

Application of Remote Sensing and Geographic Information Systems to Ecosystem-Based Urban Natural Resource Management

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Abstract.— This paper presents an integrated system to support urban natural resource management. With the application of remote sensing (RS) and geographic information systems (GIS), the paper emphasizes the methodology of integrating information technology and a scientific basis to support ecosystem-based management. First, a systematic integration framework is developed and the major functionality of each component is discussed. Next, an integrated urban storm water management system is discussed at an operational scale. Then, an application of RS and GIS with hydrologic modeling to improve storm water management is introduced. The preliminary results have shown that the integrated system has great potential to support urban sustainable development.

Introduction

Many urban areas are growing at a record pace. Urbanization affects all components of the environment, from air quality, water quality (surface water and groundwater) and soil quality to wildlife habitat. Sustainability has become the primary goal of both economic development and natural resource management. Many valuable urban resources have been adversely impacted. Ecosystem management is an attempt to optimally balance economic development and protection of environment.

A growing problem confronting natural resource managers is the management of several interdependent resources, each of which has multiple uses and multiple users with multiple value systems (McCormick 1999). The application of advanced information technology can not only speed up information retrieval and organization, it can also improve our understanding of complex ecosystem dynamics, better assess urban resources and protect / restore natural systems. Thus, remote sensing technology and GIS can directly benefit the assessment of natural resources. The powerful tool of GIS spatial analysis can

monitor multiple attributes at different scales from multiple sources, and thus assess ecosystem change. Integration of RS and GIS with a modeling and simulation (MS) system can provide a new environment for risk analysis and decision-making support.

Integration of RS, GIS and MS with Decision Support System

Peine et al. (1999) summarized the principles and practices of ecosystem management for sustainability. WEF and ASCE (1998) detailed urban storm water runoff quality management. However, very little discussion can be found on integration of RS and GIS with a decision support system in ecosystem management. We think it is important to develop an integration framework first, to systematically describe the system's components, their functionality, inputs/outputs, and sub-system coupling. Figure 1 shows a functional integration of urban resource management with application of RS, GIS, and simulation tools.

As illustrated in Figure 1, the proposed integrated system consists of five sub-systems: RS, GIS, tabular databases, modeling / simulation, and multiple criterion analysis. The coupling of the sub-system's inputs and outputs can be described as follows:

1. Remote sensing technology can provide spatial and temporal pixel information on land use, resources and site activities; this information can couple directly with a GIS geo-referenced database.
2. The tabular databases, compiled from multiple sources, link to a GIS database with multiple attributes to assess an ecosystem in light of spatial information.
3. GIS processes and displays spatial data for environmental analysis, identifies the ecosystem indices, and records the site activities. Then, GIS is used to organize the resource assessment and the input files for modeling and simulation.

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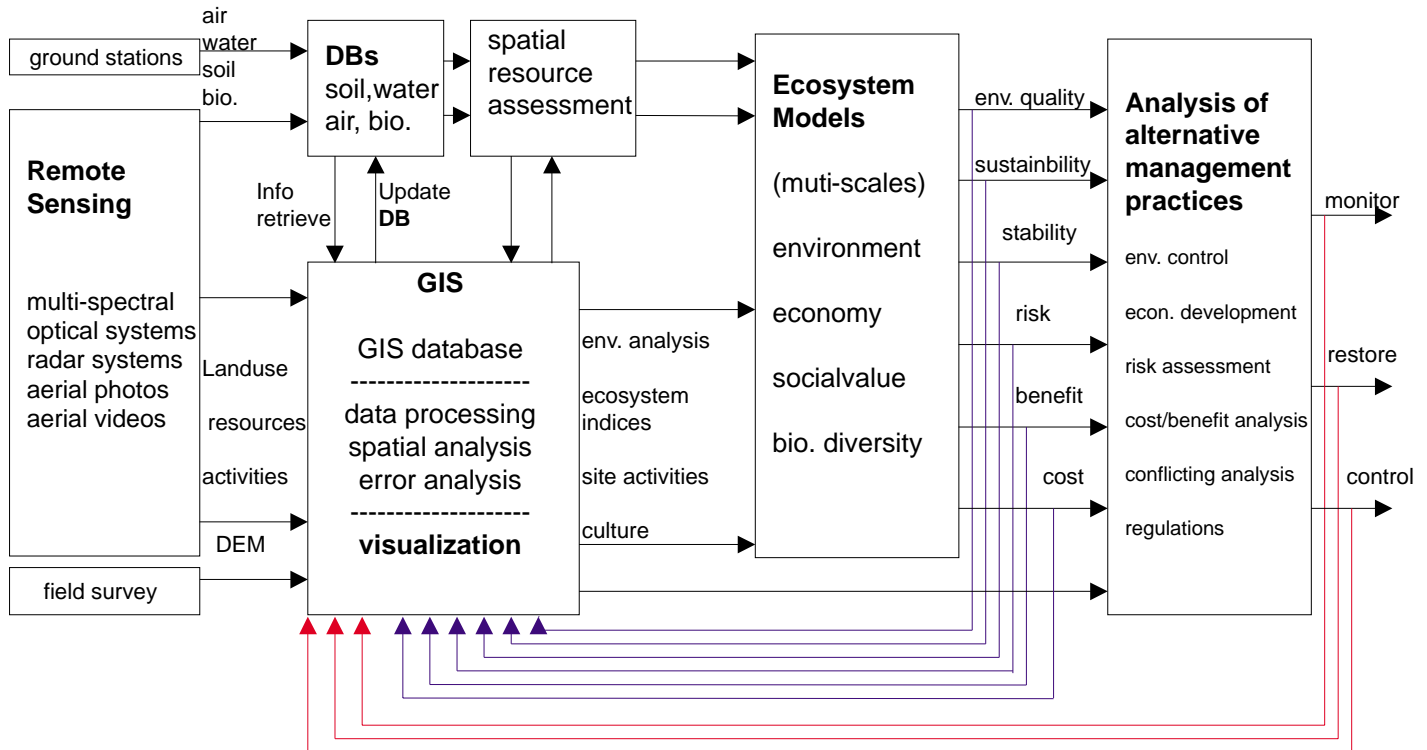


Figure 1. A functional diagram for ecosystem-based urban resource management.

4. Modeling and simulation cover the relationship of the regional environment, economy, social values and biological diversity. Under the given conditions, the regional models simulate scenarios and their environmental impacts, risk, cost, benefits, and then investigate ecosystem stability and sustainability.
5. Following regulations, a multiple criterion analysis system evaluates each scenario's consequences, risk, cost and benefits, resolves any conflicting objectives. Finally, it generates decision support reports.

As described above, GIS plays a central role in information management, as well as serving as a powerful tool in processing and visualizing spatial data.

Three major advantages of this integrated system can be identified. The spatial data collection from RS is fundamentally different from the traditional point measurements, in addition to the automatic manner in which it is acquired. Monitoring and modeling have been integrated with management to improve the scientific basis of ecosystem management. GIS can visualize a complex ecosystem at different scales, as well as spatially distributed environmental impacts.

Based on this framework, a preliminary research plan is introduced. It has implemented the above major components to support urban storm water management.

An Integrated System at an Operational Scale

The integration framework developed in previous section fits the general form of ecosystem management. To demonstrate its characteristics in watershed management practice at an operational level, an urban storm water management is taken as an illustration.

In a watershed, the hydrologic cycle integrates the physical, chemical and biological processes of a basin's ecosystem. Urban watershed-based management traditionally concerned approaches for water quantity related issues (conveyance oriented flood control and erosion control). Recently, water quality issues have been emphasized. Ecosystem-based management tries to protect and restore the ecological integrity of urban resources. Figure 2 shows a detailed functional diagram of an integrated urban storm water management system, which exactly follows Figure 1's structure, but at an operational scale. Figure 2 provides detailed information on the state variables, input/output couplings, parameters, model components, categories of analysis and actions.

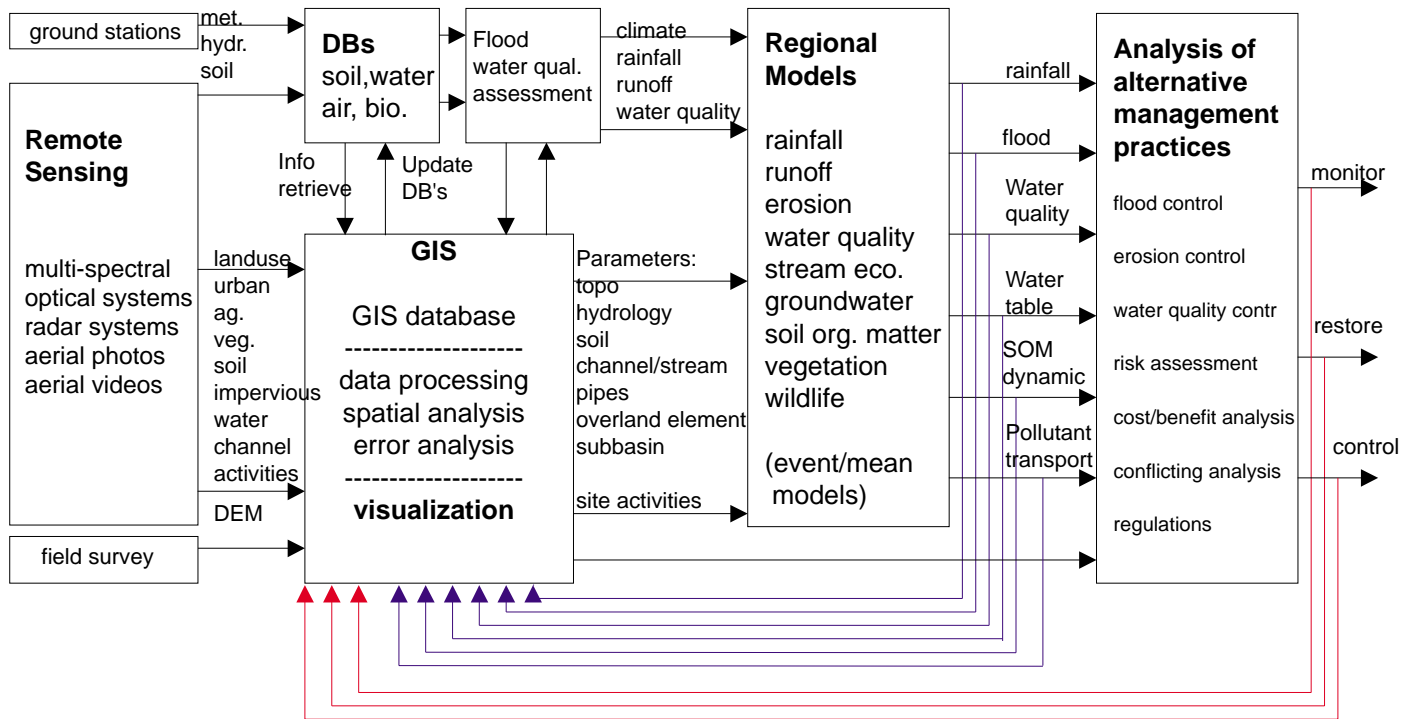


Figure 2. A functional diagram for integrated urban stormwater management.

An Application of Integrated Urban Storm Water Management

To demonstrate the characteristics of integration, a real application is introduced in this section. One research project in the Advanced Resource Technology (ART) Group, of The University of Arizona, is to implement an integration of RS and GIS with hydrologic simulation for urban storm water runoff management. The research was initialized from a project sponsored by NASA and the City of Scottsdale, Arizona in 1997. The major components of four subsystems in Figure 2 were implemented here. The study site is a highly developed urban area located in the city of Scottsdale. Multiple RS data were used, including aerial photos and different satellite images: Landsat TM, SPOT and NS001. A high-resolution GIS database was developed and digital terrain modeling was performed in ARC/INFO and ArcView. RS and GIS were integrated with a distributed hydrological simulation tool (Zhang et al 1998). The urban storm water runoff was simulated under a variety of conditions to improve flood prediction (Zhang et al 1999a). The distributed

hydrologic simulations were modeled by the kinematic wave approach and implemented in HEC-1. GIS/ Avenue, an ArcView programming language, was used to customize the information management system handling the data exchange and user interface (Zhang et al 1999b).

Figure 3 shows the application of RS and GIS to assess urban resources and monitor sensitive areas in an ecosystem. The processed satellite image provided eight categories of surface information: trees, grass, bare soil, gravel, water, asphalt, concrete and buildings. These RS data provided preliminary watershed characteristics regarding land use and urban development. Complemented with GIS data, RS data also identified and recorded some site activities. Aerial photos and geo-referenced site photos (integrated into the GIS database) detailed disturbed areas and conditions at the sensitive sites. For example, here is a construction site and the conjunction of a storm sewage pipe and a natural channel, which was partially blocked by deposited trash, used tires and other debris.

Figure 4 shows the simulated storm water runoff at different places within the watershed under the different conditions.

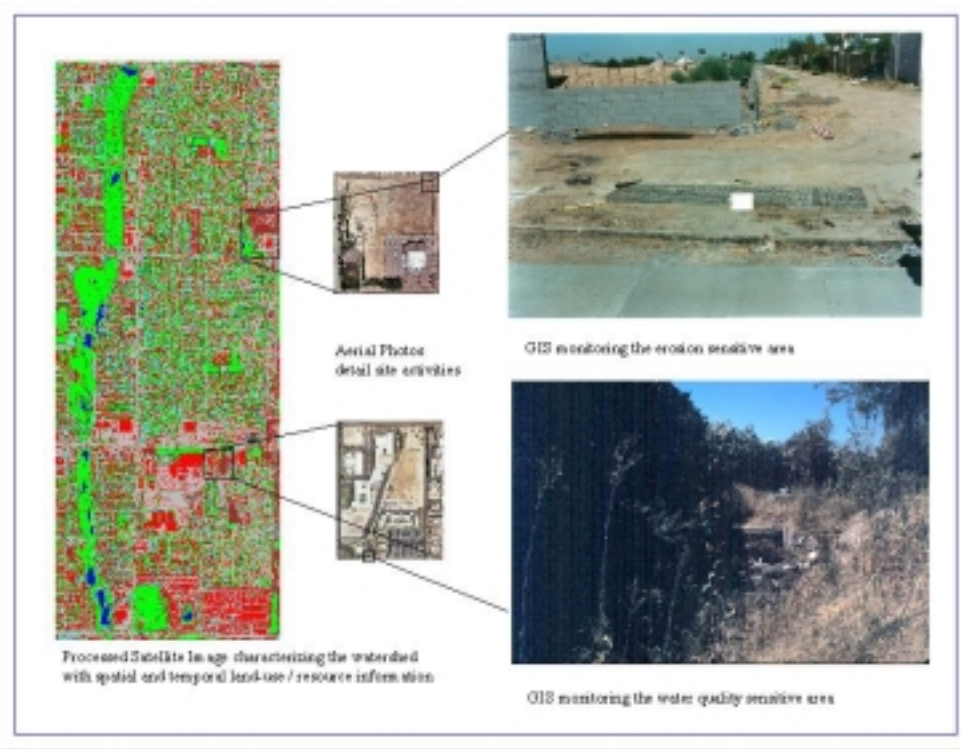


Figure 3. RS and GIS assess urban resources and monitor sensitive areas.

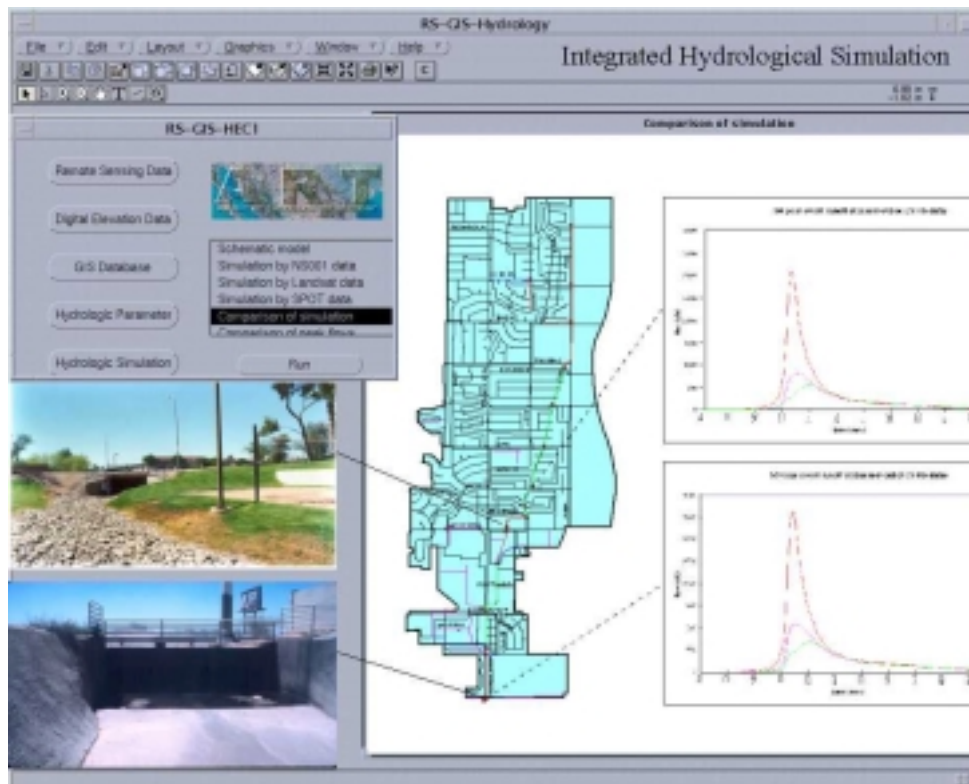


Figure 4. An integrated urban stormwater runoff simulation.

Summary and Discussion

An integration framework was systematically developed to support ecosystem-based management, with an application of RS, GIS, modeling/simulation and multiple criterion analysis. At an operational scale, an integrated urban storm water management was illustrated. An application of RS and GIS to improve storm water management was introduced. RS directly benefits resource assessment and monitoring. GIS plays a central role to process and visualize the spatial data. Modeling and simulation are tools that can evaluate alternatives, when the results of a given action might not be apparent for several years. The multiple criterion analysis tool evaluates predicted conditions under alternative actions. The integration of information technology and modeling tools provides a new environment for research of complex ecosystems, as well as a better scientific basis for management.

Acknowledgment

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