A Pragmatic Cycle for Ongoing Water Resources Research and Management

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ABSTRACT

Organizations focused on managing water resources are recognizing the need to have tools for literature review, data integration, modeling, and decision support. Decision support systems (DSS) can help to meet these needs because they are aimed at integrating data and knowledge, evaluating management options in terms of organizational objectives and risk, and facilitating multiple-stakeholder decision making where competing objectives and risk preferences must be reconciled. Using the internet, organizations can share the costs and benefits of existing and newly developed information, theories, and technologies among a broad, diverse user group.

This paper discusses an approach, based on experience, to developing DSSs through a larger, iterative cycle of ongoing, collaborative environmental research and development. Multiple stakeholders with multiple conflicting objectives need insightful, often novel, models of environmental systems. The answers developed to new research questions contribute to requirements and specifications for new tools and technology, and the technology is then built to facilitate the collaborative management process. Information added at any point can influence the collaborative management–research–technology cycle in both directions.

Stakeholder workshops to specify the DSS requirements, formulate its design, and review its use are critical. The DSS must be built progressively, first focusing on pilot areas and tractable research problems and eventually moving to a national scope. To motivate continued development, rapid prototyping is an ideal tool for achieving early success. The DSS—and the entire cycle—must also be self-maintaining. Two case studies illustrate these concepts.

INTRODUCTION

Organizations focused on managing water resources are recognizing the need to have tools for literature review, data integration, modeling, and decision support. Decision support systems (DSS) can help to meet these needs because they are aimed at integrating data and knowledge, evaluating management options in terms of

organizational objectives and risk, and facilitating multiple-stakeholder decision making where competing objectives and risk preferences must be reconciled.

Using the internet, geographically separated organizations with similar objectives can benefit from sharing experiences, data, and models. The development of enterprise- and nationwide DSSs enables organizations to share the costs and benefits of existing and newly developed information, theories, and technologies among a broad, diverse user group.

While DSSs are desirable, it is not very clear how to go about building them. This paper discusses an approach to developing DSSs by focusing on a larger cycle of ongoing environmental research that starts with the need to manage natural environments collaboratively. Environments, such as estuaries, are the focus of multiple stakeholders, each with multiple objectives that are often opposed; thus there is a need for insightful, and often novel, models of these systems. As more insight is sought, new research questions are continually raised. The answers developed to new research questions contribute to requirements and specifications for new tools and technology, which is then built to facilitate the collaborative management process. New information added at any point can influence the collaborative management–research–technology cycle in both directions, as illustrated in Figure 1.

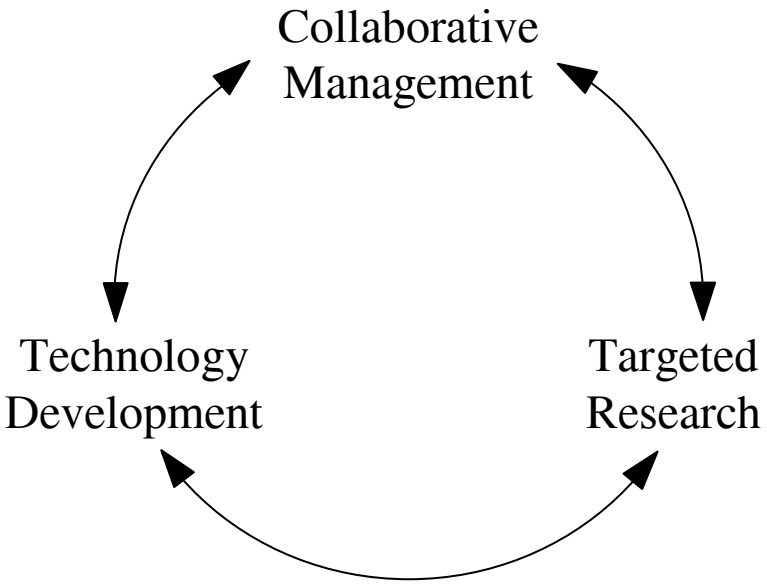

Figure 1. Collaborative management–research–technology cycle.

Establishing the cycle requires a pragmatic approach. First, the community must build the DSS to ensure community adoption. Stakeholder workshops to specify the DSS requirements, formulate its design, and review its use are critical. Second, the DSS must be built progressively—first focusing on pilot areas and tractable research problems and eventually moving to a national scope. Third, the DSS must be built with early success in mind to motivate continued development. Rapid prototyping is an ideal tool for achieving such success. Finally, the DSS—and

the entire cycle—must be self-maintaining. These concepts are illustrated in two case studies, the Northslope DSS, a tool in development for collaborative management of the North Slope in Alaska under proposed oil exploration, and a proposed DSS for management and research of the National Estuarine Research Reserve (NERR) System, under the National Coastal and Estuarine Research Technology (NCERT) Program. The proposed NCERT DSS provides a large-scale, practical example of how the collaborative management-research-technology cycle would be applied to a real-world problem.

NATIONAL COASTAL ESTUARINE RESEARCH AND TECHNOLOGY PROGRAM DSS

In establishing the NCERT Program in partnership with the NERR System, NOAA is seeking to stimulate research and scientific collaboration between the NERRs and their state agency, local governmental, and university partners to develop and implement new and innovative tools, in order to help coastal managers detect, prevent, and reverse the impacts of coastal pollution and habitat degradation. The primary focus of the effort is to address land use, habitat, contamination, and stormwater issues related to coastal development.

The challenge of establishing the NCERT Program, in partnership with the NERR System, to fund collaborative research to assist coastal managers in detecting, preventing, and reversing coastal pollution and habitat degradation, is extraordinarily complex but necessary. The program, therefore, must serve as a catalyst for a diverse array of activities that range from collecting, analyzing, interpreting, and using data to identify significant empirical and mechanistic relationships and develop new and innovative tools for resource protection and management. Developing appropriate management approaches and actions that affect public policy and influence human behavior is possible through stakeholder interactions linked to database analyses.

The skills required to do this work cut across many disciplines and areas of specialization, including biologists (marine, estuarine, riverine, coastal wetland, and upland biologists); geologists; hydrologists; hydrogeologists; geophysicists; statisticians; geographers; climatologists; modelers; coastal engineers; drinking water, stormwater, and wastewater engineers and regulators; highway and land use planners and engineers; and local and regional planning commissions. The coastal watersheds are just as diverse, ranging from very small watersheds (first-order streams) encompassing less than 50 acres (small neighborhoods), to enormous watersheds (tenth-order streams) that encompass more than a million square miles and cover more than half of the country (Mississippi River).

It is hard, then, to identify, let alone choose, a research program or suite of assessment tools that will meet the needs of a single estuarine system, let alone serve the needs of a network of estuaries such as the NERR System. This will not simply happen by creating a program, bringing people together, or sponsoring collaborative research. The approach must connect the *stakeholders* to the *science* and the

technology that they need and thus enable individual stakeholders to help themselves and each other. Each NERR watershed has both unique and generic problems and solutions. The proposed NCERT Program DSS will share knowledge, experience, and expertise and build a base of knowledge and a set of tools that will serve NERR sites individually and collectively.

Each part of the program is highly dependent on the other parts, *i.e.*, each part affects and is affected by the other parts in a highly interactive and adaptive management process, as illustrated in Figure 2. This approach will achieve the desired NCERT Program objectives by actively involving stakeholders in the development of an information system to facilitate and target future research through a collaborative decision-making and management process among NERR stakeholders.

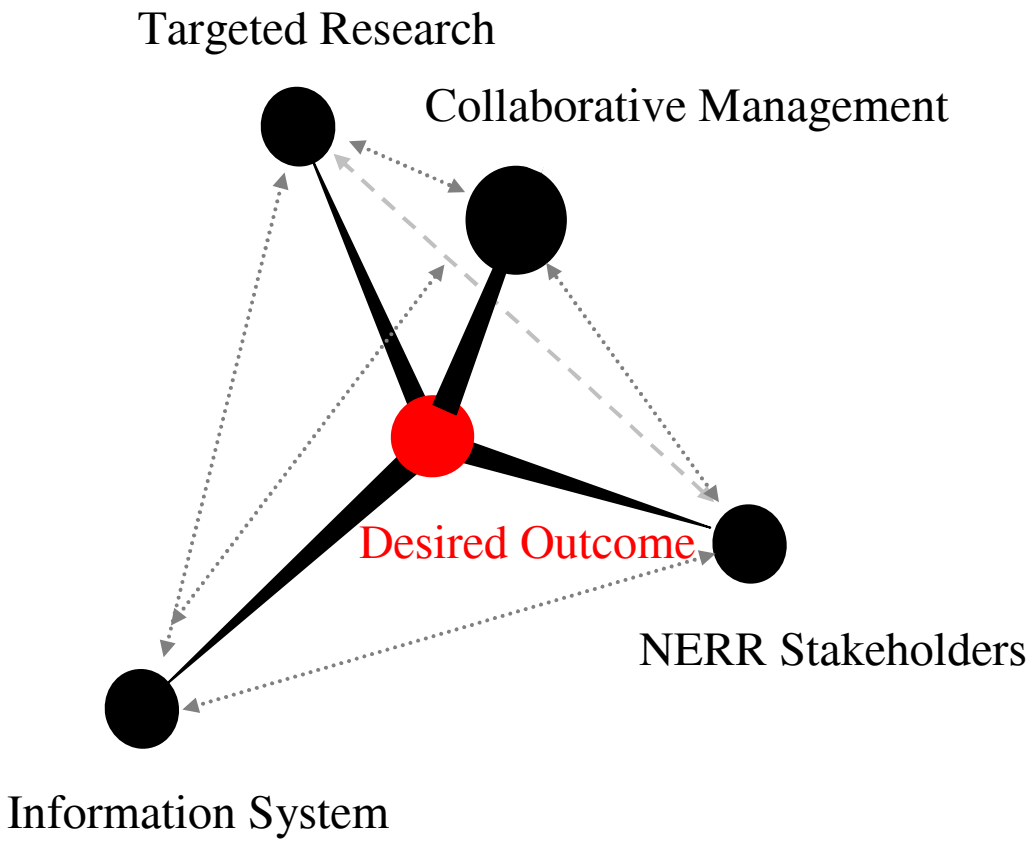

Figure 2. A model for achieving the NCERT Program objectives.

Collaborative Decision-Making Process

Conflict is a natural part of human relationships and reaching consensus is not always possible; however, when properly managed, conflict can be a positive force that leads to new ideas and new ways of doing things. It can also be a catalyst for strengthening stakeholders' relationships and developing better, longer-lasting outcomes.

The project team will coordinate and direct a collaborative process with the NERRs and their state agency, local governmental, and university partners to (a) gain

consensus on critical data needs and research tools for enhancing estuarine assessment and (b) identify appropriate management approaches and actions for restoring and protecting estuarine health. This collaborative process will be implemented using a tiered approach that will facilitate information sharing between the project team and the individual NERRs and their associated stakeholders on a local, regional, and national level.

The results of these interactions will be used to develop an information system, through existing technologies and databases, to link researchers and stakeholders participating in the NCERT Program through a central, online, federated database system via web-based and desktop applications, including NCERT.org. The proposed collaborative process and information system will support estuarine data collection and analysis, and strengthen land and water resource decision making. The end product of this effort will be a data-driven research and technology program that will allow management to incorporate trade-offs that support NERRs into the decision-making process.

A working prototype of this information system, the Analytical Framework for Coastal and Estuarine Study (ACES), has been developed and fully documented by the St. Johns River Water Management District (SJRWMD) and PBS&J. It uses a geographic information system (GIS)–based database of spatial and temporal data to describe the environment and a suite of modeling tools, based on first principles, to evaluate different management scenarios. With ACES, estuarine bulk parameters related to shape, residence time, and flushing potential can be derived, and the influence of tide and terrestrial drainage on estuarine water quality can be assessed using regression and other approaches. ACES was created through a collaborative and rapid-prototype development process involving national estuarine experts that was similar to the process proposed for the NCERT Program DSS.

Annual national NCERT Summits will be held to promote collaboration between NERR stakeholders. These meetings, used as part of a tiered approach—including local "listen-and-learn" meetings with individual NERRs and their governmental and university partners, as well as regional workshops—will engage stakeholders at all levels in the process of developing the information system and building consensus on data needs, assessment tools, and research priorities. Research priorities identified through this process will be funded through targeted grants to participating NERRs, universities, and state and local governments.

Technology Development

As the collaborative management process is implemented, stakeholders will need information to define problems, clarify objectives, and assess the effectiveness of management activities and strategies. The specific information that stakeholders require for planning and management decisions should drive which information is collected. The major challenge to stakeholders will not be collecting information—for there will be an overwhelming amount even if they gather only the specific information needed—but processing data to obtain exactly the required information.

Furthermore, the quality of the information collected is most important, rather than the quantity. Obviously, good information results in better management decisions.

Effective and sustainable management requires an estuary-by-estuary study approach. On the other hand, the NCERT goals of collaboration and efficiency through data-, model-, technology-, and idea-sharing necessitate a communal approach in which a single technological framework is used by all.

These two requirements—estuary-specific study and a single technological framework—are not mutually exclusive. The national, community-based solution proposed will enrich the understanding gained through estuary-specific studies by identifying and focusing on similarities in the research and decision-making processes. That is, while two estuaries may be largely different in their geomorphology, water chemistry, hydrodynamics, etc., the processes undertaken to identify how to model the estuary, collect the data, develop the management alternatives, and ensure stakeholder approval are largely similar. Building a nationally applicable information solution that facilitates these processes is therefore not only possible, but will bring a whole new level of data access, research finding access, and collaboration to the fore.

The project team will develop a comprehensive information system. Existing databases containing data, models, research findings, and management policy documents for all 27 NERRs will be linked to form a national cyberinfrastructure network. This network will form the foundation for storing and communicating the results of the on-going research program. Access to the network will be provided via two methods. First, a GIS-based website called NCERT.org will be created that provides a broadly accessible view of all data, models, and scientific findings. Second, a GIS-based software workbench for analyzing estuaries will be built. This workbench will form the means of conducting new research, and will be stocked with a growing set of models created as the research process continues. As new results and models are created, the user will be able to publish them directly to the national network for review by the NERR community. The research will be driven by the process of building decision support systems for estuarine management, which in turn will drive the development of natural systems models to assess the effect of management plans. The modular design of the software workbench allows researchers to submit their newly developed natural systems and decision support models to the national network so that the entire community can use them.

The NCERT DSS is an ambitious information solution that will serve the needs of a growing and diverse estuarine science community. Certainly, to build the solution from the ground up would be a large effort and would exceed the time and funding available. Fortunately, several national emerging role models and technologies can be leveraged to quickly arrive at an operational NCERT DSS Framework. The proposed framework is based on the following building blocks, as illustrated in Figure 3 on the next page:

- *A national cyber-infrastructure that enables real-time, communitywide communication.*
- *A national standard for storing estuarine information, including GIS-based data, observations data, models, and research findings.*
- *A means of including existing databases, models, and research findings in the national cyber-infrastructure and ensuring they can optionally remain in their current format, or be converted to the national standard, or some hybrid of the two.*
- *A workbench tool that works with data from the national cyber-infrastructure and enables a range of estuary analysis—from first principles to complex, systemwide modeling.*
- *A modular tool framework that allows for the development and incorporation of new tools for estuarine analysis into the national toolset—an openly available suite of tools for all NERRs to use.*
- *A broadly accessible, web and virtual globe–based tool that focuses on serving the estuarine community with user-friendly, ergonomically driven methods for learning about, analyzing, and documenting findings about estuaries.*

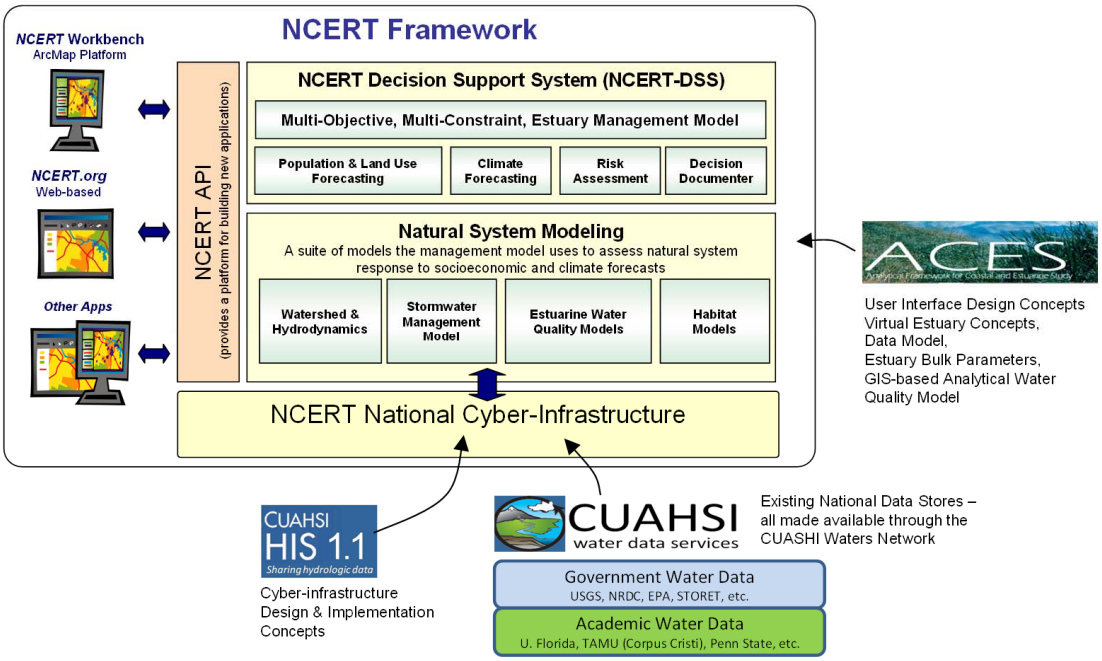

Figure 3. Proposed NCERT DSS framework.

These building blocks are each being developed in some form for efforts similar to NCERT. For example, the water resources and hydrology world is currently experiencing a leap forward in technological innovation with the continued development of the Hydrologic Information System (HIS) concept, a cyber-infrastructure based approach to making available the nation's water data (Maidment 2008). Another example is map-based web technologies, which have exploded in

recent years with the introduction of virtual globe browsers such as Google Earth. These technologies have focused heavily on making the experience the user has with a tool an intuitive one that ensures the user reaches the desired information quickly, without being required to adopt new technology concept models along the way.

Having identified the building blocks for the NCERT information solution and the emerging technologies that will be used to quickly build the solution, it is important to consider the way in which the solution will be built. A strong pragmatism is required in the process of solution development to ensure that adequate proof-of-concept is established early in the process and that sufficient developmental momentum is maintained. Sequencing of tasks and goals is paramount.

The technology developmental approach centers on the following:

- *Starting small and expanding to quickly identify challenges and ensure early success,*
- *Driving the development of technology with a realistic problem, and*
- *Establishing ownership of the solution and the design process throughout development.*

Targeted Research on Impacts of Climate Change and Population Growth

Given their wide geographic distribution across the U.S., the size, geomorphology, hydrology, and ecology of the 27 NERRs vary significantly. In addition, the degree of anthropogenic alteration and watershed development (e.g., dredge and fill, point sources, stormwater runoff) also varies widely among the NERRs. Despite this inherent variability, there are two common stressors that threaten the integrity of all the NERRs: climate change (and associated sea-level rise) and population growth (and associated impacts such as increased pollutant loading).

While each of the NERRs may have unique local and site-specific research priorities, we propose that, as part of the development of the NCERT Program, targeted research be implemented with the common focus of assessing the existing and potential future impacts of these stressors on the estuarine system integrity of each of the NERRs. Assessing and mitigating their effects are clear national priorities, and the implementation of a common thematic research platform will complement the collaborative process proposed for developing a comprehensive information system linking researchers and stakeholders participating in the NCERT Program. The targeted research results will be significantly leveraged, both through collaborative efforts and the dissemination of scientific findings nationally.

Existing data, and data collection needs, will vary widely among the NERRs. Therefore, the first step in the targeted research will be to conduct a complete inventory of available data. Data gaps will then be identified, thus establishing the first tier of research priorities. Furthermore, appropriate spatial and temporal analytical scales will need to be determined for each of the NERRs in accordance with the availability of existing data as well as locally specific management issues.

NORTH SLOPE DSS

The collaborative decision-making and management process for building a DSS described in the NCERT proposal is being implemented in the Northslope DSS, a tool for collaborative management of the North Slope in Alaska under proposed oil exploration. The Northslope DSS will support the construction of ice roads and ice pads to provide a cost-effective means of oil and gas exploration on Alaska's North Slope with minimal impact to the sensitive underlying tundra. Such ice structures have become integral to oil and gas exploration. Their widespread use represents a challenge to water resource managers, however, due to the large volume of water necessary to construct and maintain them. As the proximity of available fresh water sources has a significant impact on the planned location of ice roads and ice pads, changes in water resource management strategies could significantly impact oil and gas exploration activities.

Due to the fundamental role of water in natural and human systems, successful management of this resource is indeed essential to the broader issue of environmental protection and responsible energy development on the North Slope. The challenges of developing best management practices for water resources include the following: resource planning and management for efficient and sustainable water use; understanding and explicitly considering environmental impacts and protection; and developing and implementing effective participatory management strategies with representative stakeholder participation from all sectors.

This project is developing a water resources management solution in support of oil and gas exploration that explicitly considers optimal water use, direct and cumulative environmental impacts, and multiple objectives and values among stakeholders. The solution consists of an information system, software tools for decisions support, and methodologies for facilitating stakeholder involvement in the decision making process. The tools developed in this work will not only apply to the water management issues considered here, but will also be applicable to broader environmental management issues and industry development applications.

CONCLUSION

The challenge in building a DSS is to apply the needed resources for determining the appropriate types of research, without forcing a "one size fits all" product onto the System as a whole. **For this reason, an adaptive management process for identifying data and information needs and a mechanism for targeting and funding the necessary research are major elements of the DSS Program solution.**

Water resources management crosses many boundaries, including political, institutional, and natural. The complexity involved in the management of resources that includes inputs from all participants can be overwhelming. **Thus the proposed DSS solution provides for an inclusive, collaborative management process to**

assist in the understanding of these complexities and to arrive at better, scientifically sound management decisions.

Information management issues lie at the heart of many difficulties in making land and water resource decisions. Resolving certain information management problems—including too much information, a lack of information, data of uncertain quality, and difficulty connecting information from different sources and disciplines—can be addressed with existing technology. Other information management issues, however, must also be addressed, including a lack of standardized technology, resolving multiple data formats, easily accessing available information, and accessing data used to produce published literature and scientific reports.

The challenges of sharing data, models, and research findings must be overcome for stakeholders to fully benefit from their collaborative research efforts. In resolving these challenges, new tools must also be developed to enhance the interpretation of data and information and promote further collaboration between researchers. **For this reason, the development of a comprehensive solution for managing, sharing, and using information is a major element of a DSS solution.**

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