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SPATIAL DECISION SUPPORT TOOLS FOR ADAPTIVE MANAGEMENT OF WATER RESOURCES

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ABSTRACT: Adaptive management of natural resources involves applying a structured, iterative process of decision-making under high levels of uncertainty. It allows incremental actions to be taken while continually collecting more information to reduce uncertainty and refine management. The practice of adaptive management often requires the generation, integration, and visualization of multiple sources of spatial data to be effective. The concepts behind spatial decision support systems, which blend geospatial technologies with traditional computer-based decision support tools, combine the latest in web mapping interfaces with technologies needed for scientists collaborating with coastal resource managers to better understand changing water quality trends. This paper examines how the Fox-Wolf Hydrologic Dashboard serves as an example of a dynamic geospatial tool to support adaptive management at the watershed scale and explores the Wisconsin Coastal Atlas as a platform for spatial decision support tools that promote adaptive management of Great Lakes coastal resources.
KEY TERMS: adaptive management, spatial decision support tools, hydrologic dashboard, coastal web atlas, Great Lakes, Wisconsin

INTRODUCTION

Adaptive management was introduced to the natural resource field by C.S. Holling and his colleagues at the University of British Columbia in the late 1960s and described in his seminal book "Adaptive Environmental Assessment and Management" in 1978. Holling, along with Carl Walters (1986) and Kai Lee (1982) set the foundation of the idea throughout the 1970s and 1980s, developing a framework for the concept to be used in natural resource management applications.

Over the past couple of decades, adaptive management has taken off and been applied to forestry, fishery, water, wildlife, and many other natural resource management situations and in the process new structures have emerged. Some of the main adaptive management frameworks are the idea of passive versus active adaptive management established in the late 1980s and early 1990s (Walters et al. 1990); Resilience-Experimentalist Adaptive Management developed by Gunderson et al. (1995); and Decision-Theoretic Adaptive Management developed by Possingham et al. (2001) and Williams et al. (2007). Although there have been other decision-making structures, these frameworks have been the most widely used with varying degrees of success (McFadden et al. 2011).

Even though adaptive management has gained considerable popularity over the past few decades, the number of published results of implementation is relatively small (McFadden et al. 2011). Stankey et al. (2005) described several reasons why adaptive management has failed to become commonplace in organizations. Among the most prominent are: adaptive management is still viewed as an ideal rather than a reality; there are many definitions for adaptive management, making the process less clear to implement; the risk of investing a lot of time and money towards learning the process and not getting an equally valuable return; reluctance to perform experiments using new structures and processes; the difficulty of working across parties and outside organizational structures; and failing to create clear documentation and experimental designs.

This paper uses the Fox-Wolf Hydrologic Dashboard and the Wisconsin Coastal Atlas as a case study for describing how the use of dynamic spatial decision support tools could make this management technique more viable for water resource managers.

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FOX-WOLF HYDROLOGIC DASHBOARD

The Fox-Wolf Hydrologic Dashboard (http://indiemaps.com/hydrologicDashboard/) is an example of a dynamic geospatial tool that promotes adaptive management. The dashboard is focused on the Fox/Wolf River watershed in Northeastern Wisconsin and utilizes a web interface created with Adobe Flash to integrate and visualize distributed web services to support water resource management. It includes the following components: (1) a map frame that includes stream gages and precipitation observations, catchment areas for stream gages, watershed boundaries and land cover; (2) time-series graphs of stream flow and precipitation data from the National Water Information System (NWIS) maintained by the U.S. Geological Survey; and, (3) a linkage between the stream flow graph and the map window that allows a user to view precipitation patterns from individual storm events in the context of gage location and catchment area and view animations of NEXRAD base reflectivity for precipitation events.

Figure 1 illustrates how the dashboard helps users better understand spatial and temporal patterns associated with precipitation events. The line graph in the upper right corner of the interface shows stream flow for August 2007 on the Fox River at Berlin, Wisconsin. The bar chart beneath the line graph displays daily precipitation recorded nearby at a station near Green Lake, Wisconsin. The gray line chart below shows that the August 2007 windows are part of a broader record of stream flow for that site on the Fox River and the bottom frame on the right side displays summary statistics for the period displayed in the main graph.

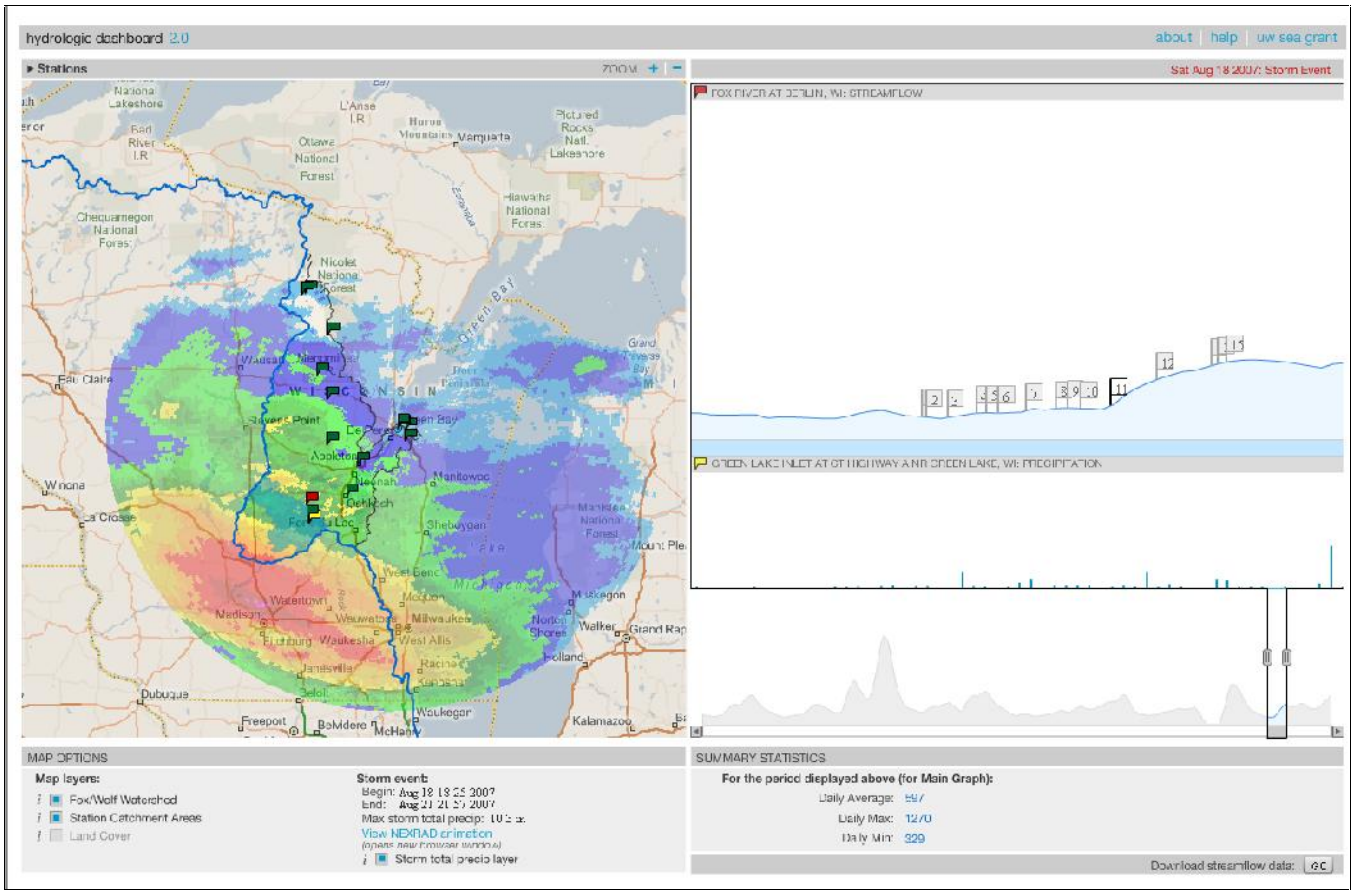

Figure 1. Storm total precipitation for an August 2007 event displayed in the Fox-Wolf Hydrologic Dashboard

The flags displayed along the primary line graph indicate storm total precipitation events in August 2007 recorded by the NEXRAD radar station at Green Bay, Wisconsin. Clicking on flag #11 displays storm total precipitation for an event that began on August 18th and ended on August 21st. The map image shows how the pattern of rainfall relates to the readings from the stream gage and its associated catchment area. Stream flow in the Fox River at Berlin started to rise around the time of event #11, but there wasn't much precipitation recorded at the nearby Green Lake Inlet gage. The most intense part of the storm passed to the southwest of the Fox River and Green Lake Inlet stations, but there was still significant rainfall in the southwestern portion of the catchment area. Clicking on the "View NEXRAD animation" link below the storm event

statistics accesses a new window with an animation of base reflectivity for the precipitation event from the Iowa Environmental Mesonet.

Visualizing the spatial and temporal patterns of large precipitation events at the catchment and watershed scales are useful for several activities undertaken by water resource managers, including water level regulation, culvert design and education and outreach associated with applying Total Daily Maximum Loads (TMDLs).

WISCONSIN COASTAL ATLAS

The Wisconsin Coastal Atlas (http://wicoastalatlas.net/) is an initiative to provide access to maps, data, and tools to support decision-making about the Great Lakes. It builds on many years of collaboration between the University of Wisconsin Sea Grant Institute and the Land Information and Computer Graphics Facility at the University of Wisconsin-Madison to leverage the sizeable investment in local government land information systems and apply geospatial technologies to support sustainable management of the Great Lakes.

Funding for the first phase of the atlas was provided by UW Sea Grant starting in February 2010. It is organized into four useful sections – maps, catalog, tools, and learn (see Figure 2). The primary web mapping interface of the atlas provides an overview of the Wisconsin coastal zone. A gallery of additional mapping interfaces provides customized perspectives related to specific coastal issues. The atlas allows users to search a catalog of coastal geospatial data. As the catalog is fully implemented, it will connect to distributed catalogs maintained by other data custodians, allowing discovery, assessment and download of a network of coastal geospatial data. In addition, the atlas serves as a gateway to spatial decision support tools relevant to Great Lakes management and provides a means to learn more about coastal issues in Wisconsin.

The initial focus of the atlas is on coastal hazards, but it is built with an open architecture that allows addition of new tools and components over time. Besides building the framework for the atlas, the first phase of the project includes tackling six research topics that address the science needed to effectively build and link coastal web atlases. These include: 1) structured design and evaluation of web atlases; 2) guidance on making choices among different web mapping technologies; 3) promotion of sound cartographic design principles for web mapping interfaces; 4) principles for development of domain spatial data infrastructures; 5) development of effective archives for coastal geospatial data; and 6) application of ontology tools to promote semantic mediation of local government spatial data sets to conduct spatial analyses of coastal issues at a regional scale.

A second phase of the Wisconsin Coastal Atlas will take the project in a new direction. The new goals focus on building on the framework provided by the existing atlas to:

- expand the coastal spatial data infrastructure for Wisconsin so that it covers watersheds and open waters of the Great Lakes;
- build the atlas as a platform for adaptive management of coastal and marine resources, coastal and marine spatial planning, and increasing the safety of water sports;
- advance social science methods to improve the effectiveness of decision support tools in coastal atlases; and,
- promote the interoperability of coastal atlases to study broader regional issues.

The enhanced coastal spatial data infrastructure supported by the Wisconsin Coastal Atlas will be used extensively by coastal resource managers, researchers, educators, and the general public. The spatial decision support tools developed as part of this project will improve the effectiveness of Sea Grant outreach staff and benefit state and federal coastal resource managers. Improved methods for GIS application development within geo-portals will lead to enhanced functions in the WCA and development of compatible atlases by other organizations in the coastal management community.

Completing an interoperable Wisconsin Coastal Atlas will complement other regional, state, and provincial coastal geographic information systems. Sharing among interoperable atlases and coastal GIS could help realize a long-time goal of scientists and coastal resource managers – management of the Great Lakes using a whole ecosystem approach (Caldwell, 1988; MacKenzie, 1996; Sproule-Jones, 2002).

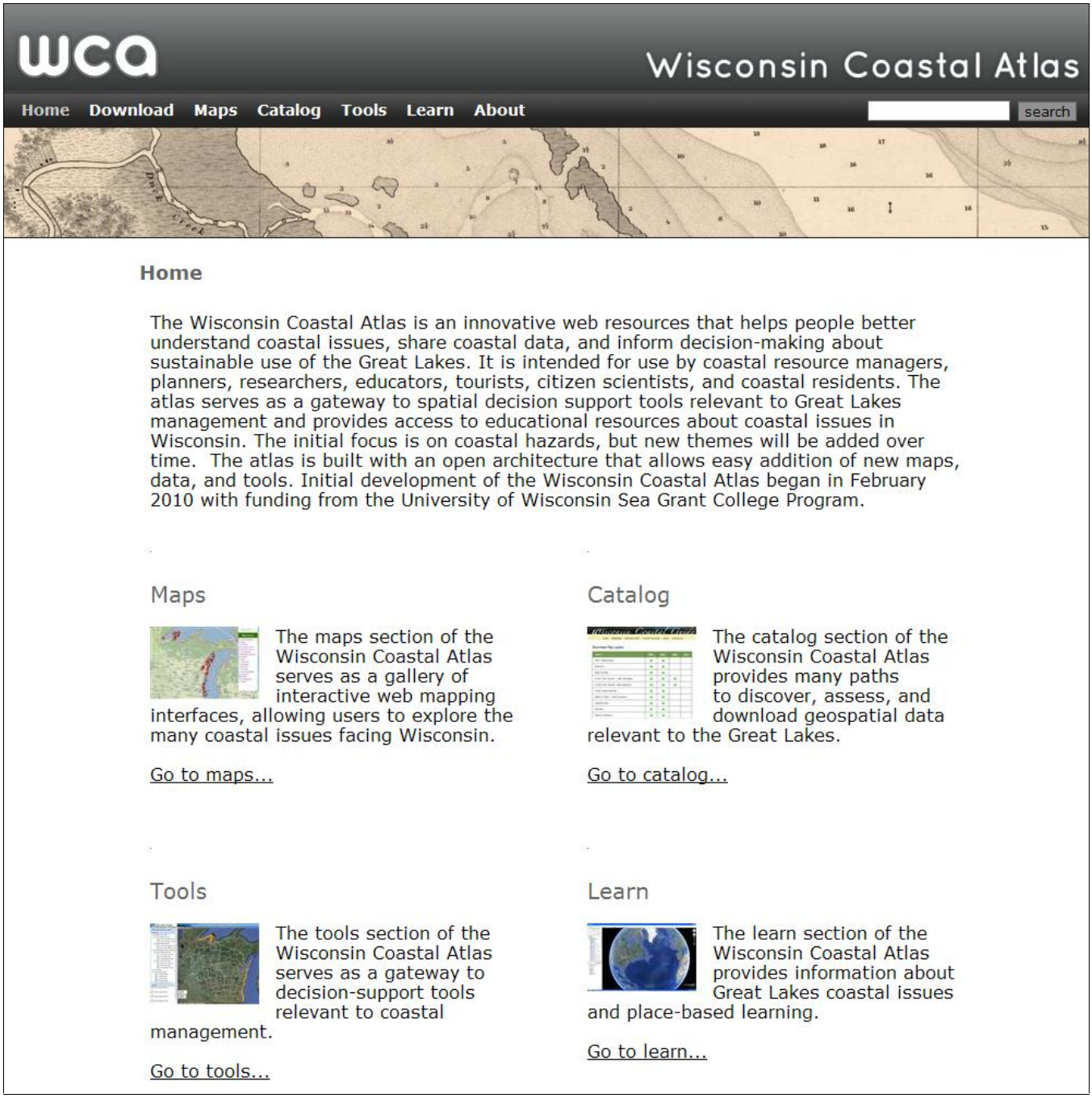

Figure 2. The four components of the Wisconsin Coastal Atlas

ENHANCING THE FOX-WOLF HYDROLOGIC DASHBOARD TO VISUALIZE THE CONNECTIONS BETWEEN LAND AND WATER RESOURCES

As defined earlier, adaptive management is an approach to resource management decision-making based on the best information available. Assessment and subsequent analysis of environmental conditions leads to revised policies or programs. The key is constantly striving to add new relevant information as it becomes available in order to revise decisions based on the impacts of the original choices.

A goal of the second phase of development of the Wisconsin Coastal Atlas is development of spatial decision support tools that can contribute to this cyclical process of assessment, analysis, and refinement of programs and projects. To support

this goal, the Fox-Wolf Hydrologic Dashboard will be enhanced to clearly illustrate the connection between precipitation events on land uses in the Fox-Wolf watershed and water conditions in the receiving water body of Green Bay.

The enhanced version of the dashboard will utilize emerging technologies for building interactive web mapping interfaces to better understand changing water quality trends in Green Bay and promote collaboration between coastal resource managers and scientists. The project team will utilize open-source JavaScript libraries such as OpenLayers for interactive mapping and HighCharts for graphing. The new dashboard will incorporate a wide range of interoperable data services from the hydrographic information systems maintained by the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI); time-series data from water quality monitoring undertaken by the Green Bay Metropolitan Sewerage District, and satellite imagery and model outputs authored by the Space Science Engineering Center at UW-Madison. Linking the visualization of precipitation events, stream monitoring data, and changing land cover patterns in the watershed to satellite imagery and point observations of receiving waters will illustrate the impacts of human activities on land to coastal waters and provide the dynamic information needed to promote adaptive management of water resources.

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