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A web-based GIS Decision Support System for managing and planning USDA's Conservation Reserve Program (CRP)

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Abstract

The Conservation Reserve Program (CRP) is one of the largest programs of the U.S. Department of Agriculture (USDA) aimed at encouraging farmers and ranchers to address soil, water, and related natural resource issues on their lands in an environmentally sustainable manner. This paper outlines the design and development of a prototype web-GIS Decision Support System (DSS), CRP-DSS, for use in resource management and assessment of environmental quality. Specifically, the DSS is targeted toward aiding USDA to better manage and plan CRP enrollments. The DSS is based on the emerging industry-standard ArcIMS GIS platform and integrates a mapping component AFIRS (Automated Feature Information Retrieval System) and a modeling component SWAT (Soil and Water Assessment Tool). Our novel integrated web-GIS DSS is implemented using web server and Java Servlet technology over an ArcIMS platform to support data access and processing in a distributed environment. AFIRS functions as a feature extraction protocol that uses multisource geospatial data sets and SWAT serves to simulate long-term trends of soil and water quality. The prototype DSS was applied to simulate the sediment and nutrient dynamics of a small watershed in the Oklahoma Panhandle. We intend to develop the prototype CRP-DSS into a full-fledged tool geared to enable USDA better manage and plan future CRP enrollments.
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Keywords: Decision Support System; Web-GIS; Environmental modeling; USDA CRP evaluation

Software availability

Name of product: CRP-DSS.
Coding language: Java (J2SE).
Software requirements: ArcGIS (9.0), ArcIMS (4.0), MS SQL server.
Hardware requirements: PCs with Windows.
Availability: Prototype.

1. Introduction

Continued human population growth and increasing demand for sustainable agriculture underscore the need for restoration of degraded cultivated soils (Doran and Parkin, 1994). Important soil restoration goals include reducing erosion, enhancing soil structural stability, and increasing soil nutrient conservation (Baer et al., 2000). United States Department of Agriculture (USDA)'s Conservation Reserve Program (CRP) seeks to encourage farmland owners to adopt sustainable management practices. Under the CRP, agricultural producers voluntarily retire environmentally sensitive land for 10 to 15 years. In return, USDA's Commodity Credit Corporation makes annual rental payments to producers and shares the cost of establishing approved conservation practices (USDA-NRCS, 2002). This

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contractual program encourages farmers to plant long-term resource-conserving vegetative covers to improve soil, water and wildlife resources. The recently announced Farm Bill 2002 further enhances the CRP program by increasing the acreage cap of 36.4 million acres to 39.2 million acres (USDA-NRCS, 2002). Furthermore, the USDA is fulfilling its commitment to soil, water, and habitat quality by issuing $1.7 billion in CRP payments to participating producers for the fiscal year 2005, allowing producers to earn an average of $4143 per farm enrolled (USDA News Release, 2005). The State of Oklahoma ranks 12th in the nation regarding acres enrolled with rental payments of more than $33 million. As of November, 2005, the total CRP in Oklahoma from 1987–2003 is 428,583.26 hectares (1,059,066.7 acres) and Texas County ranks the first in Oklahoma in terms of CRP acreage. Total CRP in Texas County from 1987–2003 is 88,045.33 hectares (217,567.7 acres) and accounts for up to 20.54% of all Oklahoma acreage (USDA-FSA, 2005).

Farmers and crop consultants in general, and legislators, economists, and scientists in particular are challenged with important decisions pertaining to the environmental objectives of the CRP (Young et al., 1994; Skaggs et al., 1994). Additionally, with about 16 million acres expiring in 2007 important, important decisions and management policies need to be formulated to continue the benefits of CRP (USDA-CCC, 2004). It is essential that accurate and timely decision-support aids and research tools are developed to help evaluate and justify the environmental benefits that accrue as a result of enrolling in the program. Currently, the USDA-Farm Service Agency uses the Environmental Benefit Index (EBI) as a rudimentary decision support tool to rank land offered for enrollment to in the CRP during the general signup period (Farm Service Agency, 1999). Scores are assigned based on expected environmental improvement in soil and water quality, wildlife habitat, and other resource concerns for the duration the land is to be enrolled in the program. A major drawback of this ranking system is lack of an objective and scientific analysis of the environmental benefit index. More of the factors that govern the assignment of the score for the lands that are bid are derived from the soil databases. USDA will be greatly benefited by a Web-enabled DSS to manage, plan, and prioritize CRP enrollments in a distributed environment.

There is no dearth of literature pertaining to the use of geospatial technologies such as remote sensing and Geographic Information Systems (GIS) in land use land cover (LULC) mapping (Fitzpatrick-Lins et al., 1987; Baldridge et al., 1975), including CRP tracts (Egbert et al., 1998). Most LULC studies make use of single source data, which although is cost-effective from a data acquisition standpoint, necessitates making compromises in the thematic detail and classification accuracy (Whistler et al., 1995) Applications that use multisource GIS data; e.g., elevation, slope, soil, and other ancillary data, have reported substantial improvements in the classification accuracy over techniques that use a single source data by providing stronger correlation between geospatial data and features of interest (Fuller and Parsell, 1990; Price et al., 1997). In the recent past, newer approaches to image classification have evolved including Decision Tree Classifiers (DTC), which involves a multistage approach to breaking up a complex feature class decision into a union of several simpler decisions (Safavian and Landgrebe, 1991; Dattatreya and Kanal, 1985; Quinlan, 1990; DeFries et al., 1998; Friedl and Brodley, 1997; Hansen et al., 2000). Our research effort is directed towards an automated system that implements a DTC approach to multisource image classification for CRP mapping.

Simulation models, which evaluate impacts of human activities on the natural environment, can efficiently and effectively exploit the immense potential of GIS and remote sensing technologies. Since all the basic units (water, soil, and air) in environmental modeling do have a spatial distribution, which does affect the processes and dynamics of interaction considerably, GIS has a lot to offer to environmental modeling (Fedra, 1993). GIS becomes a useful tool to not only manage large database that include remotely sensed data, but also facilitate extraction of spatially varying parameters as input to simulation models. GIS has successfully integrated with environmental models such as AGNPS (Young et al., 1987; He, 2003), ANSWERS (Beasley and Huggins, 1982), QUAL2E (Yang et al., 1999; Srinivasan and Arnold, 1994) and EPIC (Rao et al., 2000), BASINS (Lahlou et al., 1998) and SWAT (Di-Luzio et al., 2002). We will apply a hydrologic model, SWAT (Soil and Water Assessment Tool) to evaluate some of the environmental benefits of the CRP.

Numerous studies in the past have documented the need and benefits of integrated decision support systems for various environmental applications (Miller et al., 2007; Santhi et al., 2005; Koormann et al., 2005; De and Bezuglov, 2006). Although, these systems incorporate efficient data management systems and provide user-friendly interfaces, there is a need to implement GIS-based modeling systems that are interoperable across the Internet (Denzer et al., 2005). Developments in Internet technologies make it possible for geographically dispersed groups to access and process spatial information that is distributed across the Internet on different platforms. Decision makers can now have real-time (or near real-time) access to critical, accurate, complete and up-to-date spatial data held in multiple data stores that may not be managed or maintained by them (Miller et al., 2002; Marcdavid et al., 2001; Tan, 2002; Prato, 2003). Web-based GIS technologies, although in their infancy are mostly geared toward data dissemination with little or no online analytical capabilities. Our project aims to create a prototype Web-based GIS DSS equipped with a full range of analytical capabilities involving GIS and image data to aid in the CRP decision-making process. More importantly, our system will be able to access distributed data including access to multi-resolution remote sensing data, i.e., Landsat and MODIS, and multi-source GIS data. This will allow for differential CRP mapping at different levels, leading to efficient and effective CRP management, plan, and optimization at both county-level and state-level. We aim to develop a prototype CRP-DSS that will be integrated with Internet, GIS technologies, and distributed datasets.

In this paper, we describe the functionality and implementation of a single, seamless interactive system that fully integrates an image classification tool, AFIRS and a hydrologic-crop management model, SWAT within ArcIMS (ESRI, 2005a,b), to function as an efficient and effective tool for managing and evaluating the CRP. The integrated modeling system developed is only a prototype system implemented in a distributed computing environment. This prototype system allows us to study some fundamental issues that will be essential to develop the real CRP-DSS in the future.

2. Integrated modeling system

A system framework is designed and developed integrating AFIRS and SWAT using the industry-standard Internet mapping software, ArcIMS (Fig. 1) to function as a decision support system for CRP management and planning. The integrated system, CRP-DSS, developed for a standard internet browser, essentially provides a user-friendly interface to access and execute processes involving AFIRS (feature extraction, CRP mapping) and SWAT (hydrological modeling including estimating runoff and sediment yield). The integration involves identifying the different files (AFIRS input files, and SWAT parameter files) that are needed for image processing and model execution. These data sets reside on three different servers i.e. OSU-VCIPL, OSU-CARS, and OSU-TULSA at different locations. This integration is enabled using ArcIMS as the framework for data access and display. The selection of ArcGIS for data preparation and ArcIMS was based solely upon the functionality and growing popularity of these software packages within both the public and private sectors. The following paragraphs describe in detail the design and functionality of the prototype CRP-DSS.

3. CRP-DSS

CRP-DSS (Fig. 2) consists of different tools available in an ArcIMS environment depending on whether the user is interested in analyzing data using AFIRS or SWAT modules. The user can select the AFIRS tool for classifying image data using the multi-source spatial data. When the user selects the SWAT tool, model specification and model run components are enabled. Other tools provided in the interface include the Area Selection Tool and the Output Display Tool. The following paragraphs describe the important system component within CRP DSS.

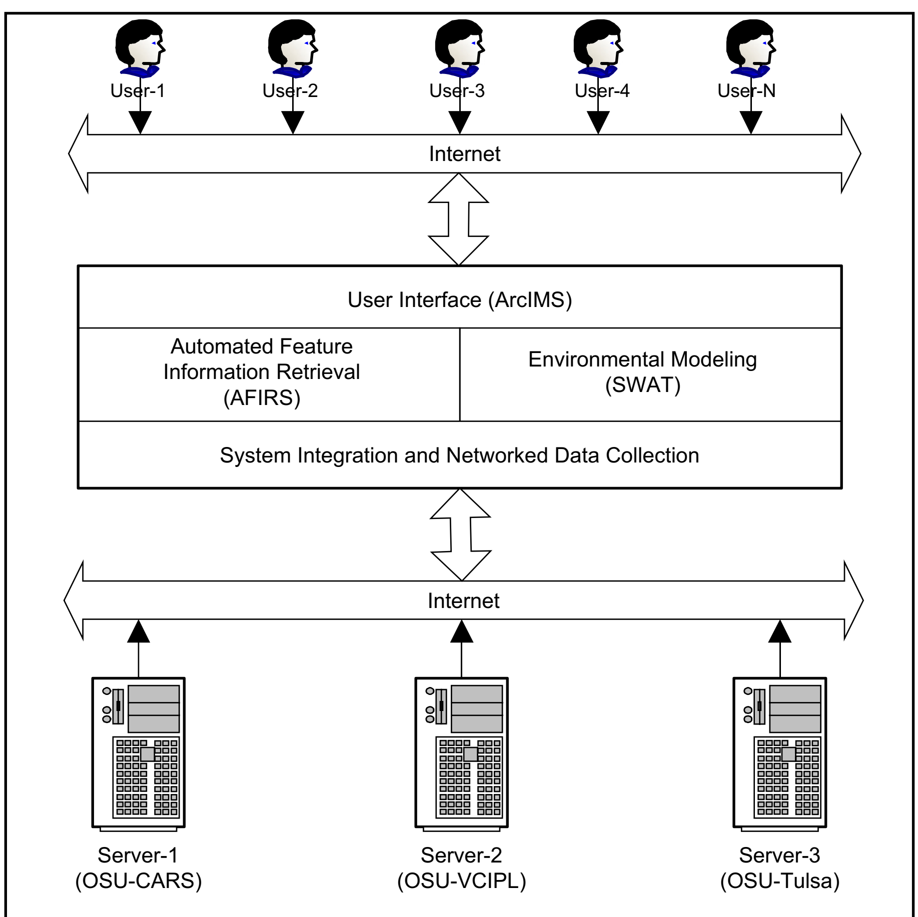

Fig. 1. Integrated system components of the CRP-DSS.

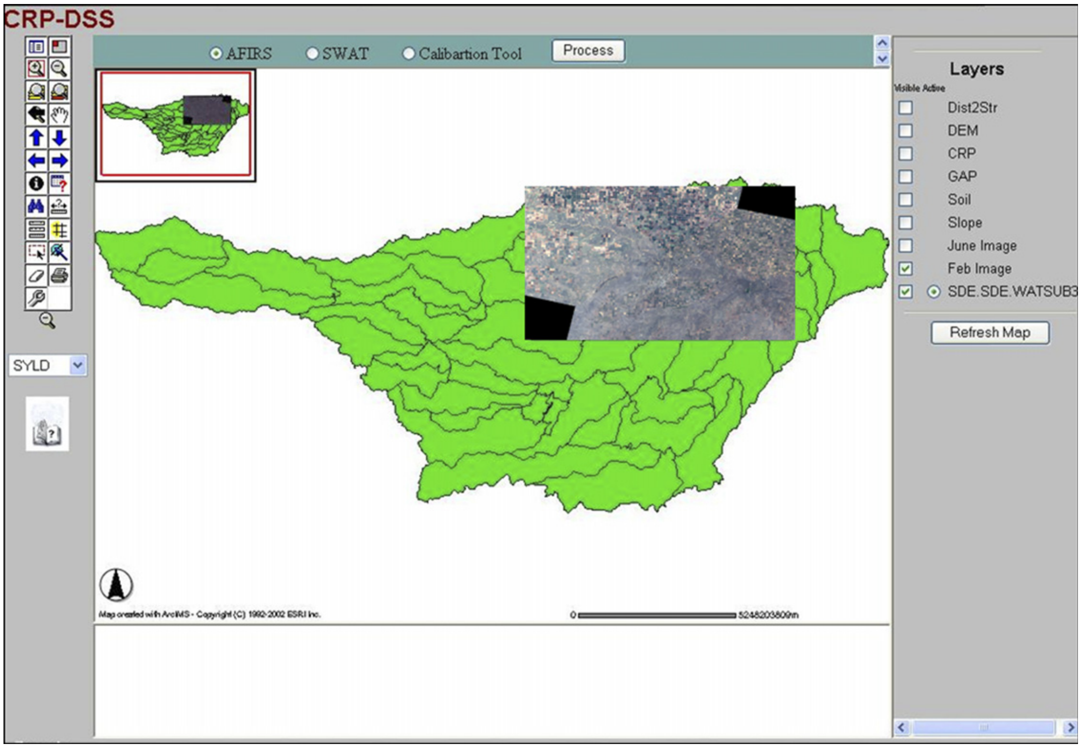

Fig. 2. Graphical user interface of the CRP-DSS.

4. Integrated system components

4.1. Automated feature information retrieval system (AFIRS)

In this project, an automated feature information retrieval system (AFIRS) as a semi-supervised image segmentation process was developed for CRP feature delineation and extraction using sampled reference data. Multisource GIS data were used; e.g., elevation, slope, and soil, etc., all of which have been reported as useful in improving classification accuracy over a single source data (Fuller and Parsell, 1990; Egbert et al., 1995; Fegan et al., 2001). The decision tree classification method can combine both categorical data (e.g. soil) and non-categorical data (Landsat or MODIS, evaluation and slope) by developing a set of classification rules based on the training data (Mitchell, 1997).

Decision tree classification (DTC) techniques have been successfully applied for a wide range of classification problems, but only recently been tested in detail by the remote sensing community (Safavian and Landgrebe, 1991) including MODIS data (Lloyd, 1990). These techniques have substantial advantages due to their flexibility, intuitive simplicity, and computational efficiency in the classification procedures. In addition to digital satellite imagery, various spatial GIS data (elevation, slope, and soil data, etc.) from different sources may be available that can provide some complementary information about a particular feature or phenomenon. Many approaches have been proposed to perform the efficient classification of multisource data by developing a consistence among a collection of observed datasets. It was shown that significant improvements on the classification accuracy could be achieved by using multisource data.

The DTC is a tree-structured classier built from a training data set, representing rules underlying training data with hierarchical and sequential structures that recursively partition the data. In this work, the C4.5 DTC is applied to CRP mapping (Quinlan, 1990). It is constructed based on the information gain ratio criterion, which measures the increase in class purity. Beginning from the root node, the C4.5 performs a top-down search through the complete hypothesis space until the stop criterion is met. A post-pruning approach called error-based pruning (EBP) (Esposito et al., 1997) was used to mitigate overfitting problems, as a result of the DTC training process. The reader is referred to Song et al. (2005) for additional details on this method.

4.2. Soil and Water Assessment Tool (SWAT)

The CRP-DSS also integrates a hydrologic/water quality model, SWAT. The Soil and Water Assessment Tool (SWAT) model is public domain software developed by the USDA-Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas. SWAT is a continuous-time model that operates on a daily time step to predict the impact of management on sediment, water and agricultural chemical yields in large ungaged basins (Arnold et al., 1998). SWAT model uses readily available inputs (elevation, land use/land cover, soil, etc.) and it is computationally efficient, and thus operates on large basins in a reasonable time. SWAT is a physically based model capable of simulating long periods of management operations. It is a distributed hydrologic model that allows a watershed to be subdivided into smaller subbasins to incorporate spatial detail. More detailed modeling could be achieved in SWAT with the concept of the Hydrologic Response Units (HRUs), which divide a subbasin into units with unique land use and soil type. The derivation of HRUs captures the variability within the subbasin. Processes in each individual HRU are calculated independently, and the output for the subbasin is the sum of all HRUs it contains. The model simulates watershed hydrology in two phases i.e., land and the routing phase. The land phase accounts for the amount of water, sediment, nutrients, and pesticides loading to the main channel of each drainage area, while the routing phase determines the transport of water, sediment, and chemical from the stream network to the watershed outlet. Additional details about the SWAT model can be obtained from Arnold et al. (1998) and Neitsch et al. (2000). Numerous studies involving soil and water resources (Arnold et al., 1998; Alexander et al., 2001; Jayakrishnan et al., 2005); have calibrated and validated the SWAT model with a high degree of accuracy, and hence this model was selected for this research project.

5. Integrated framework and development

Fig. 3 shows the schematic representation of the basic architecture of the integrated CRP-DSS modeling system. As can be seen, the system tightly couples the AFIRS and the SWAT modules within an ArcIMS environment.

This system has three main sections. At the user end, our aim is to provide a user- friendly interface for map viewing, inputting user specifications and allowing the user to remotely access and interact with ArcIMS and AFIRS/SWAT. At the

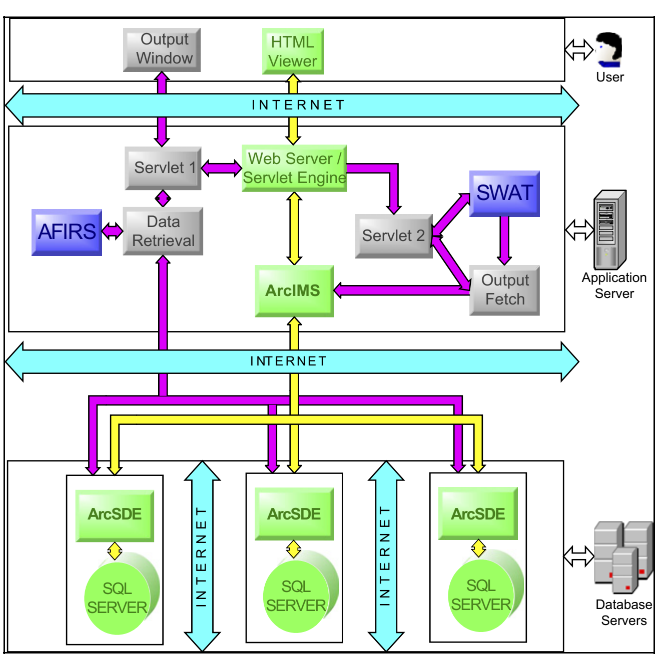

Fig. 3. Basic architecture of the CRP-DSS.

application server, the aim is to provide seamless integration of ArcIMS, SWAT, AFIRS and GIS data stores. The application server includes a data retrieval system developed using Java servlets. The servlets were supported using an Apache Tomcat Server. The servlets communicate using a HTTP network protocol with the client web browser (Fig. 3). Although security implications are a major issue, we have not considered it here in this project, and it is an area of future research. Java provides a number of advantages – Java is simple, for example when compared to other popular programming languages such as C++. It is also object-oriented and suitable for a distributed environment, which is essential for our work. Other advantages include that it is robust and secure. As Java is interpreted it is platform independent which means it will run on different hardware and operating system unlike other tools. It is more portable and also provides multithreading. Protocols were implemented for data retrieval and conversion for both AFIRS and SWAT, and also for output data visualization. The servlets efficiently control the sequence of execution of different processes for both AFIRS and SWAT, and provide the vital link between the user interface and the other modules with the integrated system. Furthermore, the servlets also perform the co-ordinate transformations and clip verification to make sure that the selected region for feature extraction and modeling is within the image to be clipped.

A web server handles requests and responses from the user end. The webserver first receives the request from the web browser. Depending upon the request, either the ArcIMS server is directly invoked or SWAT/AFIRS is activated which then calls the ArcIMS server. When the request is directly sent to the ArcIMS server, the ArcIMS server generates a map for the request and the web server sends back the map as images to the browser. Both AFIRS/SWAT are invoked remotely and executed online to process the region-of-interest selected by the user. Then the outputs of AFIRS and SWAT are stored locally for further use. The local storage allows the user to document the results or to generate faster displays and data visualization. Compared to pure on-line processing, this approach substantially improved performance of user access.

Alternatively, if the request goes to SWAT/AFIRS then, based on the coordinate parameters, the ArcIMS server retrieves the geodata associated with that region from the database. The data retrieval system forwards the data along with user input parameters to AFIRS/SWAT. After the execution of SWAT/AFIRS, the output is sent to the remote user in the form of a map added to the user browser as a dynamic layer.

The databases residing in different servers in the networked environment at physically different locations (Tulsa, OK and Stillwater, OK) were developed using MS SQL Server 2000, and the data were stored in a Geodatabase which is an efficient format for both raster and vector GIS data types. ArcSDE was used to manage the distributed database across the internet and ArcCatalog for data preparation. ArcSDE is used as the middle tier to coordinate between ArcIMS and the SQL server. The purpose of the multi- server system is to improve performance by creating multiple databases to store large raster and vector data. Furthermore, the failure to access the data from one database will not cause a system failure as the system can still function using the data from other databases.

The entire system is based on the ArcIMS (ver 4.0) platform (ESRI, 2005a,b) which consists of the ArcIMS Application Server, the ArcIMS Service (image service) and the HTML Viewer.

5.1. AFIRS tool functionality

The AFIRS tool automatically extracts features of interest based on decision tree algorithm that utilizes a multisource database involving GIS and multispectral image data. Using the Area Selection Tool, the user has the option of drawing a box in the data viewer to select a subset of the study area for image classification. The Area Selection Tool is essentially a JavaScript that extracts the defining coordinates of the bounding box drawn by the user in the viewer window. Using the coordinates, a clipping algorithm is executed to cookie-cut the raster data and vector data sets. Basically, the coordinates are converted to pixels, and using SDEraster command available in ArcSDE, a subset of the multisource data is extracted in ESRI Band Sequential (BSQ) format. With the help of Geospatial Data Abstraction Library (GDAL) commands the multisource data is converted into raw format (32-bit floating point) for analysis with AFIRS.

AFIRS analyzes the multisource geospatial database (Fig. 4) including the reference data for CRP. The reference data provides the training sites for the AFIRS algorithm. Subsequent to image processing by the AFIRS module, the results depicting the extracted features are obtained in a 32-bit format, and later converted to PNG format for display in ArcIMS. Fig. 5 shows the result of AFIRS execution which includes an RGB display of the clipped image, and the AFIRS analysis with some added morphological processing to improve output visualization. Additionally, the accuracy of the AFIRS image classification is provided in terms of three accuracy indices (Lillesand et al., 2004) i.e. Overall accuracy (Pa), Users accuracy (Pb), and Producers (Pc). The overall accuracy relates to how well the classifier delineates different feature classes in the image. The user's accuracy indicates the probability that a sample from land cover map actually matches what it is

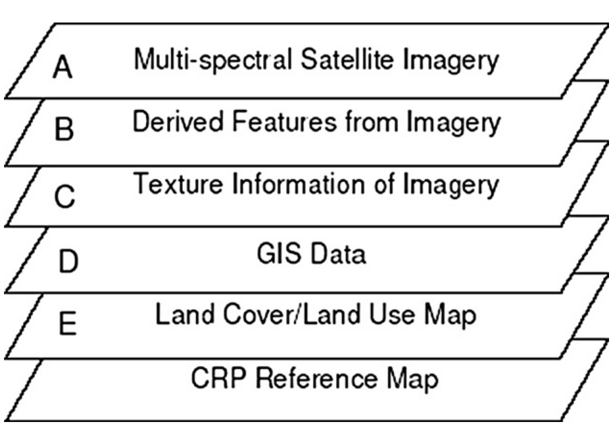

Fig. 4. Multisource Geospatial Database used in CRP-DSS.

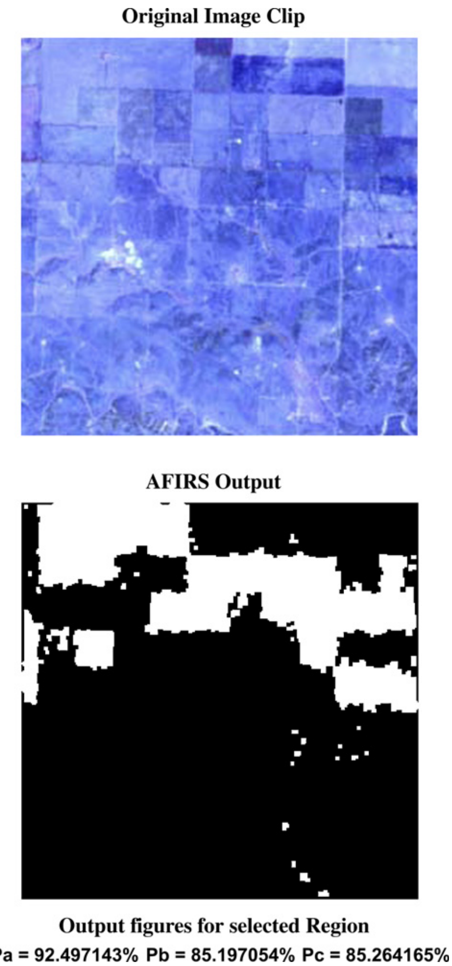

Fig. 5. A display of AFIRS output for the user-specified area. Bright areas indicate CRP pixels, while dark areas indicate non-CRP pixels.

from the reference data. In contrast, the producer's accuracy relates to the probability that a reference data will be correctly mapped. Additionally, it is important to interpret the accuracy indices, particularly Pc in context to the non-compliance issue of the CRP program.

5.2. SWAT tool functionality

In addition to the AFIRS tool, the CRP-DSS interface provides an option to execute the SWAT model. When the SWAT module is selected, the user is prompted for certain specific inputs that pertain to model run. These include the number of subbasins to model, the simulation period, and the starting year. The subbasins are delineated based on the resolution of the elevation dataset and the user's option to select the scale (low, medium or high density of subbasins for the watershed). These parameters are written out to the control file in SWAT (basins.cod). Other parameters specific to model run are held in predefined files for the different subbasins. The user can specify the area of interest on the subbasins boundary file, using the Area Selection Tool. The SDE2Shp command of

ArcSDE is used to extract the subbasin shapefile. Also, ShapeLib, a part of GDAL is used to clip the subbasin shapefile.

Once the user successfully executes the simulation, output variables (in metric units) such as sediment yield (SYLD), Organic Phosphorus (ORGP), Organic Nitrogen (ORGN), Sediment Phosphorus (SEDP), Soluble Phosphorus (SOLP) and Nitrogen in Surface Runoff (NSURQ) can be selected for display as thematic maps.

SWAT generates simple text files as output of the simulation results. Specifically, one of the important output files, basins.bsb stores simulation results for each subbasin for each year along with the sum for all the years. A Javascript was written to parse the text file, and extract the values into specific fields of the clipped shapefile. The clipped shapefile's dbf file is opened using shapelib's.dbf API and the subbasin numbers that correspond to the model run are stored. The appropriate coordinate values are extracted and set in the coordinate field for the selected subbasins. Finally, using dynamic layer and a legend range the output is displayed taking the data from the coordinate field of the Shapefile. With the results, thus appended, thematic maps can be easily produced for the variable of interest.

6. Application of CRP-DSS

CRP-DSS was applied to map the CRP tracts and evaluate the potential sediment yield at the subbasin level for the Beaver River watershed in the Oklahoma Panhandle region.

6.1. Database development

A multisource database was developed for the AFIRS and SWAT tools. Specifically, this database for AFIRS pertains to multispectral imagery (Landsat TM), Normalized Difference Vegetation Index (NDVI), Landuse and Landcover (USGS Oklahoma GAP) topographic (USGS DEM, Slope), and soils (STATSGO). Table 1 provides additional details of the database developed. Other ancillary aspatial data required by SWAT is available bundled within the model. Based on these primary spatial data, other data sets were derived including slope, distance to stream, and NDVI. SWAT model was calibrated for the region as part of an earlier project (Rao et al., 2005).

The multisource geospatial database is composed of the Landsat TM satellite imagery, derived features, and GIS data, which are all in raster format. Altogether the multisource database comprised of 52 layers including the LULC GAP data and the CRP reference data. The structure of the database is shown in Fig. 4. The database can be treated as a multi-layer image, each image pixel is a vector that contains original measured RS data and derived features, such as texture information and the Normalized Difference Vegetation Index (NDVI). Landsat TM Bands 2, 3, 4, 5, 7 were incorporated in this database with each pixel corresponding to an area of 30 m × 30 m. Although there are only three GIS layers in AFIRS database, i.e., digital elevation model (DEM) data, slope and distance-to-waterbody, they play an important role in improving the classification accuracy and robustness (Song et al., 2005).

The GIS database and SWAT model calibrations were developed for the Beaver River watershed as part of another project (Rao et al., 2005) at the Center for Applications of Remote Sensing (CARS). This database was developed using ArcView-SWAT (Di-Luzio et al., 2002) and included topography, land use, soil, climate records, agricultural management data and stream gage records. The 30-m USGS digital elevation model (DEM) was used to delineate sub-basins which are the modeling units within the watershed (Fig. 6). The SWAT model was calibrated using weather data from two USGS gage stations within the Beaver River watershed. Stream gage data for Guymon gage station (1980 to 1992) and for Beaver River gage station (1989 to 1999) were used for calibration and validation. Coefficient of determination (R^2) values for the linear regression between the observed and simulated stream flow were 0.65 and 0.61 for the Guymon and Beaver stations, respectively, and these values were within acceptable range (Peterson and Hamlett, 1997; Arnold et al., 2000).

Table 1
Multisource geospatial database developed for AFIRS and SWAT tools in CRP-DSS

Data	Resolution/ Scale	Source	Description
Landsat TM	30 m	USGS EROS	Multispectral Image
DEM	30 m	http://www.mapmart.com	Elevation, slopes, and slope length
Land use	30 m	OSU Center for Applications of Remote Sensing (OSU-CARS)	Land use land cover categories
CRP Reference	30 m	NRCS, Stillwater, Oklahoma	The spatial distribution of the CRP sites in Texas County
Soils	1:100,000	STATSGO (NRCS Soil Data Mart)	Soil physical properties e.g. texture, bulk density, etc.
Streams	1:100,000	Oklahoma Digital Atlas	Major Streams and Rivers in Oklahoma

6.2. Model run

CRP-DSS was executed to extract CRP features using the multisource geospatial database and to simulate the

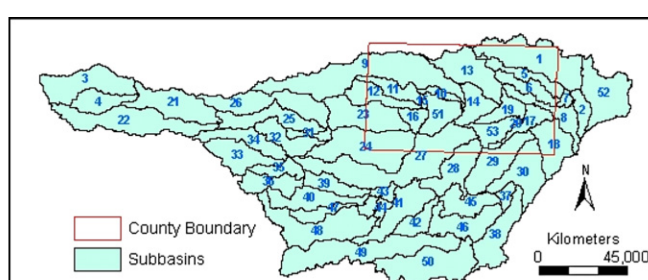

Fig. 6. The subbasins of Beaver River Watershed, Oklahoma.

long-term sediment yield in the Beaver River Watershed. After selecting the AFIRS module, an area within the Beaver River watershed was delineated using user-specified window tool in CRP-DSS (Fig. 7). Upon clicking on the 'Refresh Map' button, the AFIRS output is displayed in a simple gray-scale format depicting areas of CRP and non-CRP (Fig. 5). An accuracy estimate of the CRP is provided by accuracy assessment in terms of Pa, Pb, and Pc.

For the modeling mode of CRP-DSS, the user selects the radio button for SWAT. Some of the parameters specified included, Number of Subbasins (Medium), Number of Years of Simulation (5 years), and Starting Year (2000). After specifying the input variables (Fig. 8), the user has the option to specify the area of interest using the Area Selection tool. This enables the extraction of subbasins within the bounding box specified by the user. The user then selects the different variables of interest from the SWAT output for display as a thematic map (Fig. 8). Fig. 9 shows a sample output when sediment yield (SYLD) was selected as the variable of interest. As is evident, the western portions of the county show a significantly decreased sediment loss when compared to the eastern portions of the county. This correlates well with the distribution of CRP tracts in the county where a higher density of CRP is observed in the western portions when compared to the eastern portions. For a further discussion on the application pertaining to the evaluation of the environmental benefits as influenced by CRP, the reader is directed to Rao et al. (2005).

7. Management implications and conclusions

The system developed in the study allowed the integration of a image classification algorithm (AFIRS) and a comprehensive hydrologic-crop management model, SWAT. This integration is aimed at mapping USDA's Conservation Reserve Program (CRP) and evaluating the long-term environmental benefits in terms of soil and water quality. The use of ArcIMS and ArcSDE made possible the integration of diverse spatial data into a comprehensive database. This organized database allowed easy access and input to the AFIRS algorithm. CRP-DSS renders the simulation of field level soil-plant-water dynamics accessible to the user through a user-friendly interface. Also, visual output in the form of thematic maps for the different soil and water quality variables provide a quick and intuitive understanding of their spatial distribution. Based on the simulated results pertaining to the different soil and water quality variables, it is possible to target lands for CRP enrollments. Thus, USDA will greatly benefit by such a tool in their decision making and planning exercise in view of maximizing the benefits from the CRP program by enrolling lands that are in need of conservation, and at the same time optimizing the monetary costs (rental payments) associated with the program. Furthermore, USDA will have a scientific basis for justifying the long-term benefits of the CRP to congress and legislature.

The inclusion of a pull-down menu in CRP-DSS developed within the ArcIMS environment serves as the link between the user and the system. This provides an intuitive

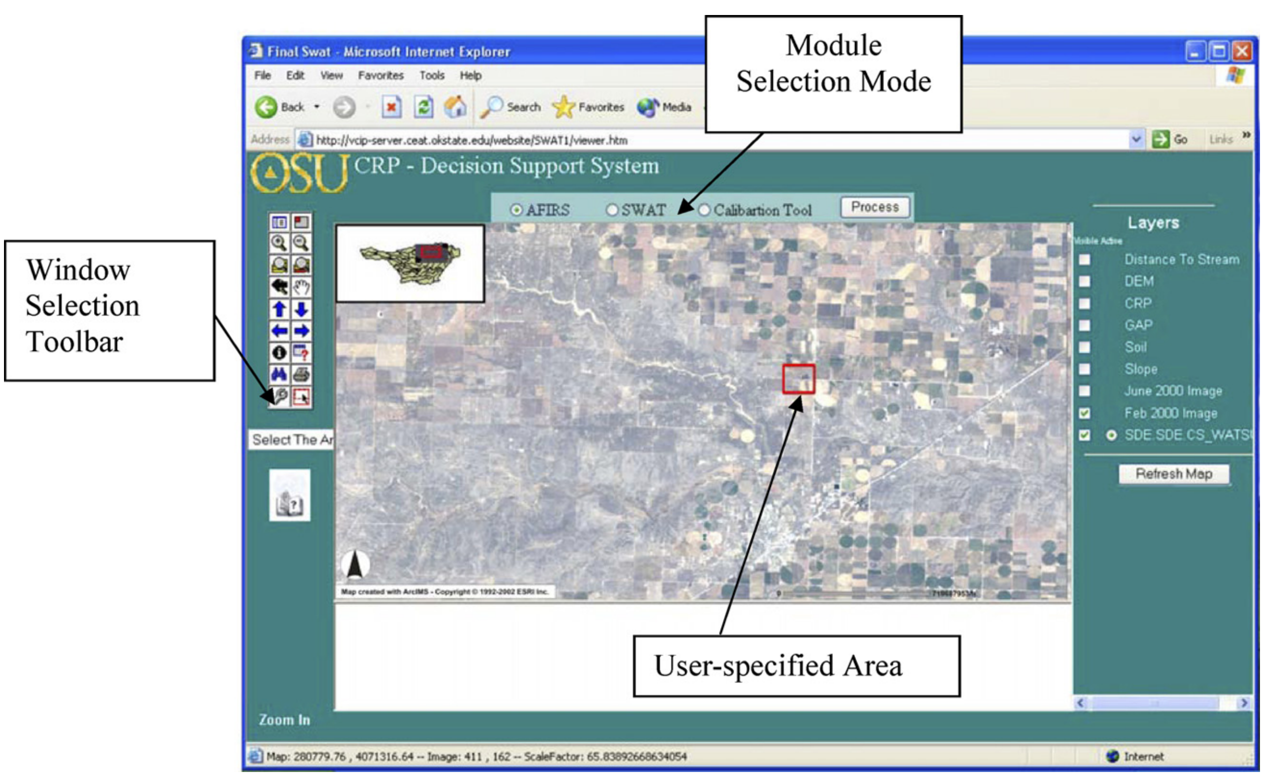

Fig. 7. User-specified processing window in CRP-DSS.

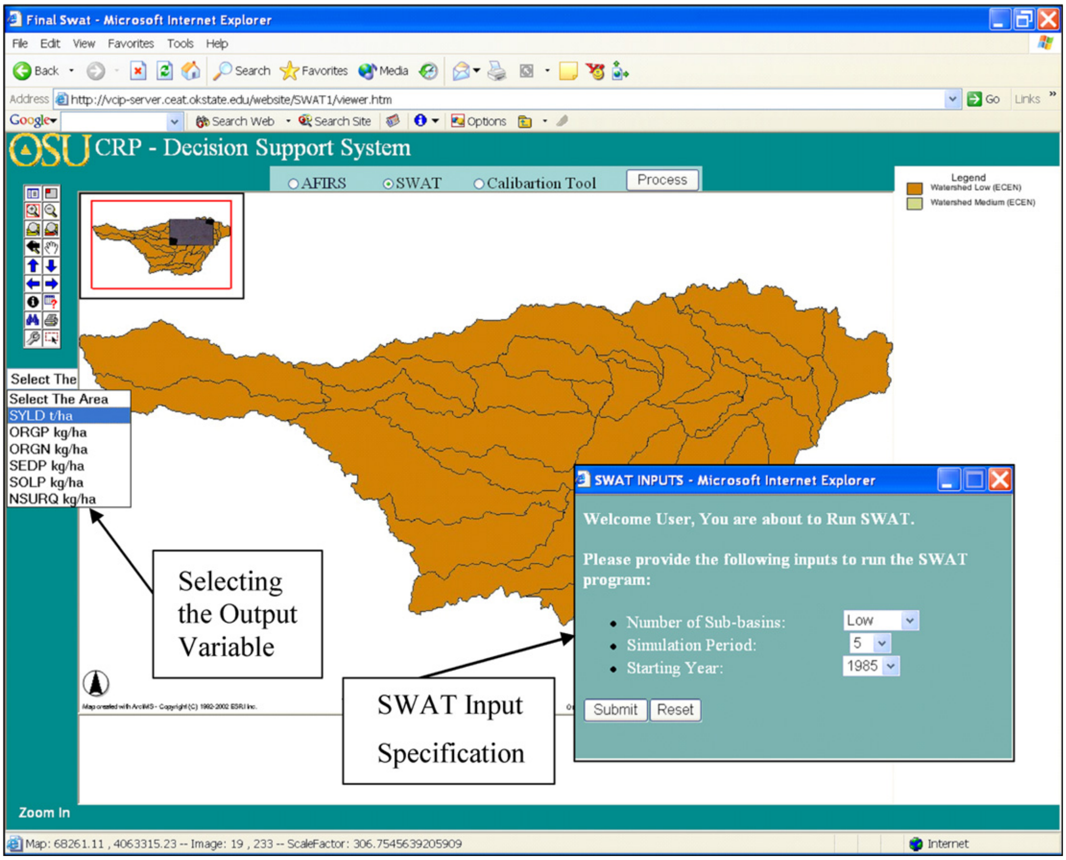

Fig. 8. SWAT input and output variable selection within the SWAT module of CRP-DSS.

and user-friendly environment to interact with the mapping (AFIRS) and modeling (SWAT) component of CRP-DSS; thus enabling users to operate the system without an in-depth knowledge of the individual components.

Integrating AFIRS within the CRP-DSS provides a robust image classification algorithm for a rapid and accurate extraction of CRP features using a multisource geospatial database. The user is also provided with an accuracy assessment of the classifier. Furthermore, CRP-DSS can provide for additional information extraction about CRP such as haying and grazing, assuming training data is available for image classification. In addition to facilitating CRP mapping, the CRP-DSS has immense potential in a compliance and regulatory role. For a $1.7 billion annual program of the USDA, the current

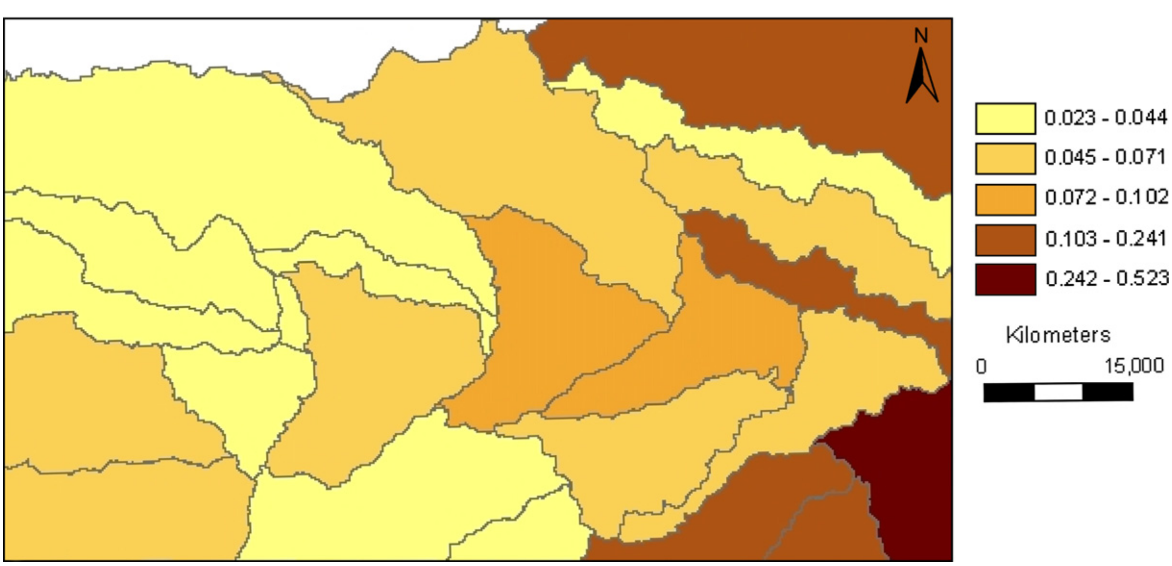

Fig. 9. Simulated sediment loss (tons/ha/year) output for the subbasins in Texas County, Oklahoma.

procedures of field verification for program compliance are cumbersome and expensive in terms of time and money expended. Moreover, our CRP-DSS in addition to addressing CRP compliance issues also has long-term potential to address non-CRP related compliance and monitoring issues such as Crop Insurance and Non-insured Crop Disaster Assistance Program.

Integrating SWAT within the CRP-DSS provides a simple framework to understand of the spatial variability of different soil and water quality variables within the context of the landscape. It is important to understand and consider the spatial relationships of different cover types and land uses that uniquely impact soil and water quality dynamics. Thus, alternate management scenarios can be studied and evaluated by altering model input parameter values, thereby functioning as a planning tool. In addition to hydrological models, other models such as ecological (i.e. habitat suitability) could be integrated into the DSS, thereby providing a more comprehensive resource management DSS.

With adequate model calibration and validation, the recommendations for best management practices should be based on long-term model runs in order to overcome variability in model input data. Since the main objective of this study was to integrate the AFIRS algorithm and the SWAT model within an ArcIMS framework, model calibration and validation were not focused upon. However, with the availability of observed data for the field, the system could be easily calibrated and validated. Efforts are underway to include a calibration tool within the CRP-DSS. Furthermore, SWAT is a widely used comprehensive model that has undergone extensive calibration, validation with demonstrated accuracy in wide applications (Di-Luzio et al., 2002). Despite lack of observed data at field scales, decision makers and planner can effectively use the CRP-DSS by simulating the relative environmental/economic benefits of CRP enrollments under a variety of scenarios. Thus, instead of an absolute perspective, a relative perspective of the effects of alternate management plans could be visualized. Nevertheless, the importance of model calibration and validation cannot be underestimated due to the site-specific nature of the data, particularly when more than relative model results are needed. It is important to realize that model adoption and use leads to subsequent understanding and familiarity with the model. It is our belief that an integrated modeling system such as CRP-DSS with its user-friendly interface will prompt users to utilize it, thus increasing the model's user community.

Additionally, the integrated system developed in this study could be a convenient tool for researchers interested in testing model performance, as data sets could be assembled in a short period of time. Thus, efficiency is improved as greater time is spent evaluating the effect of estimated parameters on model output. The framework could also serve as a building block for inclusion of additional tools geared toward better data input and output visualization, such as 3-D. The integrated system could also be an excellent teaching tool for explaining and illustrating different concepts of farm management, soil and water conservation, and systems applications in natural resources management and conservation.

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