Application of GIS Technology in Watershed-based Management and Decision Making

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With the start of a new millennium, humankind faces environmental challenges greater in magnitude than ever before because the scale of the problem is shifting from local to regional and even to global ones. Indeed, the footprint of human activity continues to expand to the point that it is exerting a major effect on nearly all of the Earth's systems. Global environmental problems such as global climate change, threat of biological and chemical warfare and terrorism, and unsustainable development in many parts of the world are evolving as significant issues for the future of the planet and of mankind. At local and regional scales, acidification of surface waters, loss of biotic integrity and habitat fragmentation, eutrophication of lakes and streams, and bioaccumulation of toxic substances in the food web constitute some of the many examples of how human- induced changes have impacted the Earth's systems.

During the past decades, more and more of the complex environmental challenges have been addressed by using a watershed approach. According to the U.S. Environmental Protection Agency (EPA), environmental management using a watershed approach constitutes "a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically defined geographic areas".

The National Research Council report also noted that a watershed approach "uses sound, scientifically based information from an array of disciplines to understand the factors influencing the aquatic and terrestrial ecosystems, human health, and economic conditions of a watershed". The watershed is considered to be the integrating focus, the most appropriate spatial arrangement and functional unit for managing complex environmental problems. For example, managing issues of bio-complexity in the environment on a watershed basis offers the potential benefit of balancing the competing demands placed on natural and human systems.

Because of the highly complex nature of human and natural systems, the ability to understand them and project future conditions using a watershed approach has increasingly taken a geographic dimension. Geographic Information Systems (GIS) technology has played critical roles in all aspects of watershed management, from assessing watershed conditions through modeling impacts of human activities on water quality and to visualizing impacts of alternative management scenarios. The field and science of GIS have been transformed over the last two decades. Once considered a Cinderella technology in selected disciplines and application domains, GIS has grown quite rapidly to become a multi-billion industry and a major player in the broader field of the ubiquitous information technology. Advancements in computer hardware and software, availability of large volumes of digital data, the standardization of GIS formats and languages, the increasing interoperability of software environments, the sophistication of geo-processing functions, and the increasing use of real-time analysis and mapping on the Internet have increased the utility and demands for the GIS technology. In turn, GIS application in watershed management has changed from operational support (e.g., inventory management and descriptive mapping) to prescriptive modeling and tactical or strategic decision support system.

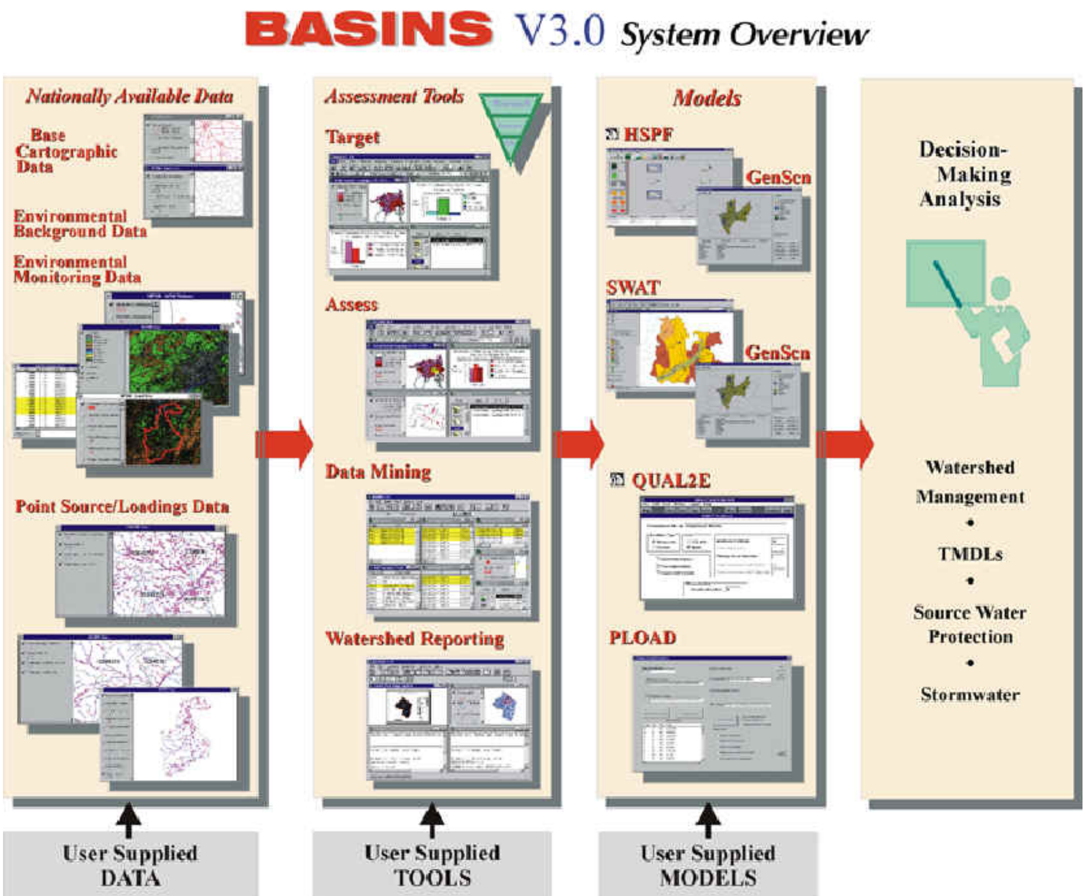
Increasingly, researchers, resource planners and policy makers are realizing the power of GIS and its unique ability to enhance watershed management.

The following list reveals some ways in which GIS has been exploited by the hydrology and watershed management community.

- **Watershed Characterization and Assessment**

GIS has been widely used in characterization and assessment studies which require a watershed-based approach. Basic physical characteristics of a watershed such as the drainage network and flow paths can be derived from readily available Digital Elevation Models (DEMs) and USGS's National Hydrography Dataset (NHD) program. This, in conjunction with precipitation and other water quality monitoring data from sources such as EPA's BASINS database and USGS, enhances development of a watershed action plan and identification of existing and potential pollution problems in the watershed.

Data gathered from GPS surveys and from environmental remote sensing systems can be fused within a GIS for a successful characterization and assessment of watershed functions and conditions.



(Source: http://www.epa.gov/ost/basins/)

● Management Planning

When faced with challenges involving water quality and quantity due to natural as well as human-induced hazards (e.g., droughts, hazard material spills, floods, and urbanization), planning becomes extremely important so as to mitigate their impacts and ensure optimal utilization of the available resources. Information obtained from characterization and assessment studies, primarily in the form of charts and maps, can be combined with other data sets to improve understanding of the complex relationships between natural and human systems as they relate to land and resource use within watersheds. GIS provides a common framework – spatial location – for watershed management data obtained from a variety of sources. Because watershed data and watershed biophysical processes have spatial dimensions, GIS can be a powerful tool for understanding these processes and for managing potential impacts of human activities.

The modeling and visualization capabilities of modern GIS, coupled with the explosive growth of the Internet and the World Wide Web, offer fundamentally new tools to understand the processes and dynamics that shape the physical, biological and chemical environment of watersheds. The linkage between GIS, the Internet, and environmental databases is especially helpful in planning studies where information exchange and feedback on a timely basis is very crucial and more so when there are several different agencies and stakeholders involved.

● Watershed Restoration (Analysis of Alternative Management Strategies)

Watershed restoration studies generally involve evaluation of various alternatives and a GIS provides the perfect environment to accomplish that efficiently and accurately. GIS has been used for restoration studies ranging from relatively small rural watersheds to heavily urbanized landscapes. Coupled with hydrodynamic and spatially explicit hydrologic/water quality modeling, GIS can assist in unified source water assessment programs including the total maximum daily load (TMDL) program. As an example, alternatives for restoring a waterbody or a watershed can be studied by creating digital maps that show existing conditions and comparing them to maps that represent the alternative scenarios. GIS can also provide a platform for collaboration among researchers, watershed stakeholders, and policy makers, significantly improving consensus building and offering the opportunity for collaborative work on interdisciplinary environmental policy questions. The integrating capabilities of a GIS provide an interface to translate and emulate the complexities of a real world system within the confines of a digital world accurately and efficiently.

● Watershed Policy Analysis and Decision Support

The field of watershed science, particularly watershed planning, is experiencing fundamental changes that are having profound impact on the use of computer-based simulation models in resource planning and management. On the one hand, the dramatically increased availability of powerful, low-cost, and easy-to-use GIS software, and more extensive spatially referenced data, are making GIS an essential tool for watershed planning and management tasks. However, with this increased use has come an increased realization that GIS alone cannot serve all the needs of planning and managing watersheds. This realization has renewed resource planners' interest in development of decision support systems that combine GIS, spatial and non-spatial data, computer-based biophysical models, knowledge-based (expert) systems, and advanced visualization techniques into integrated systems to support planning and policy analysis functions. As a component of a spatial decision support system, GIS provides very powerful visualization facilities for display and manipulation, giving immediate intuitive evaluation capabilities to which a wide range of non-technical users and decision makers can relate to.

Planning and management are based on a generic problem-solving process which begins with problem definition and description, involves various forms of analysis which might include simulation and modeling, moves to prediction and thence to prescription or design which often involves the evaluation of alternative solutions to the problem. GIS can assist the decision maker in dealing with complex management and planning problems within a watershed, providing geo-processing functions and flexible problem-solving environments to support the decision research process.

A casual look at the environmental/ecological science literature reveals intense research activities in GIS-based watershed management and planning. The explosive growth in the use of GIS for the activities listed above is testimony to its rapid evolution into a complex array of applications and implementations. What about the future? Can a set of resource management problems and issues be identified that will drive increased use of GIS (and other geospatial technologies)? Will the emerging issues of sustainable development, quality of life, and bio-complexity increase in importance to shape environmental research and the use of GIS? How can research, education and engagement activities enhance the science and management of watersheds? These and other questions, which we consider to be highly relevant to the future of GIS and Watershed Management, are open to discussion by members of our subcommittee.

Without gazing at the crystal ball certain emerging trends in availability of environmental data, human computer interaction, location based computing, cyber infrastructure, and field-based ecological research are bound to impact watershed management in the future. In addition, the rapid advances in GIS functionality and the convergence of network computing and wireless communications with geospatial technologies will give rise to a new class of applications in environmental management. We hope to keep our committee involved in dialogue on these emerging trends.

Upcoming Conferences of Interest

16-19 September 2003: International Conference of GIS and Remote Sensing in Hydrology, Water Resources and Environment, Three Gorges Dam Site, China.

29 September-4 October 2003: Sustainable Resources 2003: Solutions to World Poverty, Boulder, CO.

19-22 October 2003: Achieving Sustainable Water Resources in Areas Experiencing Rapid Population Growth, Atlanta, GA.

28-30 October 2003: First Interagency Conference on Research in the Watersheds, Benson, AZ.

2-6 November 2003: Changing Sciences for a Changing World: Building a Broader Vision, Denver, CO.

3-6 November 2003: American Water Resources Association 2003 Annual Meeting, San Diego, CA.

8-12 November 2003: Second Conference on Watershed Management to Meet Emerging TMDL Environmental Regulations, Albuquerque, NM.

10-14 November 2003: 30th International Symposium on Remote Sensing of Environment, Honolulu, HI.

17-19 May 2004: American Water Resources Association Spring Specialty Conference: GIS and Water Resources III, Nashville, TN.

28-30 June 2004: American Water Resources Association Summer 2004 Specialty Conference -- Riparian Ecosystems and Buffers: Multi-scale Structure, Function, and Management, Olympic Valley, CA