

A Web-Based Tool for Economic Analysis of Sediment Control on Rangeland Watersheds

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Abstract: This study presents a web-based spatial decision support system (SDSS) that supports watershed analysis from an economic perspective. The SDSS is intended to aid the development of sediment TMDLs sediment on rangeland watersheds. The SDSS architecture consists of three parts: the interface tier, the application tier, and the data tier. Middleware is used to integrate these three parts into one system. Dynamic web pages are used to support customized access to the system, including defining inputs, running analysis and viewing results. The middleware is used to glue the interface, model, and database together seamlessly. The embedded models include geospatial models and a watershed optimization model. The database is used to manage all the data through web-based interfaces. The SDSS supports spatial inputs, such as pasture boundaries, water points and stock ponds, and nonspatial inputs, such as cost scenarios, sediment control objectives and policy options. An embedded representative ranch model is used to optimize management options to meet profit and sediment yield objective. The screenshot for of the SDSS for the Walnut Gulch Experimental Watershed are used to illustrate the major functionality of the SDSS in assessment of Best Management Practices (BMPs) in soil conservation plans.

Keywords: BMPs, optimization, SDSS

1. INTRODUCTION

Rangeland is a major landscape in the western USA. Livestock grazing is a traditional land use of western rangeland. Grazing can increase rangeland erosion and degrade water quality. The Clean Water Act requires the states to develop Total Maximum Daily Load (TMDL) plans to improve water quality for water bodies not meeting their intended uses.

Several interest groups are directly affected by TMDLs and/or other environmental regulations. State environmental quality agencies need to define and administer TMDL programs. Public land management agencies, such as Bureau of Land Management and Forest Service, need to adjust their management policy to meet environmental requirements. Consequently, ranchers using public lands need to adjust their management to meet TMDL and other public land requirements. All these stakeholders are interested in having tools that can compare the environmental and economic effectiveness of different BMP options.

It is a challenging job to develop a TMDL for rangeland watersheds. First, there is a huge range of options of best management practices (BMPs) in a watershed TMDL plan. A TMDL consists of various BMPs and for each BMP, there are different environmental impacts and economic

costs. The possible combinations of BMPs are almost unlimited. It requires advanced analysis to find the best solution among huge combinations. Second, the management-impact relationships for rangeland watershed systems are generally complex and current understanding of the relationships cannot provide accurate prediction of the impacts from management. In fact, many relationships are empirically derived from local data. The uncertainty of prediction also requires robust methods in comparing different options.

An SDSS provides a powerful tool in watershed management and TMDL planning. An SDSS incorporates GIS to support geospatial analysis and spatial data presentation in a DSS. Prato et al. (1996) described a SDSS model for an agricultural watershed with economic, environmental and ecological modules, which allowed users to compare the management plans. Beaulieu et al. (1998 and 2000) used linear programming to perform land use optimization for watershed erosion control and GIS for spatial result presentation. Bathurst et al. (2003) presented a DSS for an agricultural economic application to maximize income and meet an environmental objective in an agricultural basin. He developed a DSS that integrated ArcView GIS and AGNPS for soil erosion analysis on watersheds.

Web-based DSS is new approach for various resource management approaches. Jensen et al. (2000) developed a web-based system that provided the just-in-time weather data and simulation models for crop management in Denmark. Ludwig et al. (2003) presented a web-based DSS to study global change impact at catchment scale. Pandey et al. (2000) developed a web-based tool to assess the long-term hydrological impacts of land use change. Engel et al. (2003) presented a web-based system to assess hydrological impacts of land use changes in watersheds. However, few systems have explicitly supported BMP planning for watershed erosion control.

This paper presents a Web-based SDSS for sediment control on rangeland watersheds from an economic perspective. The system allows users to formulate their own problems, make analysis and visualize results in a web browser. The embedded models integrate biomass production, livestock grazing, ranch operation, economics, and policy in one system (Duan 2005, Duan et al. 2006). The models are the core in supporting complex rangeland watershed analysis. Results from the

models could provide useful information in developing TMDLs on rangeland watersheds. A case study for the Walnut Gulch Experimental Watershed illustrates the possible application of the SDSS in watershed planning.

2. SDSS ARCHITECTURE

The Web-based SDSS uses a client-server model to provide the web service. More specifically, the client/server model uses a three-tier architecture, the interface tier, process tier, and data tier (Fig. 1). The interface tier, also called the presentation tier, is the interface between users and the SDSS. The interface tier includes several servers. The web server waits for users' requests. Once a request is received, the server will determine the proper response. The response may directly return a web page, or activate application processes, or forward the request to another server. The map server provides map rendering in a webpage. The web server also manages the session used for customization of web pages. This SDSS uses the Apache Server as the HTTP server and MapServer, free web map software, as the map server.

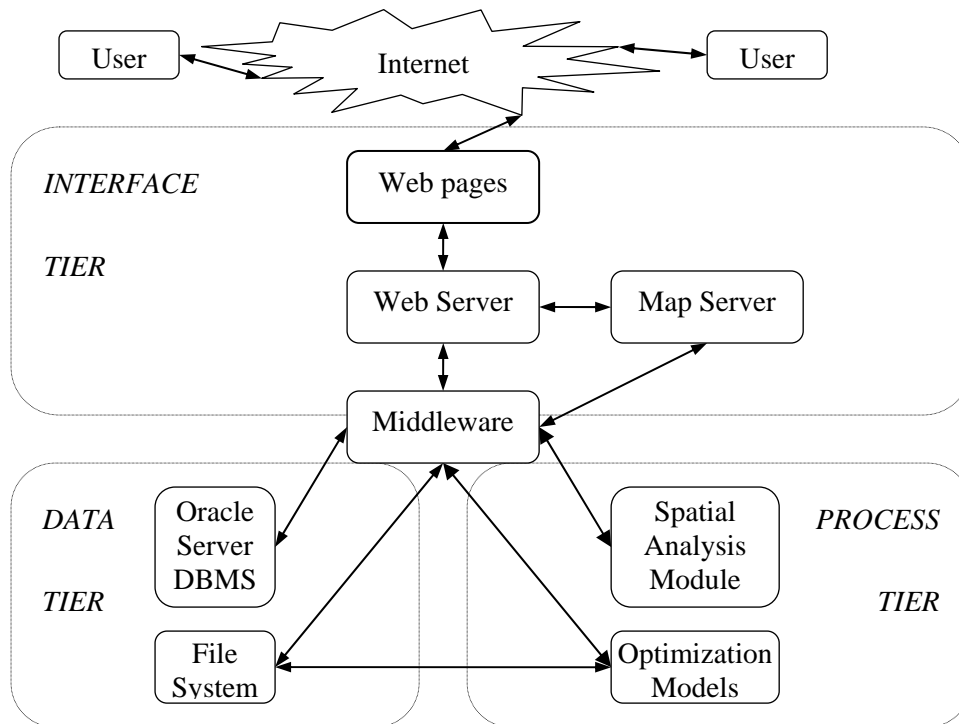


Figure 1. Adjustment of grazing over space with different sediment control objective

The process tier, also called the middle tier, includes the application logic. This SDSS had two major application processes. The spatial analysis module deals with all spatial data processing, such as creating new layers of pastures, stock ponds and

water points, overlaying of layers and deriving parameters for optimization model. The optimization models search for the optimal management to maximize ranching profits while meeting the sediment control objective. This SDSS

uses ESRI AMLs to implement geospatial applications and GAMS to implement optimization models.

The third tier is the data tier. This SDSS uses two data storage systems, a database and files. An Oracle database server was used as DBMS to manage most non-spatial data. Some of the data, mainly spatial data, was stored in files. For example, the input and output from GAMS are in text file format. The inputs and outputs for AMLs are also stored in files. The files may be read into the database or kept in the file system.

The middleware is the control centre of the SDSS linking the three tiers together (Fig. 1). The middleware handles complex user requests, activating application processes, preparing data for a web server and application logic and management of all data. Once the web server receives a request, it will activate a certain procedure and return users' proper data. The middleware is mostly in Java, mainly Tomcat Servlet. Combined with JSPs, the Servlet can create customized web pages for each user.

3. SYSTEM FEATURES

3.1 Data Management

The SDSS manages data at two access levels. The SDSS provides embedded system data that are shared by all users, but users cannot modify. The system data are the basic data for users to start an analysis. Users can also create their own data. The data can only be accessed by the creators. This two level data management provides the convenience of starting an analysis through system data and also supporting users' special analysis through user's data.

The system stores users' inputs and analysis results in the database. The 'memory' property allows users to return the system and view all their previous applications.

3.2 Customized Dynamic Web Pages

This SDSS uses JSP as the major interface to interact with users. The content of a web page depends on one's previous actions and are created from users' requests on-the-fly.

Since all users' analysis is also stored in the database and web pages are created on-the-fly based on the database, this SDSS supports real time web page updating. These web pages are dynamically updated after a user's action.

These properties are useful for this type analysis. The dynamic update allows the inputs used in following analysis. Unlike Applet-based

applications, this SDSS can remember users' data and users can go back to view their previous data at any point. One typical watershed analysis includes creating input, defining projects, running models, and viewing results. The whole process could take hours or days. The 'memory' property allows users perform a watershed analysis at different time intervals.

3.3 Economic Focus

The objective of this SDSS is to provide tools to assess BMPs. The SDSS provides various results with estimates of economic effects. The integrated model is designed to maximize profits with sediment control constraints (Duan 2005, Duan et al. 2006). The possible revenue and cost impact of different BMPs are incorporated in the model. The production frontiers from the SDSS provide the trade-off between sediment yield and profits. The abatement cost curve also can be derived. All these results provide economic measurement to compare different BMPs.

3.4 Extensibility

The SDSS also supports two types of extensions. The SDSS can be extended to other study areas if these watersheds follow the same relationships specified in the model. The other type of extension is to add new models that may be suitable for other watersheds. However, the second type of extension cannot be automatically done in the current system. Parts of the current SDSS may need to be rewritten for this type of extension.

Following, we present a case study to illustrate the major procedure of application of this SDSS in rangeland watershed management.

4. CASE STUDY

4.1 Study Area

The Walnut Gulch Experimental Watershed (WGEW) is a subwatershed of the Upper San Pedro River Basin located in Southeast Arizona, USA (Fig. 2). The total watershed area is about 149 square kilometres. The watershed is dominated by two major vegetation communities, with grassland on the eastern portion and brush on western portion near the watershed outlet. Cattle's grazing is the primary land use, on about 90% of the total area.

The high sediment in stream flow affects the ecosystem of the riparian area of the San Pedro River. Sediment is delivered from tributaries, including the Walnut Gulch Watershed. The SDSS for this watershed is expected to assess various BMPs from an economic perspective.

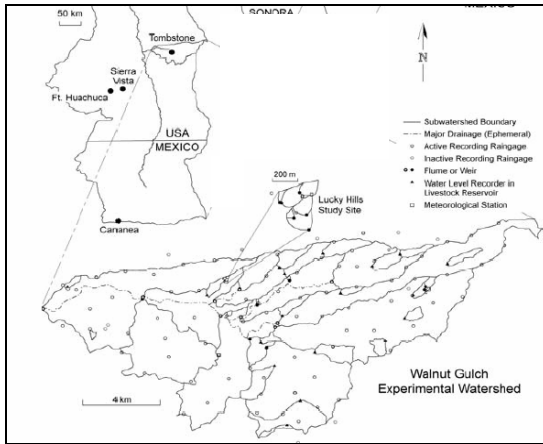


Figure 2. Location of Walnut Gulch Watershed from SWRC(2003)

4.2 Data Preparation and Parameterization

The SDSS requires several spatial layers as the system base map for users to start their analysis. These data were downloaded from the data server of Southwest Watershed Research Centre, ARS

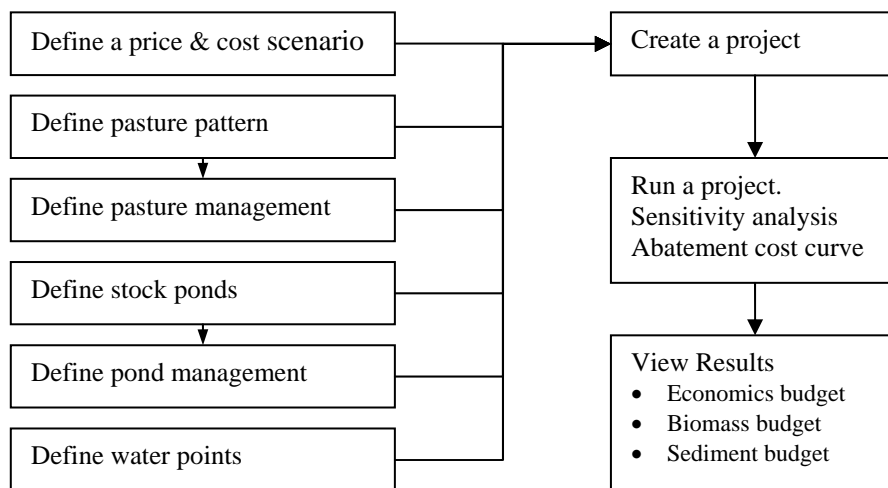


Figure 3. SDSS analysis flow chart

4.4 Screenshots of Sample Analysis

The SDSS for the Walnut Gulch Watershed is now available at the link (<http://tucson.ars.ag.gov/sdss>). In this section, we present the user's interfaces of the SDSS in screenshots. Figure 4 showed the screenshots of eight major web pages in a typical analysis. The first web page is to create a new set of price and cost values that will be used for watershed analysis. The second webpage is the map editor to create a new infrastructure, such as fence, water point and stock ponds. The third web pages are to define a pasture grazing management. The fourth web page is to create a new project that

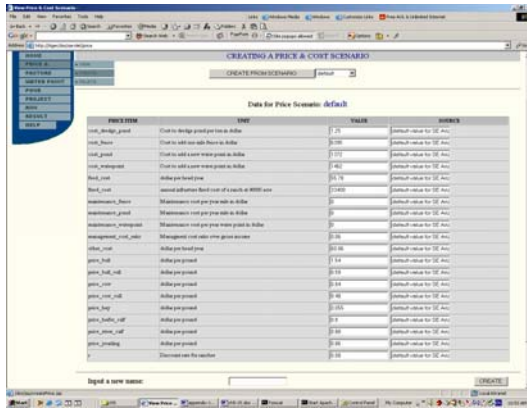
USDA. Several geo-processes were also implemented before launching the SDSS server. The ecological site data are from Arizona Ecological Site Guide (NRCS) MLRA 41, Southeast Arizona. Teegerstrom and Tronstad (2000) provided the price and cost data, and the ranch operation parameters special for Southeast Arizona.

4.3 Analysis Procedure

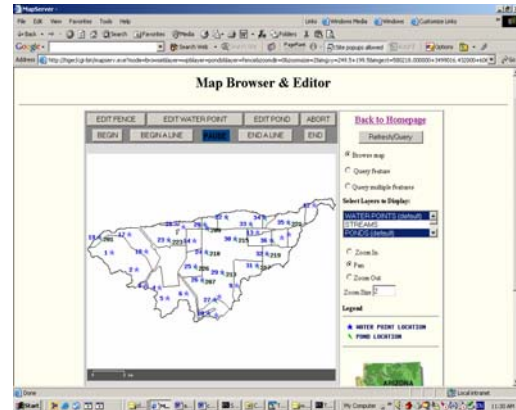
The procedures of a typical watershed analysis include defining inputs, creating a project, running a project and viewing results (Fig. 3). The inputs include price and cost data, pasture, water point is a combination of different inputs and a sediment control objective. After creating a project, users can run the optimization model, sensitivity analysis, or abatement cost curves. After running, users can view results in various formats. The procedure is self-evident and a graphical tutor is also used to guide users through the analysis procedure.

includes spatial layers, management, a price and cost scenario, policy and the model type. The fifth web page is to run a project. The sixth web page is to view the ranch budget.

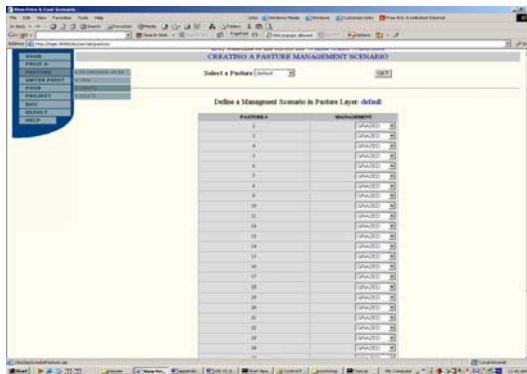
The seventh web page is to view the spatial erosion and vegetation distributions in a map. The last web page is the abatement cost curve of grazing management. These pages are only a fraction of the web pages that support the SDSS. All these web pages are customized to special users. Further information can be found Duan (2005).



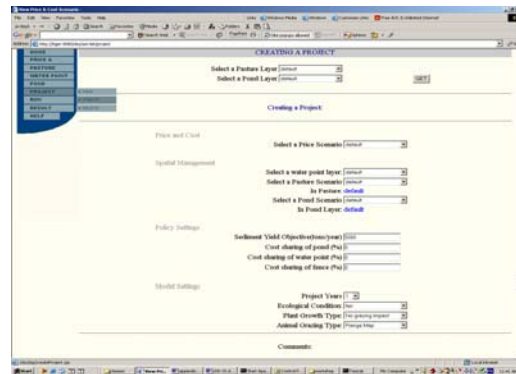
1. Creating a price & cost scenario



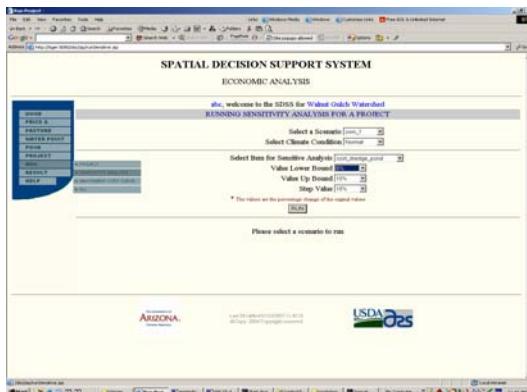
2. Creating new fence, water point or stock ponds



3. Defining a pasture management scenario



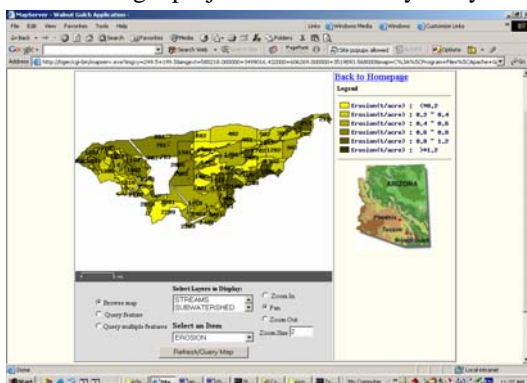
4. Creating a project



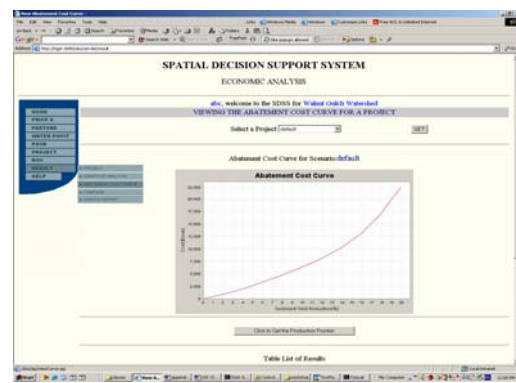
5. Running a project with sensitivity analysis



6. The economic budget of a ranch



7. Viewing erosion and biomass prediction in map



8. Viewing the Abatement cost curve

Figure 4. Screenshot of major analysis web pages

5. DISCUSSION

Development of a TMDL is complex in choosing the best ones from many BMP options for watershed conservation. This paper presents an prototype SDSS to aid the selection of BMPs for sediment control. The SDSS allows user to edit BMP input layers in a web map. Such functionality was not implemented in current web-based DSS. This SDSS used an optimization model to choose the best spatial management of rangeland from economic and sediment objectives. With these functionalities, this SDSS allow users to perform watershed analysis in a web browser. Future improvement and testing of the SDSS is needed, notably to support more BMP types and provide high quality outputs to support TMDL development.

6. CONCLUSIONS

This paper presents a web-based SDSS that supports economic analysis on a rangeland watershed. The web-based system supports data sharing as well as data separation. Users can perform watershed analysis in a web browser without considering the technical details of geospatial analysis and modelling. The SDSS is a prototype SDSS that is expected to be extended to supporting more functionality with future watershed modelling advances.

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REFERENCES

Bathurst, J.C., J. Sheffield, X. Leng, and G. Quaranta. 2003. Decision support system for desertification mitigation in the Agri-basin, southern Italy. *Physics and Chemistry of the Earth*. Vol. 28(14-15), pp. 579-587.

Beaulieu, J., D. Bennett, S. Kraft, and R Sengupta. 1998. Ecological-economic modeling on a watershed basis: a case study of the cache river of the southern Illinois. *Ann. Meetings of the Amer. Assoc. of Agr. Econ.*, 1998.

Beaulieu, J., Bennett, D.A., Kraft, S.E. 2000. Ecological-economic modeling on a watershed basis: lessons from the Cache River of southern Illinois. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4):

Problems, Prospects and Research Needs. Banff, Alberta, Canada.

Brooke, A., D. Kendrick, A. Meeraus, R. Raman. 1998. GAMS: a user's guide. GAMS Development Corporation, Washington, USA.

Duan, Y. 2005. A Spatial Decision Support System for Economic Analysis of Sediment Control on Rangeland Watersheds. Ph.D. Dissertation, the University of Arizona, 266p.

Engel, B.A, J. Choi, J. Harbor, and S. Pandey. 2003. Web-based DSS for hydrologic impact evaluation of small watershed land use changes. *Computers and Electronics in Agriculture*. Vol. 39(3), pp. 241-249.

He, C. 2003. Integration of geographic information systems and simulation model for watershed management. *Environmental Modelling & Software*. Vol. 18(8), pp. 809-813.

Jensen, A.L., P.S. Boll, I. Thysen, and B.K. Pathak. 2000. PI@nteInfo® — a web-based system for personalised decision support in crop management. *Computers and Electronics in Agriculture*. Vol. 25(3), pp. 271-293.

Ludwig, R., W. Mauser, S. Niemeyer, A. Colgan, R. Stolz, H. Escher-Vetter, M. Kuhn, M. Reichstein, J. Tenhunen, A. Kraus, M. Ludwig, M. Barth, and R. Hennicker. 2003. Web-based modelling of energy, water and matter fluxes to support decision making in mesoscale catchments - the integrative perspective of GLOWA-Danube. *Physics and Chemistry of the Earth*. Vol. 28(14-15), pp. 621-634.

Pandey, S., R. Gunn, K.J. Lim, B. Engel, J. Harbor. 2000. Developing a Web-enabled tool to assess long-term hydrological impacts of land-use change: Information technology issues and a case study. *Computers and Electronics in URISA*. Vol. 12(4), pp. 5-17.

Prato, T., C. Fulcher, S. Wu, J. Ma. 1996. Multiple-objectives decision making for agroecosystem management. *Agricultural and Resource Economics Review*. Oct. 1996, pp. 200-212.

SWRC. 2003, Walnut Gulch Experimental watershed. http://www.tucson.ars.ag.gov/WGBrochure_2003_FinalDraft.pdf

Teegerstrom, T. and R. Tronstad. 2000. Cost and return estimates for cow/calf ranches in five regions of Arizona, Cooperative Extension, Pub. AZ1193.

Duan, Y., P. Heilman and D.P. Guertin. 2006. An Optimization of Grazing Management for Watershed Sediment Control. In *Proceedings of IEEMS meeting, 2006, S14 (Submitted)*.