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Bingner, Ronald; Kuhnle, Roger; Wells, Robert; Momm, Henrique; Altinakar, Mustafa; Singh, Jaswant; Shen, Dayong

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Vorgeschlagene Zitierweise/Suggested citation:
Bingner, Ronald; Kuhnle, Roger; Wells, Robert; Momm, Henrique; Altinakar, Mustafa; Singh, Jaswant; Shen, Dayong (2014): Watershed Runoff and Sediment Transport Impacts from Management Decisions Using Integrated AnnAGNPS and CCHE1D Models. In: Lehfeldt, Rainer; Kopmann, Rebekka (Hg.): ICHE 2014. Proceedings of the 11th International Conference on Hydroscience & Engineering. Karlsruhe: Bundesanstalt für Wasserbau. S. 1101-1108.

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ICHE 2014, Hamburg - Lehfeldt & Kopmann (eds) - © 2014 Bundesanstalt für Wasserbau ISBN 978-3-939230-32-8

Watershed Runoff and Sediment Transport Impacts from Management Decisions Using Integrated AnnAGNPS and CCHE1D Models

R. Bingner, R. Kuhnle, & R. Wells
US Department of Agriculture, Agricultural Research Service, National Sedimentation Laboratory, Oxford, Mississippi, USA

H. Momm
Middle Tennessee State University, Murfreesboro, Tennessee, USA

M. Altinakar, J. Singh, & D. Shen
National Center for Computational Hydroscience and Engineering, University of Mississippi, Oxford, Mississippi, USA

ABSTRACT: Conservation planning tools that consider all sources of erosion, sheet and rill, gully, and channels, is critical to developing an effective watershed management plan that considers the integrated effect of all practices on the watershed system. The Annualized Agricultural Non-Point Source pollutant loading model (AnnAGNPS) utilizes ephemeral gully evolution capabilities with sheet and rill erosion estimated from the Revised Universal Soil Loss Equation, and channel erosion components to provide an integrated assessment of sediment loads. The model was applied to a 167 ha mixed-landuse watershed near Oxford, MS. From 1982-1995, over 80% of the total sediment load was estimated from channel sources, while ephemeral gully contributions were minimal (0.7%) as a result of reduced cropland tillage practices. Fine sediment load was estimated nearly the same as observed. Sediment load from sand was overestimated nearly twice as much by AnnAGNPS, suggesting the need to apply a model, such as the National Center for Computational Hydroscience and Engineering 1-Dimensional model hydrodynamic model (CCHE1D), that describes channel evolution processes. For evaluating large watershed systems, the Agricultural Integrated Management Systems (AIMS) has been developed through the use of a web-based browser for use by watershed managers in evaluating management practice impacts on sediment load.

Keywords: Runoff, Erosion, Sediment Load, RUSLE, Gully Erosion, PEG, AnnAGNPS

1 INTRODUCTION

The development of watershed conservation management plans involves many decisions that affect various aspects of a watershed system, with consequences that are difficult to measure. Evaluations of conservation practices are often performed as individual practices with their impacts determined locally without consideration whether combinations of practices would provide a greater impact throughout a watershed system on reducing sediment loads. Often, conservation practices developed for sheet and rill erosion are also expected to prevent ephemeral gully erosion. An example is when no-till practices are implemented expecting complete erosion control, but gullies form in the field producing significant amounts of eroded sediment (Gordon et al., 2008). Recent studies indicate that ephemeral gully erosion on cropland in the U.S. can average around 40% of the sediment delivered to the edge of the field and developing the most appropriate plan to address this is a critical issue (Gordon et al., 2007). Channel erosion sources have been shown to potentially produce over 80% of the total sediment load within a watershed (Grissinger et al., 1991). Targeted implementation of integrated conservation practices devised to address the entire system, rather than isolated sources, can provide the most efficient use of conservation resources. A combination of conservation tillage, grassed waterways, riparian buffers, and instream measures may provide greater impact on reducing sediment with less impact on agricultural productivity. Integrating these and other conservation practices for sheet and rill, gully, and channel erosion would provide a better overall watershed management plan that improves agricultural production while improving water quality.

Watershed modeling technology has been developed to aid in evaluating conservation practices implemented as part of a management plan, but often lacks the capability to identify how a source, such as sheet and rill erosion, ephemeral gully erosion, edge-of-field erosion, or channel erosion, is specifically controlled by a practice or integrated practices. Various watershed technological capabilities incorporated into an integrated modeling system can be helpful in understanding how a source is controlled from one or more practices. Integrated technologies can be used to evaluate optimal combinations of integrated practices at multiple scales that would have the least impact on agricultural productivity, resulting in the greatest economic benefits, while having the most impact on improving watershed water quality. Although, without improved research studies, subjective observations will continue to be used to satisfy quality criteria in lieu of scientifically defensible, quantitative methods to estimate the impact of an integrated conservation practice approach to addressing all sources of erosion. The U.S. Department of Agriculture's Annualized Agricultural Non-Point Source pollutant loading model, AnnAGNPS, (Bingner and Theurer, 2001) has been developed to determine the effects of conservation management plans and provide sediment tracking from all sources within the watershed, including sheet and rill, ephemeral gully (Bingner et al., 2007), and channel erosion. Since the AnnAGNPS channel erosion components have no geotechnical or channel evolution capabilities, the National Center for Computational Hydroscience and Engineering 1-Dimensional hydrodynamic model (CCHE1D) (Wu et al., 2004) has been linked together using topographic analysis tools and common databases to evaluate the effectiveness of in-channel remedial and control structures on watershed sediment loads. CCHE1D provides integrated technology with AnnAGNPS for simulations of one-dimensional unsteady flows and sediment transport in dendritic channel networks.

This study provides an evaluation of the capability of the AnnAGNPS model to simulate runoff and sediment loads from multi-landuse watersheds, including an assessment of the effects of placement and integrated combinations of various conservation practices on watershed water and sediment loads from channel, gully and sheet and rill erosion sources. In addition, a prototype of an Internet-based watershed management system developed by U.S. Department of Agriculture (USDA) and NCCHE is described. This system is designed to automate the selection of a watershed and associated input parameters for use with AnnAGNPS and NCCHE tools.

2 MODELING METHODS

2.1 *AnnAGNPS*

Requests for improvements in USDA-Agriculture Research Service (ARS) technology by the USDA-Natural Resources Conservation Service (NRCS) for watershed planning use to account for management impacts from all watershed sources of sediment led to the development of the USDA AGricultural Non-Point Source pollution model (AGNPS, Bingner and Theurer, 2001). AGNPS is a joint ARS and NRCS suite of computer models developed to predict nonpoint source pollutant loadings within agricultural watersheds. The continuous-simulation, surface-runoff computer model called Annualized AGricultural Non-Point Source Pollution Model v5.4 (AnnAGNPS, Bingner and Theurer, 2001) is the main component of this suite. AnnAGNPS is designed to assist with determining best management practices (BMPs), the setting of Total Maximum Daily Loads (TMDLs), and for risk and cost/benefit analyses in mixed-land use, watershed-scale systems. The computer model has been designed to predict the origin and track the movement of water, sediment, and chemicals at any location in primarily agricultural watersheds. The model distinguishes between erosion caused by sheet and rill (from the Revised Universal Soil Loss Equation (RUSLE) v1.06 (Renard et al., 1997)), tillage-induced ephemeral gullies (Bingner et al., 2007), other gully processes, and streambed and bank sources. Results from AnnAGNPS can be used to determine the amount of each pollutant (sediment and chemical loads) at any location in the watershed; i.e., how much of each pollutant originates and arrives at any location in the watershed.

2.2 *Potential Ephemeral Gullies*

The only USDA technology available to assess ephemeral gully erosion on an agricultural field for many years has been the Ephemeral Gully Erosion Model (EGEM, Woodward, 1999). Gordon et al. (2007) extended the capabilities of EGEM through the Revised EGEM (REGEM) as a stand-alone program, by: (1) adding a new algorithm which estimates the migration rate of the headcut; (2) adding an algorithm which creates the initial headcut's knickpoint; (3) refining some of the existing EGEM components; and (4) developing additional components into a revised and further enhanced algorithm. The integration of REGEM technology into AnnAGNPS led to additional improvements to simulate tillage-induced ephemeral gully erosion including: (i) the capability to repair gullies through tillage that redefines when ephemeral gully erosion can redevelop; (ii) the influence of prior landuse as defined from RUSLE-technology; (ii) utilization of the Hydro-dynamic Universal Soil Loss Equation (HUSLE) (Theurer and Clarke, 1991) components for sediment transport determination; (iv) enhanced gully width calculations; and (v) the determination of the amount of scour hole erosion. These enhancements and the inclusion of REGEM-technology have led to the Tillage-Induced Ephemeral Gully Erosion Model (TIEGEM) within AnnAGNPS to provide a watershed-scale assessment of management practice effects on sediment production from ephemeral gully erosion within croplands.

Whether a specific location within the watershed develops into an actual gully depends on many factors including, climate, management, soil characteristics, and topography. Locations identified as having a high probability of forming gullies, based on topographic analysis, are termed as potential ephemeral gully (PEG) locations, but require certain runoff, management and soil conditions to produce gully erosion. These ephemeral gully locations are often hidden by vegetation and are difficult to identify. Defining these PEG locations throughout the watershed can be aided through the use of automated topographical analysis components included in the AGNPS suite of tools and developed based on the TOpographic PAramertiZation model, TOPAZ (Garbrecht and Martz, 1996) model. In the PEG component, potential ephemeral gullies mouths (PEG points) can be determined based on a modified Compound Topographic Index (CTI) that considers contributing area, local terrain steepness, and planform curvature (Momm et al., 2012). These points are locations along a flow path with a high probability of knickpoint formation, with the resulting headcut advancing upslope to form ephemeral gully channels.

3 WATERSHED FOR TESTING

The study site consisted of a 167 hectare mixed-landuse subwatershed of the Goodwin Creek Experimental Watershed (GCEW) located in North-Central Mississippi, USA. The GCEW is part of the USDA-ARS Benchmark Conservation Effects Assessment Project (CEAP)-Watershed Assessment Study project (Figure 1). This watershed is defined by a gage at subwatershed 14 and contains several sources of sediment, including sediment from sheet and rill, gully, and channel sources. Within this watershed, rainfall, runoff and sediment data were collected on a partial continuous basis from 1982 to the present. This study only includes 1982-1995 conditions, since sediment collection was discontinued after 1995 making simulation comparisons with observed data difficult. In 1982, the cultivated landuse was nearly 50% of the subwatershed, but by 1989 there were no cultivated land areas. This provides an excellent location to study the impact of agricultural practices on sediment load. The watershed has detailed information describing climate, elevation, soil and landuse conditions for each year of the study. Comparisons between simulated and observed data provide not only validation of the model, but also the basis for evaluating the effects of alternative conservation practices.

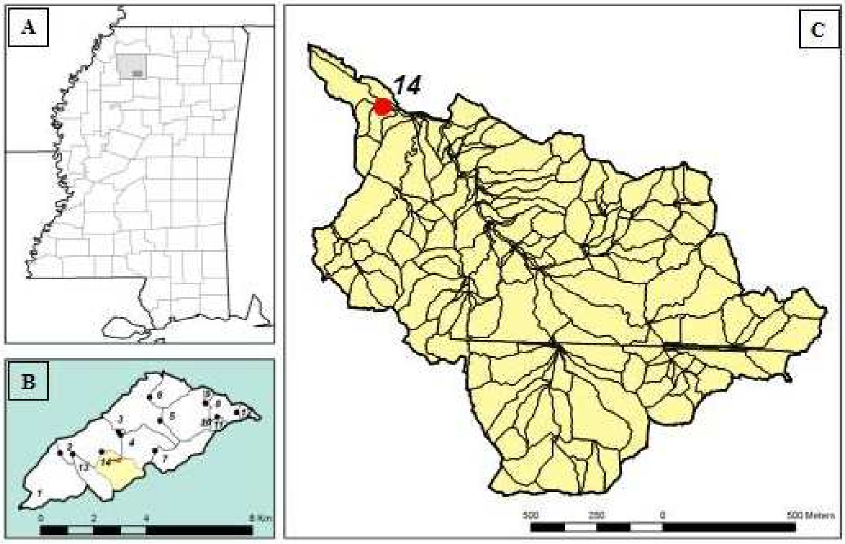

Figure 1. Geographical location of the site in the State of Mississippi, USA (A) and represents a subwatershed of the USDA-ARS Goodwin Creek Experimental Watershed (B). The subwatershed outlet was selected downstream of station 14 (C).

4 RESULTS AND DISCUSSION

4.1 *Rainfall and Runoff*

Observed average annual rainfall depth during the 1982 to 1995 period was 1360 mm. AnnAGNPS estimated annual runoff of 578 mm yr^{-1} at Station 14 was close to the observed 584 mm yr^{-1}. Simulated monthly runoff matched the observed trends, where peak runoff months coincided with peak precipitation months (Figure 2). The coefficient of determination for monthly runoff was 0.94 with a regression slope of 0.90 (Figure 3).

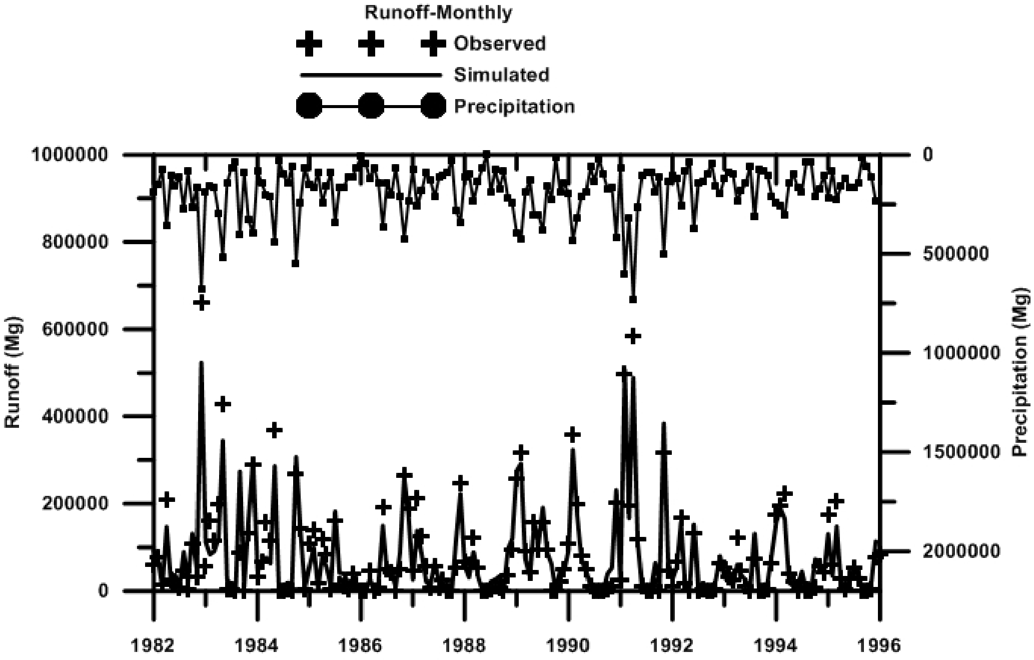

Figure 2. Monthly observed precipitation and runoff and simulated runoff from 1982-1995 at station 14 from the USDA-ARS Goodwin Creek Experimental Watershed.

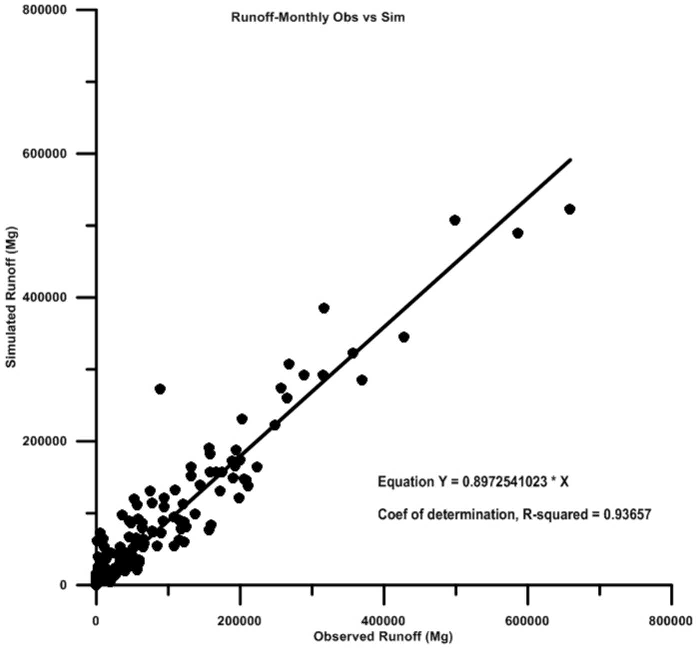

Figure 3. Monthly observed versus simulated runoff from 1982-1995 at station 14 from the USDA-ARS Goodwin Creek Experimental Watershed.

4.2 *Sediment Load*

4.2.1 *Total Sediment Load*

Average annual AnnAGNPS estimated total sediment load to the gage at Station 14 was 2700 Mg yr^{-1} compared to the observed total sediment load of 1800 Mg yr^{-1}. Simulated monthly sediment load trends matched the observed monthly sediment load trends (Figure 4). The coefficient of determination for monthly sediment load was 0.73, with a regression slope of 1.10 (Figure 5). The contributions to total load from channel sources was 81%, from sheet and rill sources was 18.3%, and from ephemeral gully sources was 0.7%. This agrees with previous studies on GCEW describing sediment load originating from channels sources as between of 75% and 85% (Grissinger et al. 1991), 64% and 79% (Kuhnle et al. 1996) for the fraction of fine and total sediment load, or 63% of fine sediment load through the use of radionuclides (Wilson et al., 2008). While there were 38 PEG points defined within Subwatershed 14, only a few of the potential gullies resulted in actual ephemeral gully erosion since the management practices for most of these locations did not disturb the soil. If management practices were to revert from pasture land to cropland many of these potential gullies then would produce erosion unless additional conservation practices were implemented such as grassed waterways.

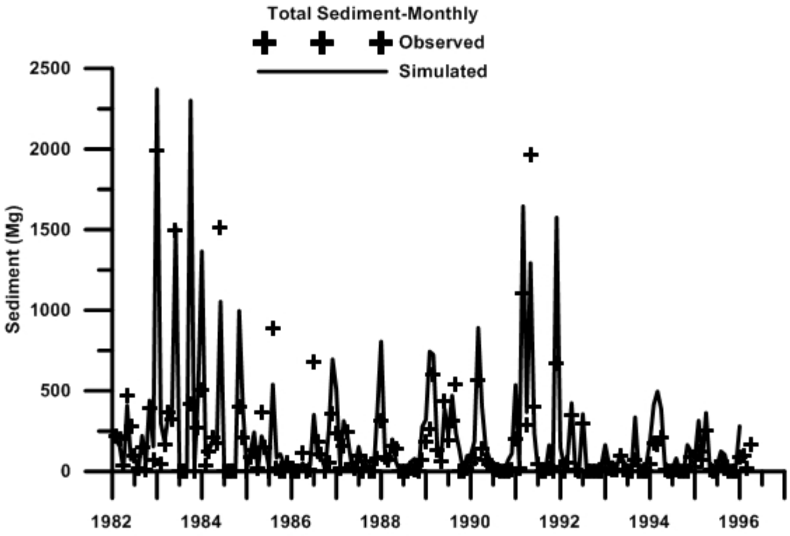

Figure 4. Monthly observed and simulated sediment load from 1982-1995 at station 14 from the USDA-ARS Goodwin Creek Experimental Watershed.

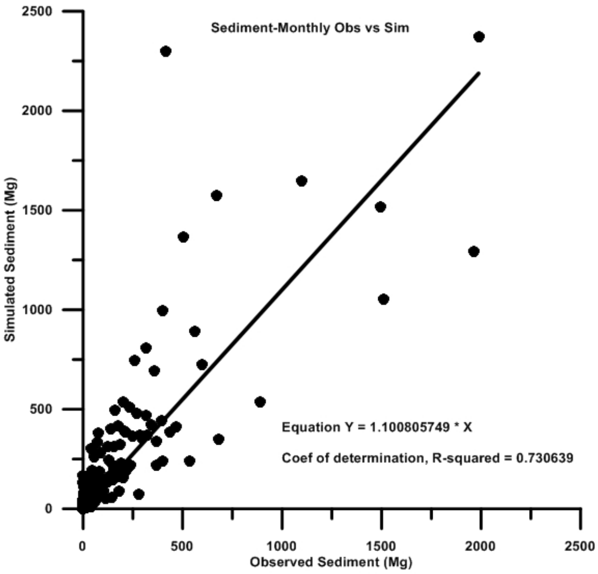

Figure 5. Monthly observed versus simulated sediment load from 1982-1995 at station 14 from the USDA-ARS Goodwin Creek Experimental Watershed.

4.2.2 *Fine Sediment Load*

The simulated average annual fine sediment load (silt and clay) at Station 14 was 980 Mg yr^{-1} compared to the observed fine sediment load of 960 Mg yr^{-1}. Seasonal influences were defined as periods from when tillage influences may be detected from April–July, August-November, and December-March. Fine sediment concentration seasonal influences appear in the simulation results associated with the April-July period (Figure 6), but the observed fine sediment load peaks appear in the December-March period. This may suggest that the sediment transported in the channel is stored from the April-July events until larger flow events occur in the December-March period to flush the channel of fine sediment. Since AnnAGNPS does not account for storage of sediment between flow events, the use of the CCHE1D model may provide a better accounting of the timing of sediment transport within channel erosion events and the evolution of the channel.

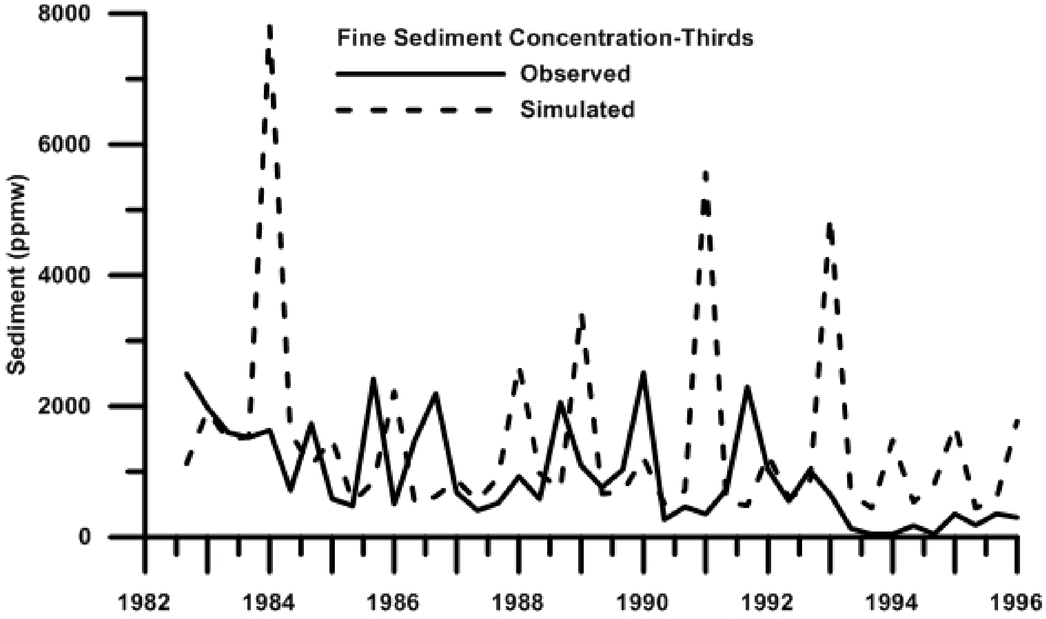

Figure 6. Monthly observed versus simulated fine sediment concentration associated with thirds of the year from 1982-1995 at station 14 from the USDA-ARS Goodwin Creek Experimental Watershed.

4.3 *Implementation of USDA-NCCHE Agricultural Integrated Management System (AIMS)*

The development of a web based Agricultural Integrated Management System (AIMS) is designed to automate the selection of a watershed and associated input parameters for use with AnnAGNPS and NCCHE tools. The AnnAGNPS model will be incorporated into an automated web-based system to facilitate the determination of watershed loadings such as runoff and sediment at sub-watershed outlet locations. This would then be coupled with the CCHE1D model for improved channel process simulations.

The long-term goal of AIMS is to develop a platform that provides secure access to a series of modules and applications covering a range of analytical capabilities in relation with integrated agricultural management. This platform will provide common and easy access to various national databases in order to facilitate input data preparation for these analytical tools associated with the target users of this technology, such as officials and watershed managers of NRCS, other federal agencies, such as U.S. Environmental Protection Agency (USEPA), U.S. Geological Service (USGS), U.S. Army Corps of Engineers (USACE), consulting companies, agriculture producers, and university scientists.

The project has two main objectives:

1. Development of an automated web-based system that will be used for evaluating the impact of agricultural and channel conservation management practices from any watershed in the USA. The users will not be required to have GIS software installed on their computer or possess GIS capabilities to assemble and process watershed data. A rapid AnnAGNPS simulation utilizing

information extracted from existing databases will provide users with an estimate of runoff and pollutant loadings at the watershed outlet.

2. Development of a geo-spatial database used for input data preparation of watershed modeling components. The DEM, soil, landuse, climate and other associated data utilized by the model for any selected watershed can be downloaded for individual application by the user on their own computer system. The developed geo-spatial database can be useful for the development of other hydraulic based models such as overland flow models. This system may also be integrated with other modeling applications such as utilized by USGS, USEPA, and others.

The AIMS project is designed for application at a larger watershed scale, such as the 12-digit Hydrologic Unit Codes (HUC) scale. Users would select a HUC 12 watershed in the web-browser to designate where the outlet of the drainage area occurs (Figure 7). The web-based program would then determine all of the AnnAGNPS input parameters based on TOPAZ defined channels and polygons and national databases to describe soils, management and climate (Figure 8). Users could then download all of the AnnAGNPS input and output files to apply additional simulations or analysis.

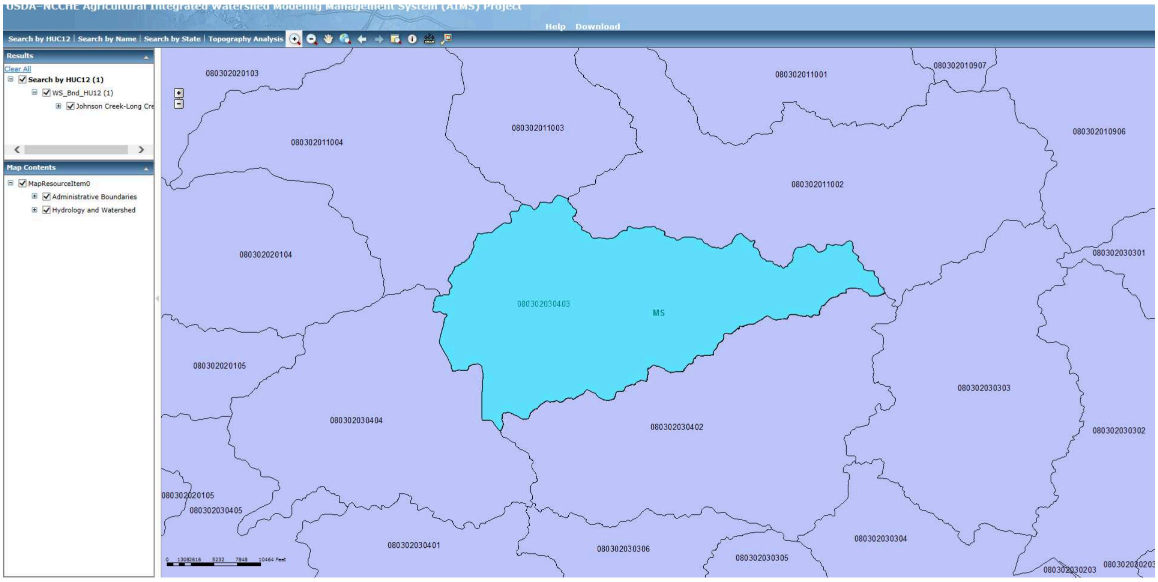

Figure 7. USDA-NCCHE Agricultural Integrated watershed modeling Management System (AIMS) online interface used to select the HUC 12 digit watershed that identifies the outlet of the watershed drainage area of interest.

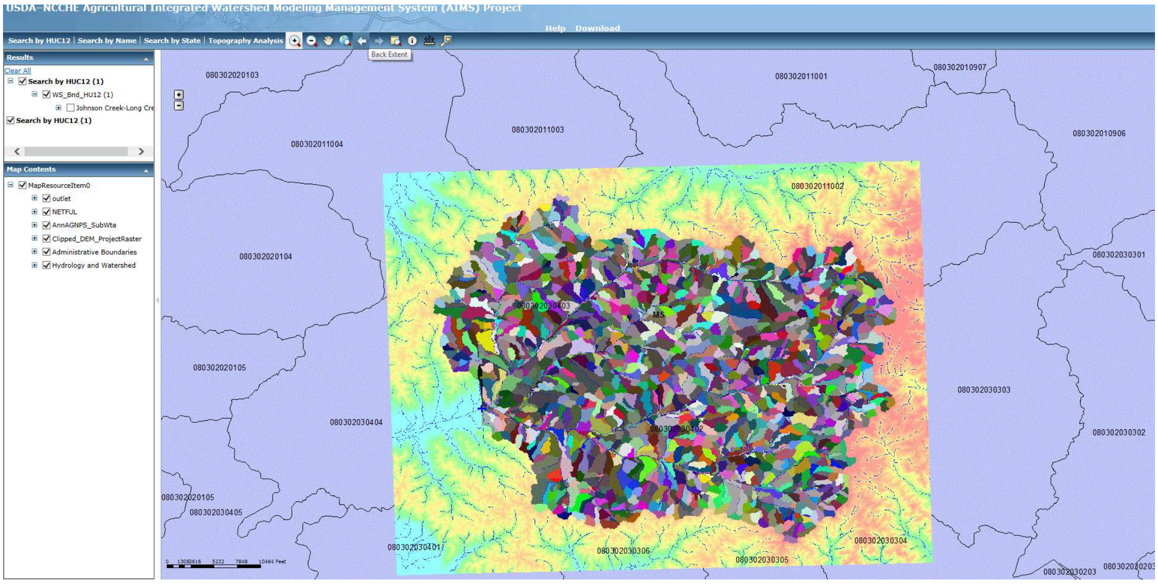

Figure 8. USDA-NCCHE Agricultural Integrated watershed modeling Management System (AIMS) online interface defined outlet (black dot) and subareas associated with outlet for the Long Creek HUC 12 watershed in Mississippi (HUC #080302030403) for use with AnnAGNPS.

5 CONCLUSIONS

The AnnAGNPS was applied to a mixed-landuse watershed where over 80% of the total sediment load was estimated to be from channel sources. Ephemeral gully contributions to total sediment load in the watershed were minimal (0.7%) as a result of reduced cropland tillage practices. The fine sediment load of clay and silt was estimated to be nearly the same as observed. Sediment load from sand was overestimated by nearly twice as much by AnnAGNPS, suggesting the need to apply a model, such as CCHE1D, that better describes channel evolution processes. Developing enhanced technology and research to assess management plans is critical for planning and implementing conservation practices specifically designed for erosion control. Improved integration of national databases describing watershed characteristics and flow are needed to provide timely information to decision makers. Expanding capabilities of computer and Internet systems using remote sensing data acquisition opportunities will continue to provide an interesting challenge to developing effective watershed planning technology. Models need to continue to incorporate the latest watershed research at the surface and subsurface scales critical for evaluating new and existing management practice impacts related to improving the health of ecosystems as water quantity and use issues become an expanding national and worldwide problem.

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