levels, and noise levels to residents, schools and daycare centers, senior centers and care facilities, businesses, and recreational users in the project area and along the transport route	MNDNR, City of Duluth	N/A
Equipment Operation, Traffic, and Transport **Air Quality** **Noise and Light Pollution**	Provide a means for residents and other affected populations to provide feedback, questions and/or lodge complaints about general construction activities and excess traffic, air, and noise impacts	MNDNR, City of Duluth	N/A
Equipment Operation, Traffic, and Transport	Hire companies with a proven safety record; local companies given priority in hiring can benefit the local economy	MNDNR, City of Duluth	MNDNR – adopted in contract City of Duluth – N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Equipment Operation, Traffic, and Transport **Air Quality** **Noise and Light Pollution**	Route trucks, other equipment and vehicle traffic away from neighborhoods, schools and daycare centers, senior centers and care facilities, and recreation areas to the extent possible to minimize the risk of traffic impacts and exposure to noise and air pollution	MNDNR, City of Duluth, and associated contractors	N/A
Equipment Operation, Traffic, and Transport	Take additional safety measures and/or limit the amount of truck traffic at the start and end of the school day to create safe routes to and from school for children	MNDNR, City of Duluth, and associated contractor	N/A
Equipment Operation, Traffic, and Transport	Take into account traffic patterns, road geometry, and frequency and timing of trips to minimize traffic disturbance and congestion	MNDNR, City of Duluth, and associated contractors	N/A
Equipment Operation, Traffic, and Transport	Repair damage to roadways caused by construction vehicles and transport (e.g., potholes, broken curbs, collapsed manholes, rail crossing damage)	MNDNR, City of Duluth and associated contractors	MNDNR – adopted in contract City of Duluth – N/A
Equipment Operation, Traffic, and Transport **Air Quality**	Consider the use of rail or barge to transport sediment between the two sites, as these routes would avoid residential areas, minimize roadway traffic impacts, likely reduce the number of trips (given the larger capacity of rail cars and barges),	MNDNR and associated contractors	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
	and minimize traffic-related air pollutants in the residential areas		
Equipment Operation, Traffic, and Transport	Route material transport traffic away from neighborhoods, schools and daycare centers, senior centers and care facilities, and recreation areas to minimize the risk of exposure to particulate matter and contaminants in excavated material	MNDNR and associated contractors	N/A
Equipment Operation, Traffic, and Transport	Minimize impacts of the hydraulic pipeline and project-related barge traffic on recreational boaters and the navigation channel of the St. Louis River by using signs, markings, and warnings	MNDNR and associated contractors	MNDNR – included in EAW, adopted in contract
Equipment Operation, Traffic, and Transport **Air Quality**	Minimize exposure to material in transport by covering transport vehicles and implementing other fugitive dust measures, including watering access routes, and covering exposed soils/ stockpiles	MNDNR and associated contractors	MNDNR – included in EAW, adopted in contract
Equipment Operation, Traffic, and Transport **Crime and Safety**	Implement traffic calming measures (such as speed humps, raised crosswalks/ intersections, traffic circles, medians, curb extensions or bump-outs, and signage or pavement markings) and bikeway improvements (such as clear painted bike lane markings and signage to already designated bike routes) to improve safe access to the parks and	City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
	minimize the risk for increased accidents should the parks and other nearby enhancements increase the amount of traffic in the area post-construction		
Air Quality	Include mitigation specifications in the contract (reduced idling and requirements for equipment fitted with catalysts and filters) and incentives for contractors with idle reduction policies, and newer or retrofitted equipment	MNDNR, City of Duluth	MNDNR – adopted in contract City of Duluth – N/A
Air Quality	Select native trees and plants for planting that will do well in warming climate Note: Trees have the greatest potential to filter air pollutants, followed by shrubs, and then grasses	City of Duluth and associated contractors	N/A
Air Quality	Select trees that have tall, broad canopies for increased shading and place in areas where people may congregate	City of Duluth and associated contractors	N/A
Noise and Light Pollution	Include noise mitigation criteria/ specifications in the contract (e.g., absolute noise criterion for equipment, restricted idling, and use of mufflers, dampeners, shieldings, and enclosures)	MNDNR, City of Duluth	MNDNR – included in EAW, adopted in contract City of Duluth – N/A
Noise and Light Pollution	Include incentives or priority in hiring for contractors who have established noise mitigation programs/policies and/or newer fleets	MNDNR, City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Noise and Light Pollution	Limit construction activities to daylight hours or the hours specified in the Duluth noise ordinance (7 am – 9 pm), whichever is more restrictive (i.e., sunset December-March is between 4:30 and 7:30 pm). Limit noisy operations to non-sensitive time periods (e.g., mid-day)	MNDNR, City of Duluth, and associated contractors	MNDNR – contractor must adhere to city code City of Duluth – N/A
Noise and Light Pollution	Avoid nighttime construction activity to the extent possible. During winter, sunset is between 4:30 and 7:30 pm (much earlier than 9:00 pm). When necessary, implement measures to minimize light illumination impacts on nearby residences	MNDNR, City of Duluth, and associated contractors	MNDNR – contractor must adhere to city code City of Duluth – N/A
Noise and Light Pollution	Implement noise monitoring in the vicinity of both sites to assess <u>overall</u> noise levels (i.e., baseline noise plus project noise) and implement mitigation measures, as necessary, to minimize impacts	MNDNR, City of Duluth, and associated contractors	MNDNR – contractor must adhere to city code City of Duluth – N/A
Noise and Light Pollution	Position stationary noise sources as far away as possible from noise sensitive areas (areas where a quiet setting is a generally recognized feature or attribute, such as residential areas, parks, recreational and wilderness areas, and cultural and historical sites)	MNDNR, City of Duluth, and associated contractors	MNDNR – contractor must adhere to city code City of Duluth – N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Noise and Light Pollution	Implement hearing protection and operations schedules to avoid exposure of construction workers to noise above NIOSH recommended exposure limits (73% of the time construction workers are exposed over the recommended exposure limits)	MNDNR, City of Duluth, and associated contractors	MNDNR – adopted in contract City of Duluth – N/A
Noise and Light Pollution	Prohibit the use of truck engine brakes, unless in case of emergency	MNDNR, City of Duluth, and associated contractors	N/A
Noise and Light Pollution	Ensure any lighting used in the parks are intelligently-designed, low glare, efficient outdoor lighting fixtures that direct illumination toward the ground (rather than upward) and evaluate the potential for motion sensors on lighting in certain areas of the parks or parking lots to minimize over-illumination	City of Duluth	N/A
Crime and Safety	Construction activities that alter existing routes and access points should have clear signs and barriers to minimize the potential for trespassers	MNDNR, City of Duluth	MNDNR – adopted in contract City of Duluth – N/A
Crime and Safety	Clearly communicate the improvements being made to Grassy Point to alleviate existing	City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
	perceptions of crime and personal safety issues and encourage utilization of the space post-restoration		
Crime and Safety	Follow Crime Prevention through Environmental Design (CPTED) guidelines, including lighting and planting configurations. Where possible, reduce dense planting and shrubs around narrow pedestrian paths	City of Duluth	N/A
Crime and Safety	Lighting should be improved and police surveillance considered to reduce crime and the perception of risk at these sites	City of Duluth	N/A
Crime and Safety	Provide clear signage and maps for pedestrian and bicyclist access to the parks. Important elements of access and design include effective wayfinding systems such as the use of landmarks, signage, distance to destination markers, and interest points to assist in navigating the routes easily	City of Duluth	N/A
Crime and Safety	After improvements of parks begin, increase enforcement or police presence to "set the tone." Communicate to police department that their presence is important in the beginning to deter bad behavior and reduce crime. This is especially true at Grassy Point where it is more secluded and	City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
	thereby, necessitates more formal surveillance. Delegation of those resources should be determined by the number of visitors and the expected frequency of crimes		
Crime and Safety	Consider using the National Highway Transportation Safety Administration's (NHTSA's) Walkability and Bikeability Checklists to inform design of trails within the parks and leading to the parks	City of Duluth	N/A
Crime and Safety	Improve pedestrian and bicycle access to Grassy Point from the Irving neighborhood; current access is by footpath or walking/biking along Waseca Industrial Road	City of Duluth	N/A
Recreation, Aesthetics, and Engagement with Nature	Recommend that the City solicit deliberative community and stakeholder engagement and examine the pathways through which the park efforts could impact health to help inform the park improvements design and implementation	City of Duluth	N/A
Recreation, Aesthetics, and Engagement with Nature	Offer diverse opportunities for recreation at both sites, including publicly-accessible gathering spaces, fishing piers, birding platforms, access to the water for water-based recreation, and trails, considering maintenance requirements of installed features	MNDNR, City of Duluth	MNDNR – adopted in design, included in EAW City of Duluth – N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Recreation, Aesthetics, and Engagement with Nature	Preserve and enhance fishing opportunities, with more formal locations (e.g., piers) and social gathering opportunities adjacent to those locations. The creation of Big Island at Grassy Point would provide an opportunity for a fishing pier and access to a fishery with more biodiversity; a bridge would be needed to access Big Island	MNDNR, City of Duluth	MNDNR – adopted in design, included in EAW City of Duluth – N/A
Recreation, Aesthetics, and Engagement with Nature	Create a higher upland area on Big Island to form a more sheltered bay, providing safer harbor for kayaks and canoes	MNDNR	MNDNR – adopted in design, included in EAW City of Duluth – N/A
Recreation, Aesthetics, and Engagement with Nature **Crime and Safety**	Areas that support both human-powered and motorized boats should include measures to enhance safety and minimize potential for user conflict	MNDNR, City of Duluth	N/A
Recreation, Aesthetics, and Engagement with Nature	All swimming areas should include measures to enhance safety and minimize potential for user conflict. Measures should include signage about the availability of lifeguards and current water quality status. Buoys should separate swimming and boating areas	City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Recreation, Aesthetics, and Engagement with Nature **Social and Cultural**	In advance of construction and in all project phases, clearly communicate to recreational and water users, through multiple media sources, reliable and timely information about the construction periods, disruptions to the Western Waterfront Trail and walkability and accessibility to both project sites, and the planned changes at both sites so that users can anticipate the improved resources and plan to visit	MNDNR, City of Duluth, and nonprofit organizations	MNDNR – adopted in contract City of Duluth – N/A
Recreation, Aesthetics, and Engagement with Nature	Provide additional parking to increase access to and utilization of the restored Kingsbury Bay and Grassy Point sites, using caution to minimize any potential environmental impacts of the added parking	City of Duluth	N/A
Recreation, Aesthetics, and Engagement with Nature	Perform wetland restoration at the mouth of Kingsbury Creek to preserve the cold-water habitat for trout and provide deeper water for kayak and canoe access	MNDNR	MNDNR – adopted in design, included in EAW
Recreation, Aesthetics, and Engagement with Nature **Social and Cultural**	The planners should strive to create natural spaces for social interaction and opportunities for social gatherings near the additional planned fishing piers, especially at Grassy Point, similar to the improvements at Chambers Grove Park	MNDNR, City of Duluth, other partners	MNDNR – adopted in design City of Duluth – N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Recreation, Aesthetics, and Engagement with Nature	Because recreational amenities are enjoyed by residents, any plans for future changes should include recognition of the value placed by residents who use the resources frequently	City of Duluth	N/A
Recreation, Aesthetics, and Engagement with Nature	Preserve and upgrade current birding locations, as well as enhance access to newly created birding habitat. Signage, raised platforms, and telescopes are all potential amenities. Upland plant communities should be restored to maximize potential for pollinator, including bird, habitat	MNDNR and City of Duluth	N/A
Recreation, Aesthetics, and Engagement with Nature	Recognizing the value placed on the existing resources, any changes to park amenities could add new features to existing parks and green space	City of Duluth	N/A
Recreation, Aesthetics, and Engagement with Nature	Create a water trail to serve as a by-way for kayaks, which can be nominated as a nationally designated water trail, and may provide opportunities for recognition and funding	City of Duluth and nonprofit organization partners	N/A
Recreation, Aesthetics, and Engagement with Nature	Research and develop co-management models, where neighborhood organizations have more formal responsibility for park management. Co-management arrangements could empower the neighborhood and ease the maintenance burden on the city of Duluth	City of Duluth, EPA, other academic and nonprofit organization partners	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Recreation, Aesthetics, and Engagement with Nature **Social and Cultural**	The City should provide a means for assessing park usage and the ends to which the sites are being used (e.g., for social cohesion, spiritual reflection, and access to cultural resources). This could include reaching out to the University of Minnesota-Duluth Environmental and Outdoor Education program or other local organizations to create a service learning or citizen science project that monitors, through a 5-year monitoring and evaluation timeline, the use of the parks for these means or providing signage at the sites that includes a description of how to report usage of the park, including a QR code that sends them directly to a feedback form	City of Duluth, UMD, and nonprofit organization partners	N/A
Recreation, Aesthetics, and Engagement with Nature	Explore partnerships with organizations to facilitate access, education, and equipment sharing, additional recreational opportunities and leadership capacity building for underrepresented communities	City of Duluth, EPA, other academic and nonprofit organization partners	N/A
Social and Cultural	The planning team should conduct stakeholder meetings to the extent possible to gather information needed to understand the social and cultural significance of these parks to the various populations in the community, including but not	MNDNR and City of Duluth	N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
	limited to a cultural heritage assessment of the sites		
Social and Cultural	The planners should strive to create natural spaces for solitary spiritual reflection. Attention should be paid to develop spaces for spiritual reflection that minimize the noise and distraction from the nearby industry and take into account the vistas from the space	MNDNR and City of Duluth	MNDNR – adopted in design City of Duluth – N/A
Social and Cultural	Signage may be considered that demarcate culturally-significant spaces and promote quiet reflection. The Duluth Indigenous Commission, Fond du Lac Band, and 1854 Treaty Authority should be consulted when developing signage to denote spaces that are significant for Native American populations	City of Duluth	N/A
Social and Cultural	The planning team should prioritize the placement of native, medicinal, and culturally-significant plants	MNDNR and City of Duluth	MNDNR – adopted in design City of Duluth – N/A

Pathway(s)	Recommendation	Party(ies) Responsible for Implementation	Recommendation, Adoption, Implementation (as of April 4, 2019)
Social and Cultural	Attention should be paid to promote the presence of wildlife that may be culturally significant and specifically the abundance of fish for subsistence fishing	MNDNR and City of Duluth	MNDNR – adopted in design, included in EAW City of Duluth – N/A
Social and Cultural	Consult with 1854 Treaty Authority, Duluth Indigenous Commission, and Fond du Lac Band resource managers to identify significant sites for any use and determine the best approach to preserve, enhance or interpret resources	MNDNR and City of Duluth	MNDNR – adopted in design City of Duluth – N/A
Social and Cultural	Outreach should be conducted to engage and encourage park use by the African American youth in Duluth, perhaps through the YMCA, the Valley Youth Center, and the Duluth Outdoor Collaborative	City of Duluth and nonprofit organization partners	N/A
Social and Cultural	To encourage park use by minority groups, the City of Duluth Parks Department could hire leaders from these underrepresented populations to work in public engagement, outreach, and park operations	City of Duluth	N/A
Social and Cultural	Bag stations for dog poop pick-up should be installed at each park	City of Duluth	N/A

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