An Internet-based Spatial Decision Support System for Rangeland Watershed Management

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Abstract

The impact of livestock grazing on water quality, especially erosion and sedimentation, is an important concern in the southwestern United States. In response to Federal and State regulations, Best Management Practices (BMPs) for rangeland management are being developed and implemented in many western states, although the efficacy and economic impact of many practices have not been examined. To assess the potential effectiveness of BMPs, a Spatial Decision Support System (SDSS) has been designed to integrate water quality, livestock management and economic concerns. The SDSS was developed through the integration of hydrologic, erosion, livestock management and economic simulation models linked with a geographic information system and database management system. The SDSS can help managers select the type and location of BMPs based on site-specific data and is deployed via the Internet providing access through a web browser. The SDSS provides land managers with a means to identify critical areas causing water quality degradation and design and implement watershed management practices to improve water quality. The poster will describe the SDSS and provide case study examples of its application.

Keywords: GIS, hydrologic modeling, non-point source pollution

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Introduction

Traditional ranching communities in the western United States are under increasing stress. Global competition, development, and changing environmental perceptions are altering the face of rural America. This is especially true in the rural Southwest where ranching has historically been a primary economic activity. The long-term viability of ranching in the southwestern United States is questionable given decreasing beef consumption, increasing urbanization pressures, and negative public perceptions of livestock grazing.

An important issue that impacts rangeland management and livestock grazing is land and water quality, especially erosion and sedimentation. In Arizona, sediment is a principal non-point source pollutant with almost 960 miles of stream channels polluted with sediment, which is over three times greater than impairment caused by the next leading constituent (U.S. Environmental Protection Agency 1998). The advent of Total Maximum Daily Loads (TMDLs) by the U.S. Environmental Protection Agency establishes criteria to evaluate pollutant contribution from land-use impacts and other non-point sources. Under section 303(d) of the Clean Water Act, TMDLs are designated as a tool for watershed-based water quality management decisions; however, problems with implementation of these watershed management programs are due to the inadequacy of procedures, models, and methodologies caused by insufficient focus on watershed-wide diffuse source properties (Novotny 1999). Since management of non-point source pollutants and TMDLs is inherently spatial, distributed hydrologic and water quality simulation models coupled with geographic information systems can be used to simulate the impact of various land-use conditions on water quality.

To complicate the issue, many livestock growers manage ranches composed of a mixture of federal, state, and private land, all with different goals and regulations. A rancher operator may face a multitude of

BMPs on a single livestock allotment that overlaps multiple land ownerships. A single livestock allotment may cross several watershed boundaries; conversely, several livestock allotments managed by different ranchers may lie within a single watershed. Since TMDLs are assigned at the watershed level, integrated impact of management actions across different ranch allotments and land ownership must be assessed (U.S. Environmental Protection Agency 1999).

Ranch planning has traditionally been done at the allotment or pasture level. For example, ranch management plans developed by the USDA Natural Resources Conservation Service (NRCS) primarily address erosion and erosion control within a ranch in concert with other watershed plans, but seldom explicitly assess the potential impacts beyond the allotment boundary. Although numerous hydrologic/erosion/water quality models have been developed (National Resource Council Committee on Watershed Management (NRC) 1999), none are currently capable of supporting allotment planning and the implementation of different BMPs across a watershed.

Effective watershed management and planning requires the integration of knowledge, data, simulation models, and expert judgment to solve practical problems and provide a scientific basis for decision making at the watershed scale (NRC 1999). A user-friendly decision support system (DSS) that would help different stakeholder groups to develop, understand and evaluate alternative watershed management strategies is needed. The DSS would consist of a suite of computer programs with components consisting of database management systems (DBMS), geographic information systems (GIS), simulation models, decision models, and easy to understand user interfaces.

The difficulty in developing the DSS is not a lack of available simulation models but rather making these models available to decision makers, a key observation made by the National Resource Council's Committee on Watershed Management (1999). Over the last forty years the federal government has spent millions of dollars on model development. The USDA-Agricultural Research Service (ARS) currently supports many simulation models addressing various environmental concerns from erosion to exotic species. While these simulation models are used extensively in research settings, they are infrequently incorporated into the decision making process. Reasons for this exclusion include: data requirements are usually only attained in a research setting; models are complex and underlying assumptions are poorly understood by resource managers; and deriving model input parameters is extremely time consuming and difficult. These models represent a valuable library of knowledge that should be utilized. To use these models, expertise in database management system, geographic information systems, computer operating systems, remote sensing and Internet searching for data gathering, graphics, as well as watershed domain knowledge is required. Few seasoned professionals have all these skills, much less the typical watershed stakeholder.

The poster will review the development of an operational GIS-based, integrated watershed-planning tool deployed via the Internet that provides land managers with the information necessary to evaluate the effects of livestock grazing impacts on water quality. The tool will be capable of evaluating available BMPs that can be implemented to mitigate detrimental impacts and assessing economic ramifications of management decisions.

Internet-based SDSS

The Automated Geospatial Watershed Assessment (AGWA) (Miller et al. 2002a) application was developed by the University of Arizona and USDA-ARS Southwest Watershed Research Center in a collaborative effort with the EPA's National Exposure Research Laboratory to evaluate landscape change. AGWA, which served as the starting point for the Internet-based SDSS, is based on ESRI's ArcView (ESRI 2000) GIS application and performs hydrologic model parameterization and results visualization for KINEROS (Smith et al. 1995) and the widely used SWAT (Arnold et al. 1994) watershed scale hydrologic simulation models. The application derives hydrologic model parameters from readily available digital elevation models, soils, and land cover data sets and allows users to spatially visualize changes in hydrologic response through the use of remotely sensed land cover scenes from different time periods. The primary purpose of AGWA is to evaluate the hydrologic response of land cover change (Hernandez et al. 2000, Miller et al. 2001, Kepner et al. 2002, Miller et al. 2002b) and the impact of geometric complexity on watershed scale simulation models (Semmens et al. 2001).

While the AGWA application simplifies hydrologic modeling and reduces the time needed to parameterize a simulation model and improves results visualization, it contains a number of shortcomings. AGWA is based on ESRI's ArcView 3.2, requiring users to have proprietary and expensive software installed, limiting the number of users who can utilize this application. Customizing ArcView 3.2 is conducted through ESRI's proprietary object oriented programming language, Avenue, which prevents the integration with more powerful programming environments. The application also requires users to have an understanding of GIS principles, further limiting its user base.

With advances in Internet technologies and specifically Internet GIS, the current effort developed and deployed a version of the AGWA application through the web targeting rangeland watershed managers. This project, funded by the USDA Cooperative State Research, Education, and Extension Service, provides land managers with access to GIS and hydrologic modeling technology without requiring users to manage complex spatial data sets and model parameter sets. The application allows land managers to compare environmental and economic effects of different land management systems.

The Internet architecture used in development determines the complexity and efficiency provided by an application. Currently, there are two types of Internet applications: client-side and server-side. Client side strategies require the majority of the processing to be conducted by the client, requiring the web browser to load a program (such as an applet or plug-in) the first time users request to view spatial data. This "thicker client" architecture provides the advantage of more functionality for users and requires fewer interactions with the server. However, applets are not persistent and must be downloaded at the inception of the application, and plug-ins are required to be downloaded and installed like traditional applications (Plew 1997). This type of architecture is typically best for applications with literate users (Plew 1997) because users are required to have knowledge of handling and manipulating the data. Server-side strategies perform all processing on the server, relying on the spatial server to conduct the analysis and generate output (Peng 1997). These thin-client applications require a high-performance server due to the computation intensity and have higher network congestion since each operation performed by users must communicate with the server. However, users have access to large and complex data sets and since client machines perform little processing, users are not required to have sophisticated computers (Foote and Kirvan 1997). Since tradeoffs exist between functionality, efficiency and required knowledge, integrated decision support systems should support multiple weight clients providing access to users with different backgrounds, experiences, and network connection speeds.

The Internet-based SDSS uses both architectures. Thicker client programs are used to allow users to enter their own data, such as the location of their own fences and water sources. However, Internet-based AGWA is primarily a thin client application. The databases and models are housed on the host server plus all simulations are preformed on the host server. The simulation results can then be viewed on the web browser. This provides the user with some basic functionality but still provides the advantages of a thin client application.

SDSS Functionality

The Internet-based SDSS provides core functionality required for rangeland watershed management planning and decision making. Users have the capability to dynamically delineate watersheds by clicking on a map to locate a watershed outlet (Figure 1). Using this boundary, users can perform simulations using hydrologic models with parameter sets derived from soils and land cover GIS data layers and spatially visualize results. In essence, the Internet application performs the same operations as the current standalone AGWA application using ESRI ArcView 3.2.

The application provides a "thicker" client to delineate rangeland management systems that consist of pasture boundaries, water points, and sediment detention structures. Each management practice contains user-defined attributes that are incorporated into the modeling process. Hydrologic and economic simulations are performed on user delineated management systems and results are presented in a spatial, graphical, and tabular format. Users can create "what if" scenarios such as locating water sources at different locations within a pasture or change the location of pasture boundaries and compare the runoff, sediment yield, and cost of different scenarios.

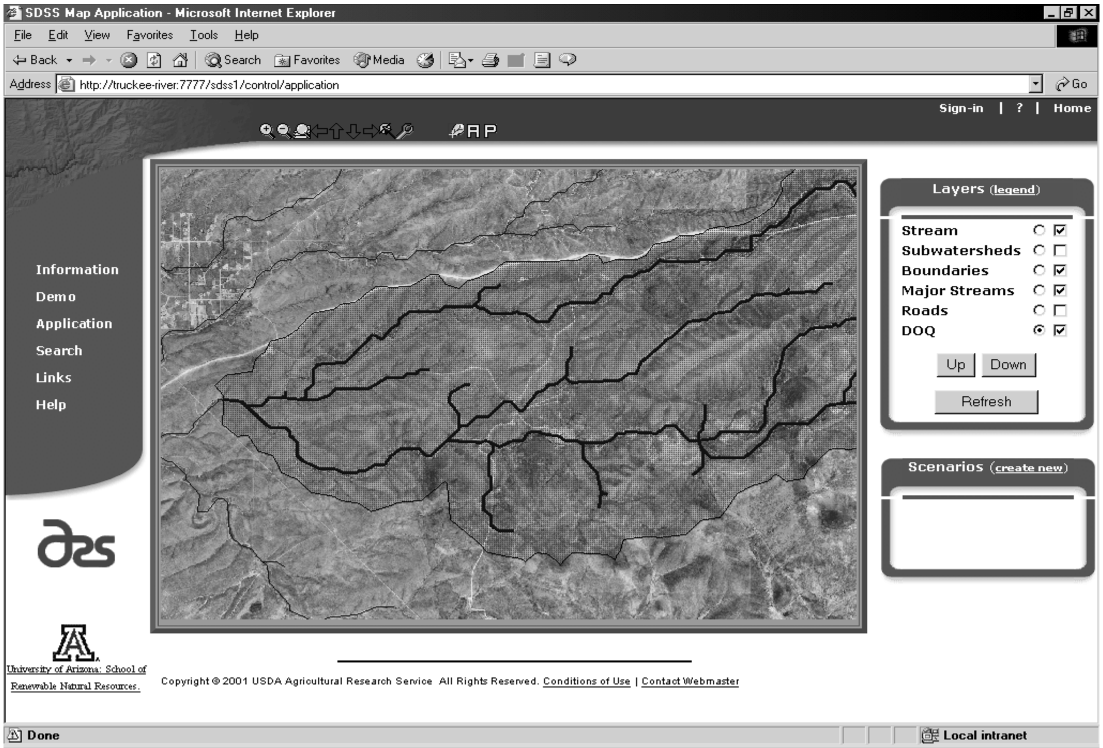

Figure 1. The Internet-based spatial decision support system (SDSS) provides users with the functionality to delineate watersheds by "clicking" on the map locating the watershed outlet.

The application can assess the effects of many of the common best management practices related to livestock management. Currently, the Internet-based SDSS can assess the impacts of fence locations, water source locations, stock ponds and changing vegetation cover and type. Vegetation management is modeled using the NRCS ecological sites guides. Using the vegetation information (herbaceous canopy cover, herbaceous basal cover, shrub basal cover, rock cover, etc.) on an ecological site's states, the Internet-based SDSS can change the hydrologic parameters for KINEROS. The user can delineate an area for improvement, such as shrub removal, and indicate the future transition state. The user can use either the average vegetation condition or simulation the response for low or high precipitation years. The location of fences and water is used to model the level of forage utilization across a pasture.

Areas near water within a pasture will be more heavily grazed (Guertin et al. 1998). Based on current stocking rates and rotation systems the vegetation condition within a pasture will be assessed and its hydrologic impact simulated.

The user can use the Internet-based SDSS to change the management system and evaluate the effects of a set of different scenarios. The Internet-based SDSS can then perform a change analysis showing the hydrologic and economic effects of the different scenarios. The user can either save the results for later review or publish a report on the results.

Conclusions

The Internet-based SDSS for rangeland watershed management is currently being validated. As with other applications deployed via the web, the Internet based SDSS provides advantages over traditional desktop applications. First, the application is centrally located, simplifying distribution and maintenance. The application also uses predefined spatial data layers allowing the uncertainty in data inputs to be tested and quantified *a priori* using a Monte Carlo simulation approach (Malczewski 1999). In addition, the Internet based approach increases the user base by reducing costs of access to users. The current version of the Internet-based SDSS was targeted for rangeland watershed management. In future versions the Internet-based SDSS the functionality will be expanded to address

Integrated Watershed Management and Planning for semiarid watersheds. This will include the ability to address water supply and flooding issues as well as water quality and address the affect of other land uses including urbanization. Additional information can be found at http://www.tucson.ars.ag.gov/sdss

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