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INTEGRATION OF WATERSHED TOOLS AND SWAT MODEL INTO BASINS[1]

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ABSTRACT: BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) version 3.0, is the updated software system developed by the U.S. Environmental Protection Agency Office of Water in order to meet the requirements of developing Total Maximum Daily Load (TMDL) programs. BASINS provides an enhanced set of nation-wide databases, several new and interchangeable tools and models integrated in a new modular architecture, operating within ArcView Geographical Information System (GIS) for desktop PCs. This paper describes the integration of three new key components: (1) a tool that optimizes the automatic definition and segmentation of the watershed and stream network based on topography (Digital Elevation Models), NHD (National Hydrography Dataset) or other ancillary stream data; (2) a tool to define the Hydrologic Response Units (HRUs) over the watershed and subwatersheds; and (3) SWAT (Soil and Water Assessment Tool) model and a respective integrated user-friendly interface. The first two components, based on raster functionality, improve the previously adopted simplistic methods for the hydrologic definition, segmentation and basic geomorphic assessment of the watershed and open to the usage of external datasets besides those distributed with the whole BASINS package. In addition, these components share generating datasets, hereby promoting the usage by other tools and models as well as other models that in the future could be introduced in BASINS. The third component introduces the SWAT model into BASINS. SWAT is a hydrologic distributed model with proven success in watershed assessment of both agricultural and urban scenario management effects on water quality and is based on over 30 years of USDA modeling experience. The description of these integrated components is followed by a simple, yet promising, application to the Upper North Bosque River watershed in Texas, using the default data distributed with BASINS.
(KEY TERMS: BASINS; GIS; NPS; SWAT; DEMs; watershed delineation; ArcView.

INTRODUCTION

The severe consequences involved with runoff of excess nutrients from land fields are generally off-sight. Pieces of evidence, such as fish and marine life deaths and marshland damages from algae blooms, are often forwarded from the source locations and appear after traveling hundreds of miles along rivers, and ground water pathways, increasing loading, and concentration of pollutants. This problem affects more than one-third of the nation's coastal areas, and has spread worldwide. Severe problem areas were found along the coasts of nine states in the U.S. (U.S. EPA, 1999) as well as streams and rivers that drain inland watersheds, and carry the pollutants to lakes and coastal zones (Atlas of America's Polluted Waters) (U.S. EPA, 2000). The Atlas shows that there are more than 20,000 nationally identified waterbodies that do not meet state water quality standards, comprising more than 300,000 miles of rivers and streams, and more than five million acres of lakes. States listed these waters in their most recent submission to EPA, mostly in 1998, as required by section 303(d) of the Clean Water Act. This provision of the Clean Water Act requires the development of a TMDL for each listed water system, which is a pollution appraisal for a specific segment of the system: river, lake or stream. States review water quality conditions, and identify specific waters that are polluted, and work with local governments and interested parties in a cooperative, bottom-up process to develop TMDL programs. The ultimate goal of the program is to estimate the quantitative effort to achieve water

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quality goals and address the specific problems of a particular waterbody.

Mathematical modeling and GISs offer the potential for supporting the development of TMDLs. Hydrology based computer models provide for the understanding of complex hydrologic mechanisms, which are all significant in determining the importance of nonpoint source of pollution (NPS). GISs provide the required management of increasing volumes of spatially referenced data.

Based on this perspective, the U.S. Environmental Protection Agency's (U.S. EPA's) Office of Water, developed the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) software system. BASINS adopt ArcView as a GIS base engine and assembles watershed related databases, tools and linked mathematical models to help carry out multipurpose watershed and water-quality based analysis by regional, state, and local agencies. BASINS 3.0, the new version of the system, is setting out to continue achieving these primary goals: (1) to facilitate examination of environmental information; (2) to support analysis of environmental systems; (3) to provide a framework for examining management alternatives; and (4) to embrace a flexible modeling system able to effectively integrate assessment of point and nonpoint pollution sources at a variety of scales, using models that range from simple to highly evolved. The main objective of this paper is to describe the integration and a basic application of our three additional, fundamental components of the newly proposed BASINS framework.

BASINS 3.0 SYSTEM OVERVIEW

BASINS 3.0 provides data, GIS utilities, and models to assist in the assessment of watersheds ranging from that of a single impaired stream segment to the development of a river basin management plan. BASINS 3.0, like the previous version (Lalhou *et al.*, 1998), provides data and analysis tools in a single ArcView GIS version 3.x (ESRI, 1996a) based package to simplify and speed up the watershed and water quality based assessment process. In addition BASINS 3.0 presents a new modular system architecture in which individual functions and tools are grouped into customized ArcView extensions. A BASINS ArcView extension is a set of software objects that can be used to provide new functionality to BASINS without altering existing projects. Based on newly established design and conventions, these extensions are designed to load in ArcView and work properly only within BASINS. The implementation of these outlined extensions also permits multiple individuals to contribute without conflict to a single BASINS development effort. This allows BASINS users to load only the extensions needed for their BASINS project, replace provided upgrades available via the Internet and develop new extensions that might also be useful to the whole BASINS user group.

Based on this new functionality, BASINS 3.0 provides enhanced data and GIS tools to assist the user in analyzing observed data and extracting various useful data. Some of the existing tools have been improved, for instance the manual watershed delineation tool (Mayers *et al.*, 2001). New tools have been added, such as the online National Hydrography Dataset (NHD) (USGS and U.S. EPA, 2000) downloading tools (Mayers *et al.*, 2001), WinHSPF (Windows Hydrologic Simulation Program Fortran) (Duda *et al.*, 2001) and GenScn (GENeration and Analysis of model simulation SCeNarios) (Kittle *et al.*, 1998). However, a new key feature is the development and introduction of a composite, and advanced watershed modeling system implemented, and designed to be a set of default BASINS extensions. Two components of the watershed system allow the user to: efficiently segment the watershed and calculate several subunit geomorphic parameters from the elevation information (DEM), import, classify, and overlay land use and soil maps, and choose the optimal combination of the Hydrologic Response Units (HRUs) classes for each subwatershed. These components were implemented taking full advantage of GIS's raster vector combined functions. The third component of the watershed system offers the Soil and Water Assessment Tool (SWAT) as an alternative model for the estimate of NPS loading under various environmental conditions and in combination with measured or Permit Compliance System (PCS) loading.

The watershed system is derived from, and includes part of the functions of the developing AVSWAT (Di Luzio *et al.*, 1998), a single ArcView extension that has recently been enhanced, and developed parallel to BASINS 3.0 in order to work exclusively with the SWAT model. In BASINS the system is organized as separated, and customized extensions bringing to the user these additional functions and advantages: (1) offers the utilization of intermediate watershed databases built using extension tools distributed with BASINS and/or those which are user defined; and (2) usage of user supplied data as an alternative to the data distributed with the BASINS package.

The tools within the watershed system have been developed for the USEPA by Blackland Research Center, a Texas Agricultural Experiment Station part of the Texas A&M University System in Temple, Texas, and the SWAT model has been developed by the USDA-ARS Laboratory in Temple, Texas.

Figure 1 shows an overview of the BASINS 3.0 system highlighting the newly developed extensions which make up the new watershed modeling system described below.

BASINS 3.0 DEVELOPED EXTENSIONS

Automated Watershed Delineation (AWD) Extension

Within the BASINS framework, this component is fundamental for deriving the hydrologic geographic extent of a model application like a TMDL project. The developed extension provides a user driven, and sequentially accessible set of tools by which the user can interactively define the watershed, and stream segmentation and activate options to speed up the process in order to improve the results. Figure 2a shows the automatic watershed delineation user's interface.

Preprocessing of the DEM. In the initial basic steps, the tool applies elementary raster functions, provided by ArcView along with its Spatial Analyst Extension (ESRI, 1996b) and the derived Hydrology Extension (Kopp, 1998) to implement the standard methodology based on the eight-pour point algorithm, and the steepest descent (Jenson and Domingue, 1988) for delineating streams from a raster digital elevation model (DEM). Typical DEMs used for U.S. watersheds, which are distributed with BASINS, are the three arc second, 1:250,000-scale U.S. Geological Survey (USGS) DEMs (USGS, 1993). As is noted above, the user could utilize data from external sources, such as the higher resolution one arc second, 1:24,000 scale USGS or the developing USGS NED DEMs. The two following optional tools are provided in order to optimize the preprocessing.

Focusing Watershed Area. Since it is often the case that the processing DEM is more extended than the study area, using an included tool, the user is able to define and restrict the area in which the hydrological analysis will take place, thereby reducing the computation time. In doing so, the user can import a predefined map (either raster grid or vector shape polygon format) or draw interactively a mask over the displayed DEM.

Stream Burning and NHD Data. The integration of a vector hydrography layer into the DEM corrects certain hydrologic features of a watershed that may become obscured or oversimplified during the digital delineation process. These inconsistencies are due to the problem of map scale and the lack of adequate DEM vertical resolution in areas of low relief. There are several ways to implement this method, commonly referred to as "stream burning," and there are evidences that further investigations are needed to define the process that combines accuracy and processing efficiency (Saunders, 1999). The AWD applies one of the stream burning algorithms (Saunders, 1999) before the filling preprocess. The adopted algorithm simply assigns all stream grid cells with the elevation values from the original DEM while

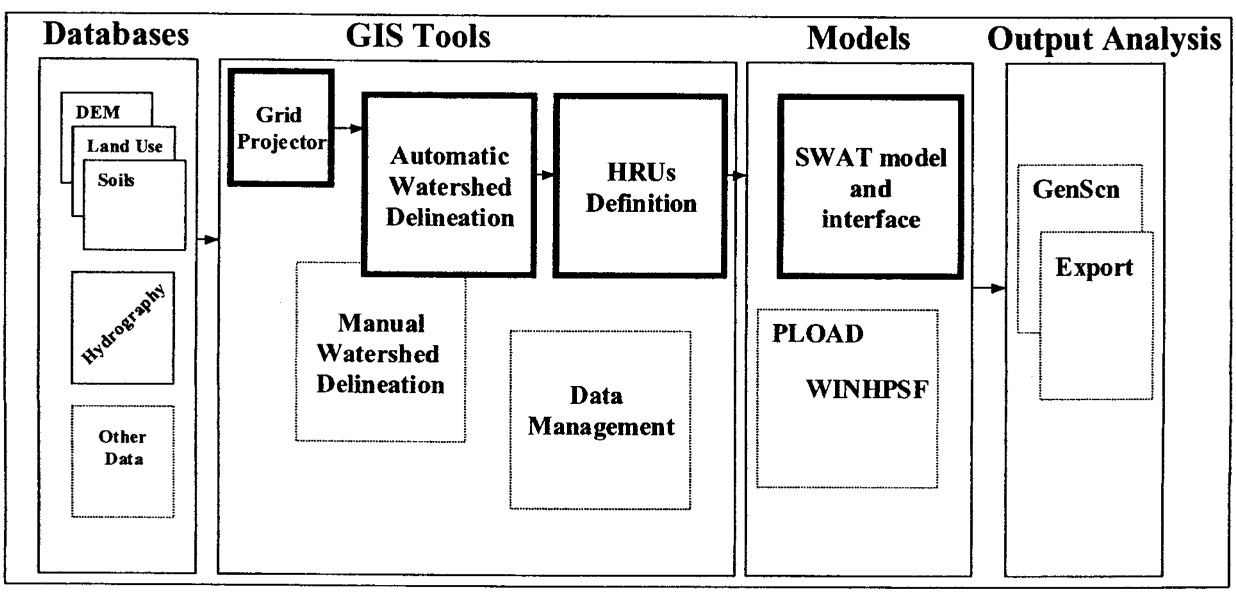

Figure 1. Overview of the BASINS 3.0 System – Components of the New Watershed Modeling System Are Highlighted.

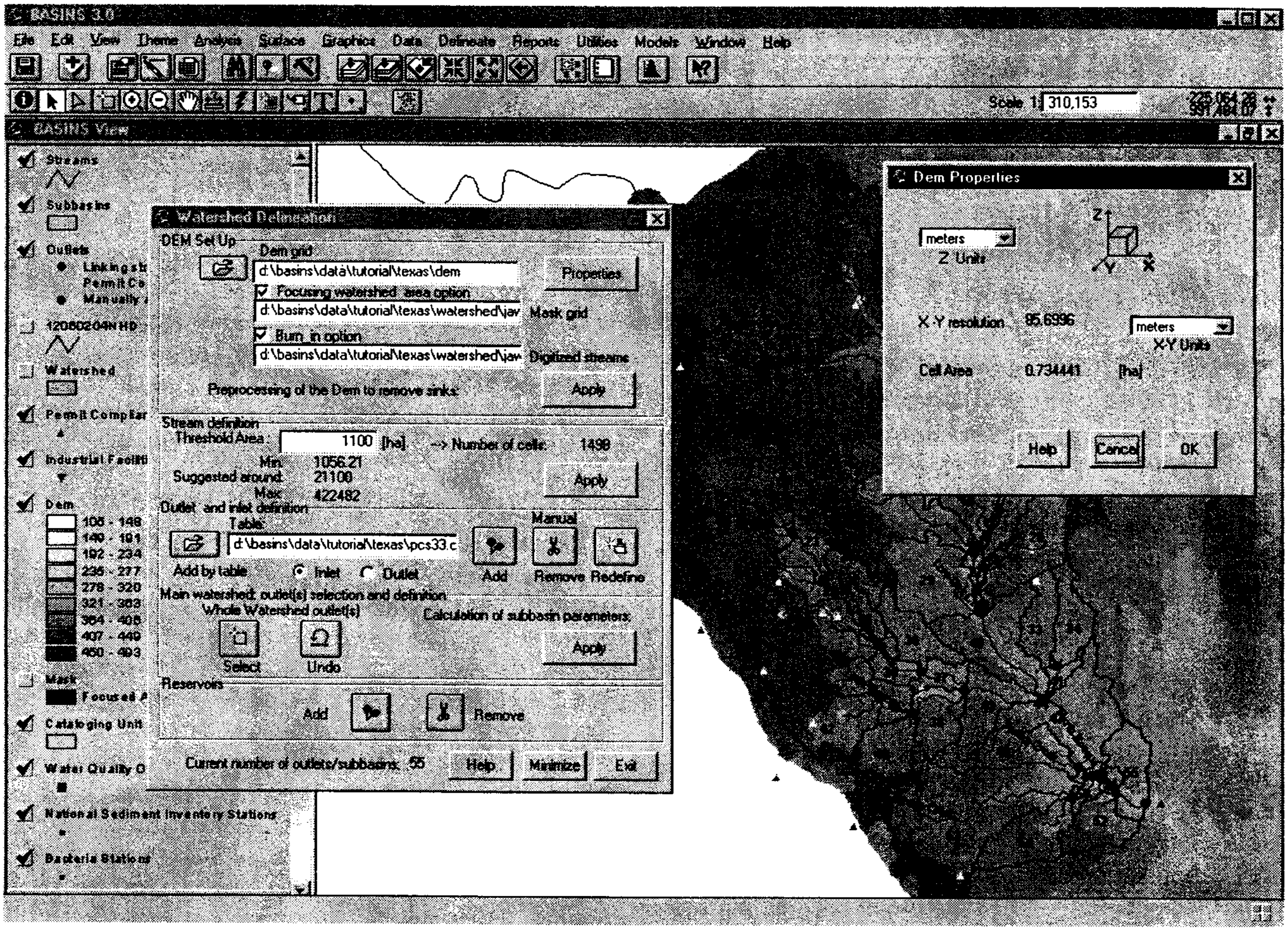

Figure 2a. Automatic Watershed Delineator Interface in BASINS 3.0.

assigning all off-stream cells with the DEM values in addition to a remarkable offset value (5000 m). The National Hydrography Dataset (NHD) (USGS and U.S. EPA, 2000) is a potentially useful hydrography layer that can be used within this method. The NHD is a feature based database that interconnects, and uniquely identifies the stream segments or "reaches" that comprise the U.S.'s surface water drainage system. More specifically, it contains reach codes for networked features, and isolated lakes, flow direction, names, stream level, and centerline representations for areal waterbodies. The AWD uses this code information to trace, select, and retain only the networked features that are suitable for use with the "stream burning" method. To be precise, it selects those linear features providing a stream connectivity frequently lost through reservoirs and wide rivers. A similar filtering algorithm is also applied when USEPA Reach File Version 3.0 (RF3) (U.S. EPA, 1998a) data are used, whereas all the features are used when U.S. EPA Reach File Version 1.0 (RF1) (U.S. EPA, 1998b) or any other digitized map is used as the hydrography layer.

Subwatershed, Outlet Locations and PCS Data. Once the above preparatory steps are completed, the user is allowed to define the extent and detail of the resulting derived stream network. This is achieved by entering a threshold value on the draining area which corresponds to an equivalent contributing number of grid cells (flow accumulation grid) making up the stream branch. The user is allowed to modify the sub-watershed outlets (initially located by default at the most downstream edge of each stream segment), add new outlet points, or remove any of them. In order to perform this, the user utilizes a set of tools by clicking on the screen using the mouse or importing a table of point locations (for example stream gauge or sampling locations). Also during this phase two types of inlet locations can be defined: point sources of discharges and watershed inlets. Point source of discharge could include sewers, treatment plants, and waste water discharge. The AWD allows for the import and location of the Permit Compliance System (PCS) facility location on the stream network; the PCS is the national database used to track compliance with the National Pollutant Discharge Elimination System (NPDES) Permit requirements. The PCS locations are distributed with BASINS along with the surface water loading values, computed using the EPA Effluent Decision Support System (EDSS) for 1990 to 1999. Watershed inlets are used when a portion of the watershed area is not directly modeled (because other simulation models or observed data are used), and is thereby excluded from the watershed modeling framework. For both types of inlets, the user provides discharge data records that will be routed through the stream network. Once the outlet and inlet locations are specified, the user defines the main watershed outlet(s) through a customized selection tool and watershed, and the subwatershed boundaries definition is performed by a process, which includes tracing the flow direction from each grid cell until either an outlet cell or the edge of the DEM grid extent is encountered. The watershed, as well as the subwatersheds, boundaries are created and the user completes this section, reviewing, and modifying the respective outlets in order to make the new implied set of sub-watersheds as needed.

Calculation of Watershed and Subwatershed Parameters. This procedure determines all of the geometric parameters of subwatersheds and stream reaches using raster grid and map algebra functions. For example, land slopes of subwatersheds are automatically calculated by averaging slope values of the respective grid cells; slope, length, and width are calculated for the mainstream channel flowing from each subwatershed inlet to the subwatershed outlet and for the longest stream channel, extending from each subwatershed outlet, to the most distant point in the subwatershed. Once this step is completed, a report describes the topographic asset of the watershed, and a set of geomorphological parameters (Table 1) are stored as attributes of the derived vector shape themes. This dynamically developed database is commonly available to all of the current modeling extensions in BASINS, namely SWAT, WinHSPF, and PLOAD (GIS Pollutant Load Application) (CH2M Hill, 2001).

Hydrologic Response Units Definition Tool Extension

This extension defines the distribution and combination of the land use and soil categories over the watershed and subwatersheds. A set of tools (Figure 2b) allows for loading and clipping land use and soil maps (either in raster grid or vector shape format) on the watershed area. The watershed clipped land use and soil maps are reclassified into various categories which need to match the land use categories of the target hydrological model. This task can be accomplished either by using a tool to click and drop the categories of the target model or by applying predefined look-up tables.

TABLE 1. Subwatershed and Main Stream Reach Geomorphological Parameters Estimated by the Automated Watershed Delineation Extension.

Subwatershed	Main Stream Reach
Area	Cumulated Drainage Area
Slope	Length
Field Slope Length	Slope
Length of the Longest Path Within the Subwatershed	Width
Slope of the Longest Path Within the Subwatershed	Depth
Width of Longest Path Within the Subwatershed	Minimum Elevation
Depth of the Longest Path Within the Subwatershed	Maximum Elevation
Elevation of the Subwatershed Centroid	

The derived thematic maps are overlayed using raster functions, which are highly efficient when compared to the equivalent vector type. On the base of the obtained distribution, and combination of the HRUs, the user is provided with options to either use the predominant or subdivide into smaller subunits based on the combination of all controlled percentage of land uses and soils (HRU), thereby reducing the total number of modeling units. Currently, the tool is customized to allow land use map reclassification either for the SWAT or HSPF model. A typical land use dataset used for U.S. watersheds is based on Anderson level II classified landuse/land cover layer, created using the 1:250,000 scale U.S. Geological Survey (USGS, 1990) and USDA-NRCS State Soil Geographic Database STATSGO (USDA-SCS, 1992) soil association datasets. Both of the databases are distributed with BASINS, however, the user is allowed to input any other source of data. The application of this extension completes the watershed asset reports, and the dynamically developed watershed database needed to provide the inputs for the chosen model.

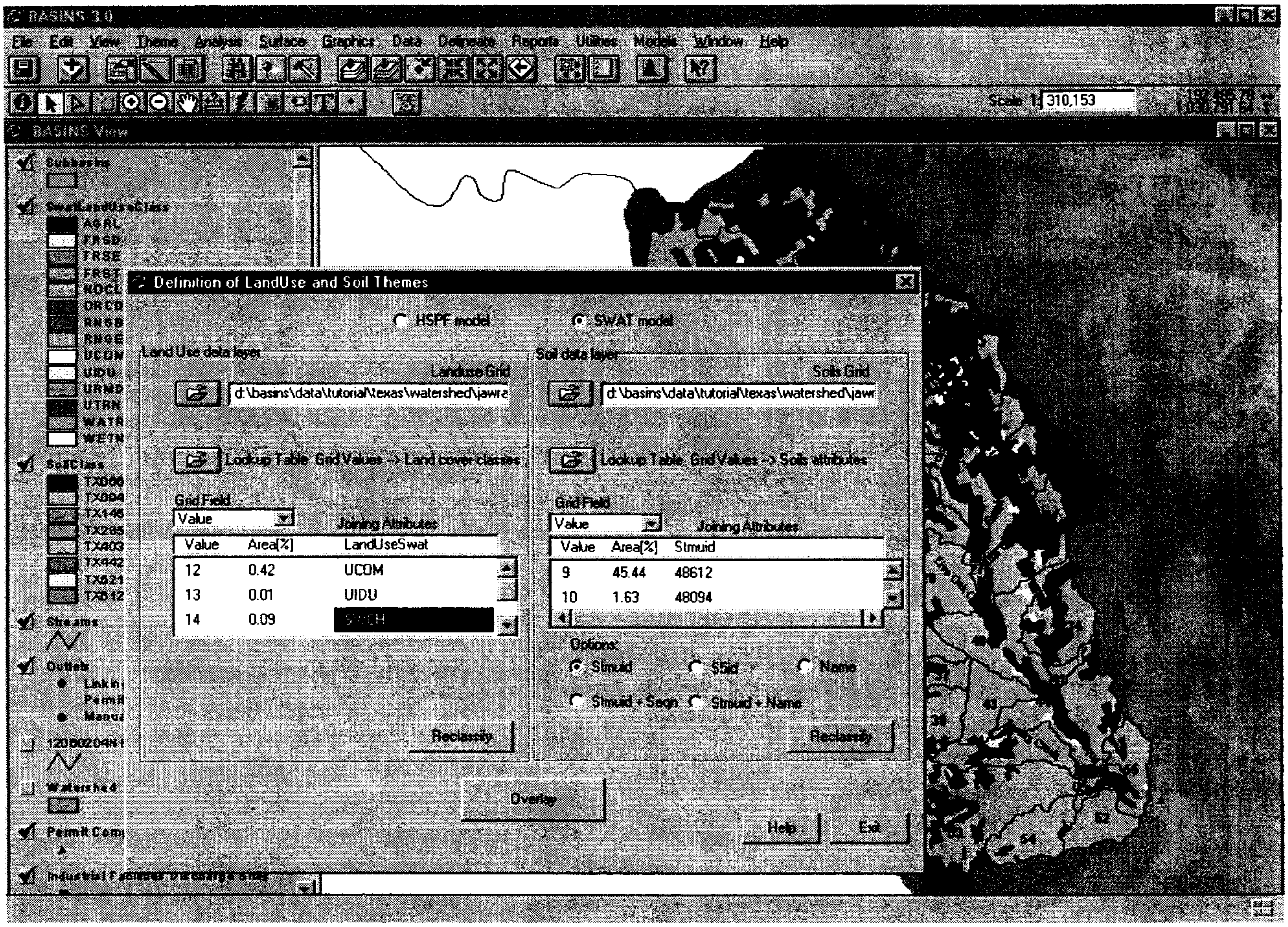

Figure 2b. The HRUs Definition Tool Interface in BASINS 3.0.

Swat Model and Interface Extension

The developed BASINS' extension provides the core SWAT model and an interface completely integrated in the ArcView-BASINS system, allowing the user to interact with the different components of the model, as well as the different components of the other tools, without leaving the BASINS environment. The interface includes several tools, grouped within a customized View (Figure 2c), allowing the user to set up the input parameters, run and calibrate the SWAT model, and export the simulation results.

SWAT Model. The SWAT model (Arnold *et al.*, 1998) builds upon over 30 years of USDA modeling experience. SWAT is a complex, conceptual, hydrologic, semidistributed model with spatially explicit parameterization. It is a continuous time model that operates on a daily time step. The objective in model development was to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged basins. To satisfy this objective, the model is (1) physically based (as calibration is not possible on ungauged basins); (2) based on readily available inputs; (3) computationally efficient to operate on large watersheds in a reasonable time; and (4) capable of continuous simulation over long time periods, which is necessary for computing the effects of management changes. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. A complete description of the model components is found in Arnold *et al.* (1998). The watershed schema is divided into subwatersheds with unique soil/landuse characteristics or HRUs. The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile (0-2m), shallow aquifer (typically 2-20m), and deep aquifer (> 20m). The soil profile can be subdivided into multiple layers. Soil water processes include infiltration, evaporation, plant uptake, lateral flow, and

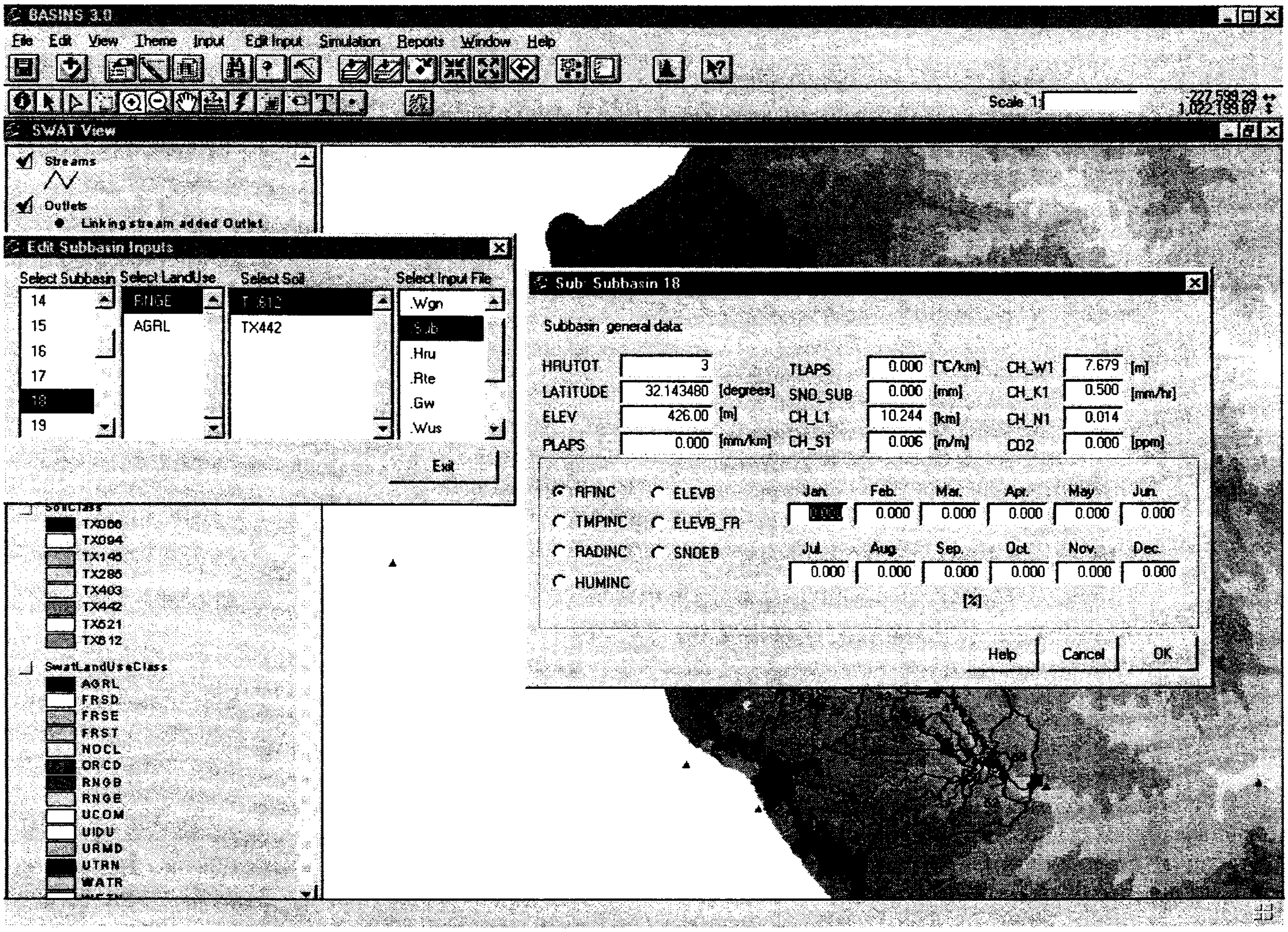

Figure 2c. SWAT Model Interface in BASINS 3.0.

percolation to lower layers. Percolation from the bottom of the soil profile recharges the shallow aquifer. A recession constant (Arnold *et al.*, 1995), derived from daily stream flow records, is used to lag flow from the aquifer to the stream. Other shallow aquifer components include evaporation, pumping withdrawals, and seepage to the deep aquifer. Flow, sediment, and NPS loading from each HRU in a subwatershed are summed, and the resulting loads are routed through channels, ponds, and reservoirs to the watershed outlet. The hydrologic components of the model have been validated for numerous watersheds, and a comprehensive validation of stream flow was performed for the entire conterminous United States (Arnold *et al.*, 1999). For BASINS 3.0, the SWAT2000 version of the model has been developed with a complete review of the nutrient cycle and pesticide components and the addition of new features like subdaily time step, bacteria, and metal tracings. The following are some of the most important simulated variables: (1) flow discharge, (2) sediment yield, (3) nitrogen and phosphorus phases, (4) pesticides, (5) metals, and (6) pathogen concentrations.

SWAT Database Editors. A set of model databases contains the default parameters for: (1) plant growth and urban land use, (2) tillage, (3) fertilizers/ manure, and (4) pesticides. These parameters are used within several mathematical equations of the model to perform the simulation of fundamental components of the model system. One component of the interface encompasses tools that allow BASINS's users to edit and/or add new entries in any of these databases in order to match the model assumptions of the land management with those of the case study watershed. Two additional databases, with respective editors, are developed to store custom user soil and weather data.

Weather Station Datasets. This tool allows the user to input station locations and respective datasets for rainfall, temperature, solar radiation, relative humidity, and wind speed. The interface not only geocodes the station locations and associates each subwatershed to the closest one, but it also labels the missing daily data records so that the SWAT model will be able to replace them using a built in weather generator. In fact, all the weather data are optional since the model is able to generate a dataset based on statistical parameters of specified weather stations provided with a long series of data. A database containing statistical data from 1041 weather stations in the U.S. (Nicks, 1985) is distributed and available for modeling watersheds in the U.S.

Input Parameterization. Based on the previous settings (watershed segmentation, HRUs, and weather stations definition) the interface creates and populates a database to store the input parameters of the model. The requested ASCII format inputs of the models are also created at the same time. The editing dialog tools allow the user to review and edit any of the input parameters, check the validity based on predefined and editable range values, and extend the current editing dataset records to other target subwatersheds and/or a land use soil combination input set. The input types are soil, weather, subwatershed or landuse soil item, stream reach, ground water, water use, management, pond, and lake. Land management input parameters such as planting, harvesting, tillage operation, irrigation, and nutrient and pesticide applications are important input parameters to set. An input dialog allows the user to set up crop rotation scenarios, scheduling the operations by date or by crop heat units. Other input tools allow the user to edit point source discharge and watershed inlet loading, specifying either constant values or records with yearly, monthly, or daily time step. As mentioned above, point source discharge locations are added to the watershed configuration during the watershed discretization. If point sources were defined from PCS data import, loading records could be automatically defined.

Model Execution. The user sets up the simulation control codes: evapotranspiration method, length of simulation (beginning and ending day of simulation), type of simulation (time step of inputs and outputs), and several others. The execution of the model starts the simulation after an optional validity of all necessary input files. Once the model runs, a set of controls allows the interface to read the ASCII format model outputs tables and convert them into dBASE format, the default table format in ArcView. These tables can be exported in order to be charted, mapped, and statistically evaluated in the comparison with observed data. This output evaluation can also be easily accomplished using GenScn (Kittle *et al.,* 1998), another tool being distributed with BASINS 3.0.

Calibration Tool. This tool allows the user to interactively perform calibration on the model simulations. The user can target the most sensitive input parameters of the model, set their variations (in percent of the current value or by an absolute value), activate them for target subwatersheds and landuse soil combinations, and rerun the model. The calibration scenarios can be saved, modified later, or exported in order that they may be used within the same or another watershed project.

EXAMPLE APPLICATION

BASINS 3.0 has been successfully applied to the Upper North Bosque River (UNBR) (Figure 3). The UNBR watershed covers about 932 km^2 in the upper portion of the North Bosque River (NBR) watershed, almost entirely within Erath County in central Texas. The NBR watershed is a known problem watershed due to concentrated animal feeding operations and is of particular water quality concern since the Bosque River flows through Erath, Hamilton, and Bosque Counties before discharging into Lake Waco, which is used for the public drinking water supply for the City of Waco and several adjoining communities. A TMDL program is being developed in UNBR and NBR watersheds. Table 2 shows part of the information reported in the 303 (d) list for the USGS Cataloging Unit Number 12060204. The Texas Natural Resource Conservation Commission (TNRCC) and Texas State Soil and Water Conservation Board (TSSWCB) are working with the EPA to ensure that the new program complies with federal regulations and guidance. The program includes extensive sampling and the use of computer simulation models to identify sources of nutrients and to determine how they are partitioned throughout the watershed. Since 1991 the Texas Institute for Applied Environmental Research (TIAER) at Tarleton State University has been monitoring UNBR (McFarland and Hauck, 1999). Within the UNBR watershed there are 16 stormwater monitoring sites equipped with automated samplers (Figure 3). Dairy farming is the dominant agricultural practice in the UNBR watershed: 127 dairies with a combined herd of 38,556 cows are included. This makes UNBR the most vulnerable zone of the NBR

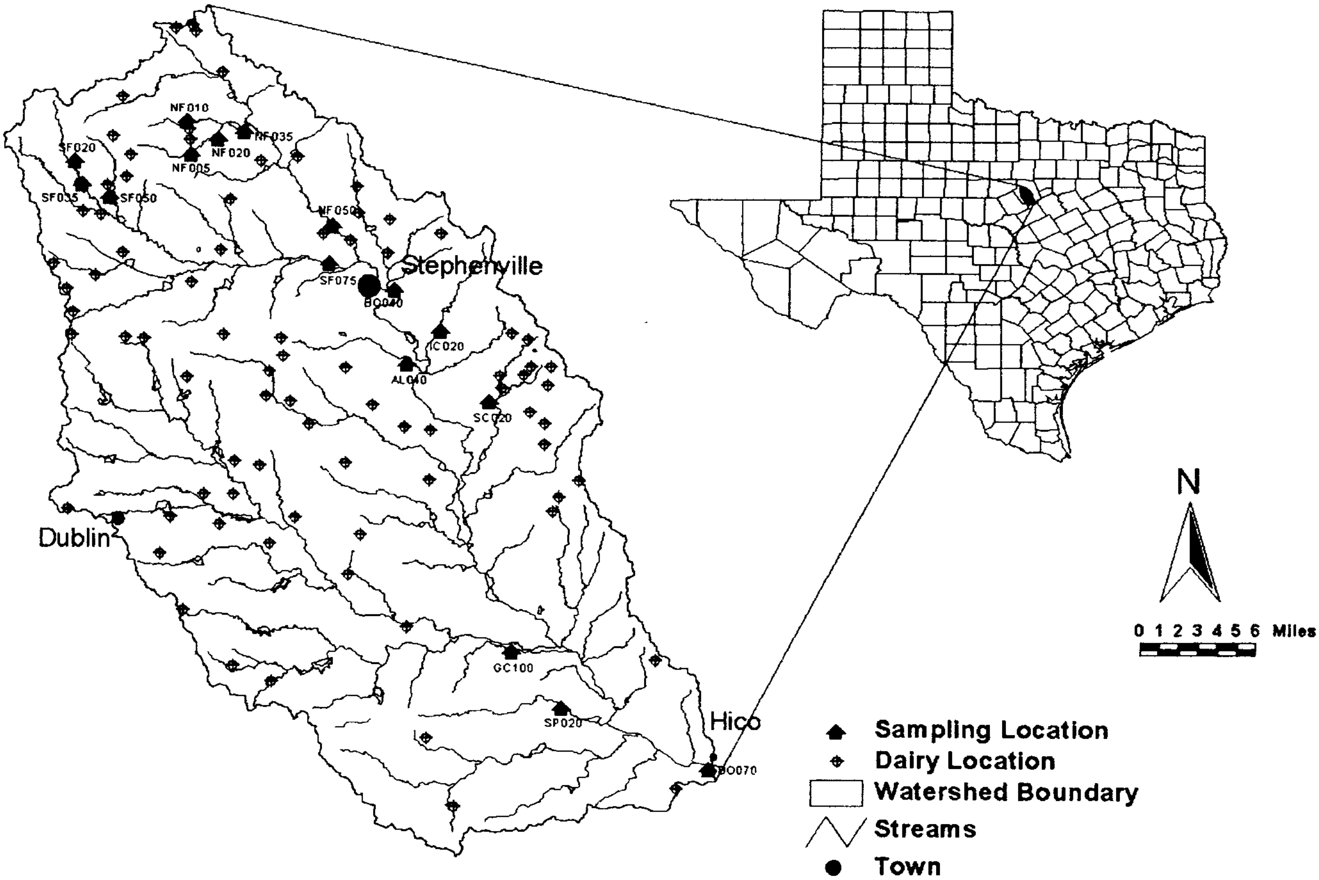

Figure 3. The Upper North Bosque River Watershed in Central Texas.

TABLE 2. USGS Cataloging Unit 12060204 Information in the 303 (d) List.

Listing State	Identification	Waterbody	Parameter of Concern	Potential Sources of Impairment
TX	TX-1226-1998	North Bosque River	Pathogens, Nitrogen, Phosphorus, Pathogens Organic Enrichment/Low	Nonpoint Source
TX	TX-1255-1998	Upper North Bosque River	Dissolved Oxygen, Chloride, Sulfate, Total Dissolved Solids, Nitrogen, Phosphorus	Nonpoint Source

watershed. In addition, other significant agricultural practices include the production of peanut, range cattle, pecan, peaches, and forage hay. The UNBR watershed is 98 percent rural with the primary land uses being rangeland (43 percent), forage fields (23 percent), and dairy waste application (7 percent).

The basic GIS databases within BASINS have been used: three arc-second USGS DEM for cataloging unit 12060204 and relative NHD dataset, USGS landuse and STATSGO soil maps. One of the main thrusts of the UNBR program will be to find ways to manage dairy wastes in order to lessen runoff pollution. The landuse map has been slightly modified to contain the land areas of manure application as accomplished by Santhi *et al.* (2001) for the entire NBR watershed. This will reproduce the most common, and generally the most desirable, method of utilizing manure because of the value of the nutrients and organic matter. For this illustrative example, the watershed has been delineated using the location of the sampling station BO070 next to Hico as the main outlet. The results of the simulation with SWAT are here compared with the observed data at the same station. Daily rainfall data were obtained from 14 gauges within the watershed, either associated with the sampling gages, or included in several National Weather

Service stations. The watershed has been segmented into 55 subwatersheds. The PCS locations within UNBR watershed are listed in Table 3. Loading records for the Stephenville wastewater treatment plant have been replaced with those more detailed used by Saleh *et al.* (2000) for an extensive application of an earlier version of SWAT model in UNBR.

TABLE 3. Permit Compliance System (PCS) Facilities Within the Upper North Bosque River Watershed.

Permit Number	Facility	Location
TX0024228	Sewerage System	Stephenville
TX0130192	Dairy Farm	Erath County
TX0130231	Dairy Farm	Dublin
TX0130508	Dairy Farm	Dublin
TX0130818	Dairy Farm	Dublin
TX0130907	Dairy Farm	Dublin
TX0130923	Dairy Farm	Dublin
TX0130966	Dairy Farm	Dublin
TX0131156	Livestock	Dublin

The applied BASINS system has shown the easy watershed simulation set up along with the application of the agricultural and waste management scenario and the calibration tool to reproduce the hydrologic and nutrient calibration setting operated by Santhi *et al.* (2001). In addition, the system showed to be particularly useful in the definition of the main outlet, the subwatershed outlets, location of the point sources, linkage with soil data base, definition of the land use classes, and input of all the data at the subwatershed and HRU level.

The results of the simulation for the period January 1993 through July 1998 are reported in Figure 4, and Table 4 shows their goodness of fit and reproduces those of Santhi *et al.* (2001), thereby representing the first complete verification of the newly applied system. The basic application of the BASINS system, including SWAT with the new bacteria component using the scenario encompassing the extended area of land waste application and with designed timing and methods of application (Santhi *et al.,* 2001), provides a 40 percent reduction of the fecal coliform bacteria concentration when compared to the current management. This indicates that the system could also help

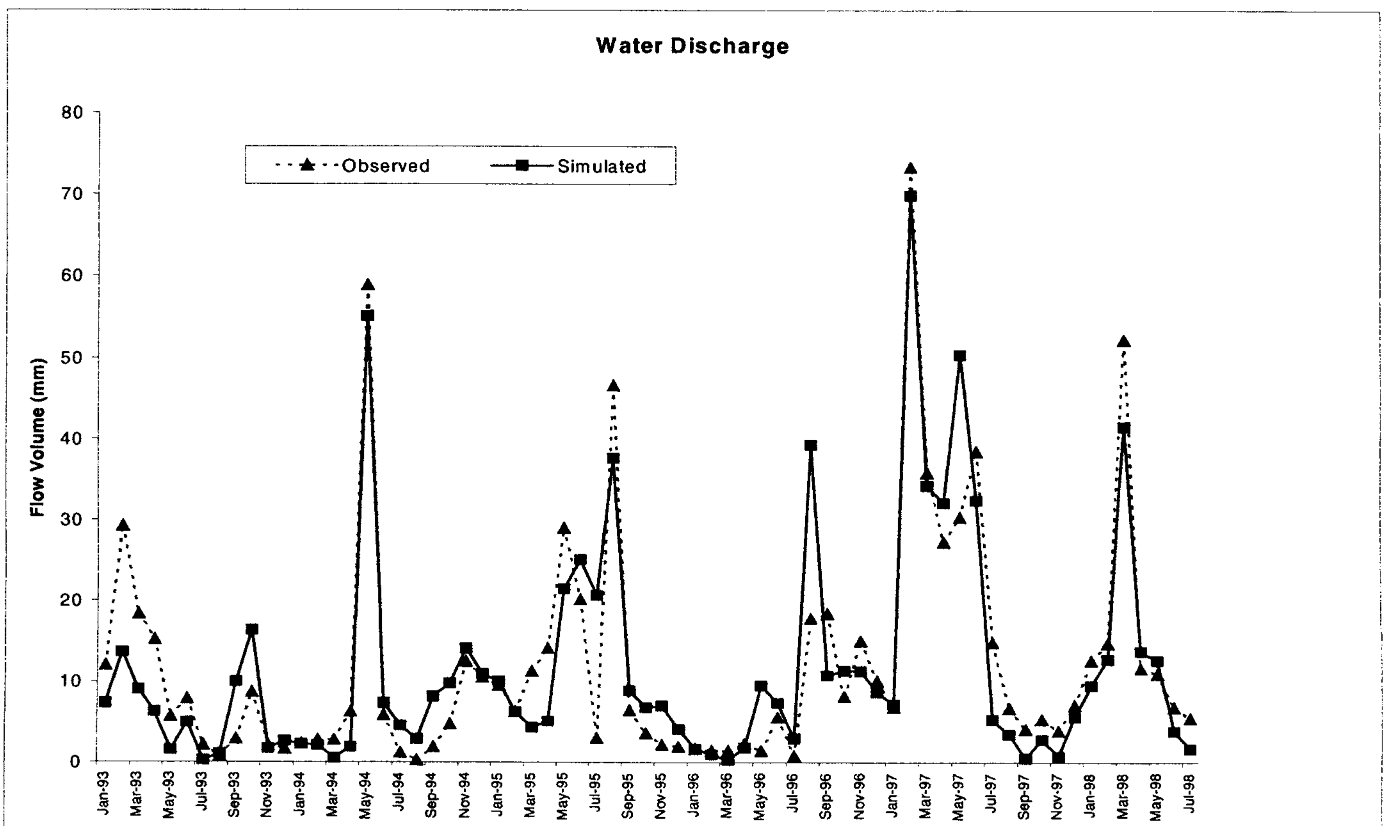

Figure 4a. Sampling Station BO070: Observed and Simulated Water Discharge in UNBR Watershed Using SWAT Within BASINS – Analysis Period January 1993 Through July 1998.

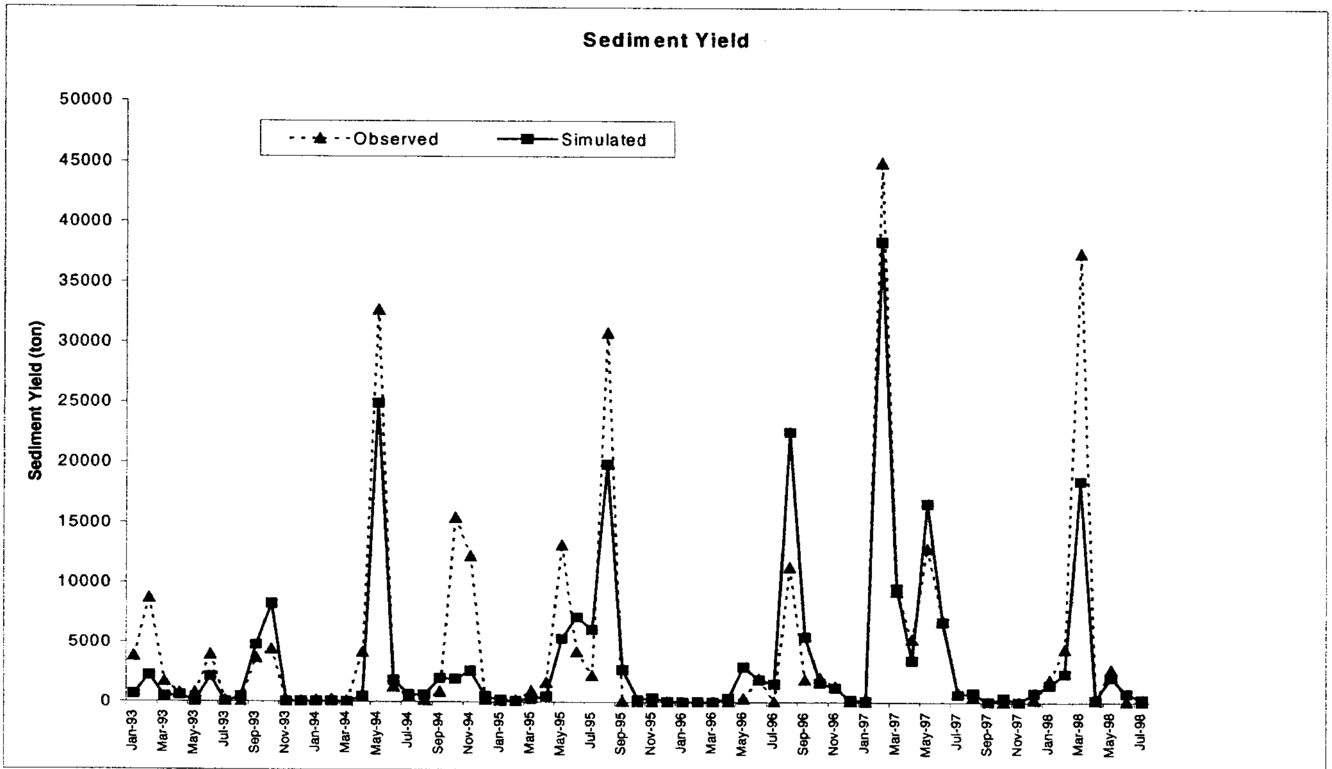

Figure 4b. Sampling Station BO070: Observed and Simulated Sediment Yield in UNBR Watershed Using SWAT Within BASINS – Analysis Period January 1993 Through July 1998.

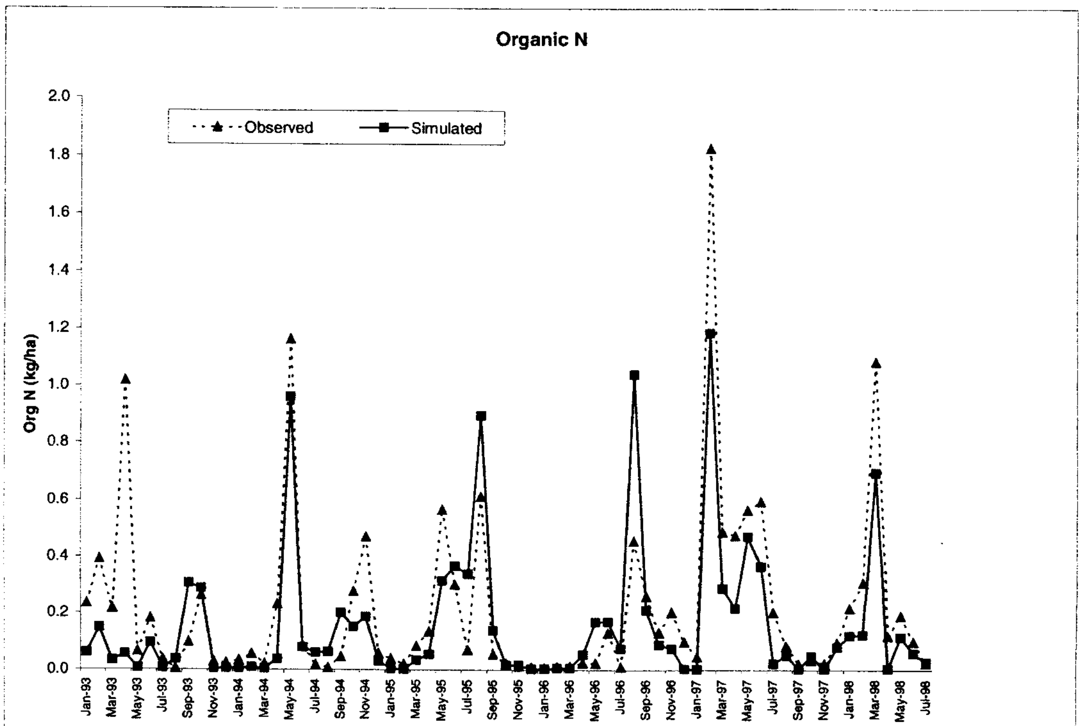

Figure 4c. Sampling Station BO070: Observed and Organic Nitrogen in UNBR Watershed Using SWAT Within BASINS – Analysis Period January 1993 Through July 1998.

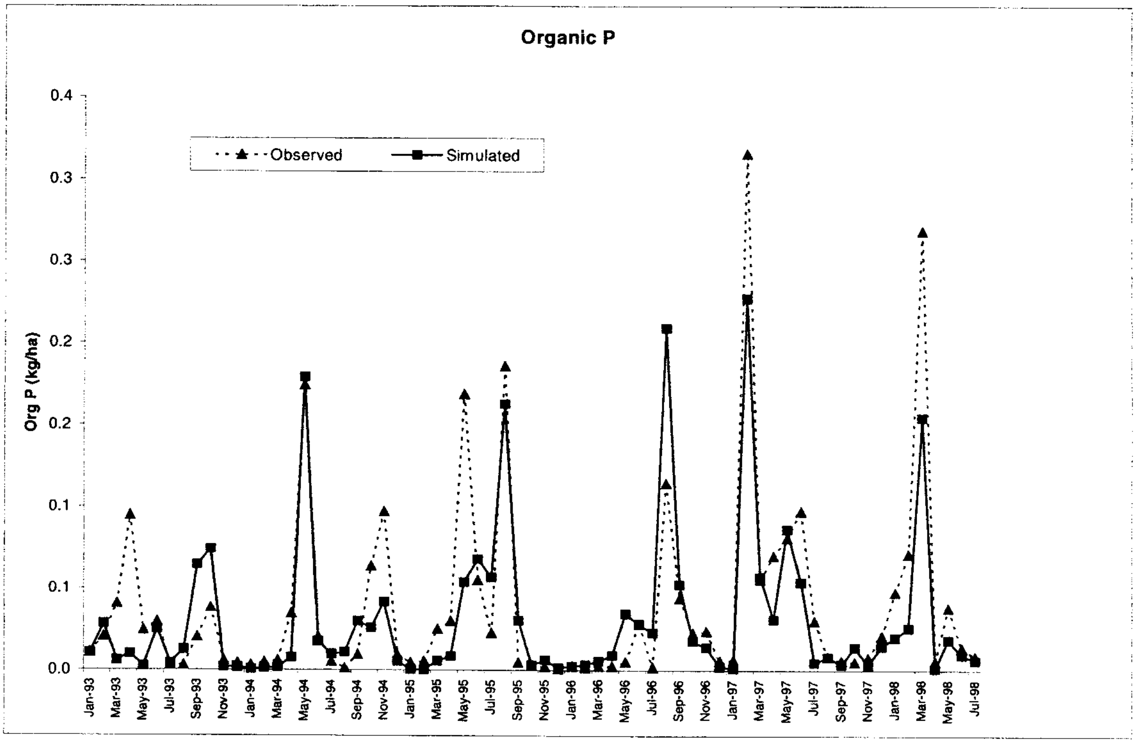

Figure 4d. Sampling Station BO070: Observed and Simulated Organic Phosphorus in UNBR Watershed Using SWAT Within BASINS – Analysis Period January 1993 Through July 1998.

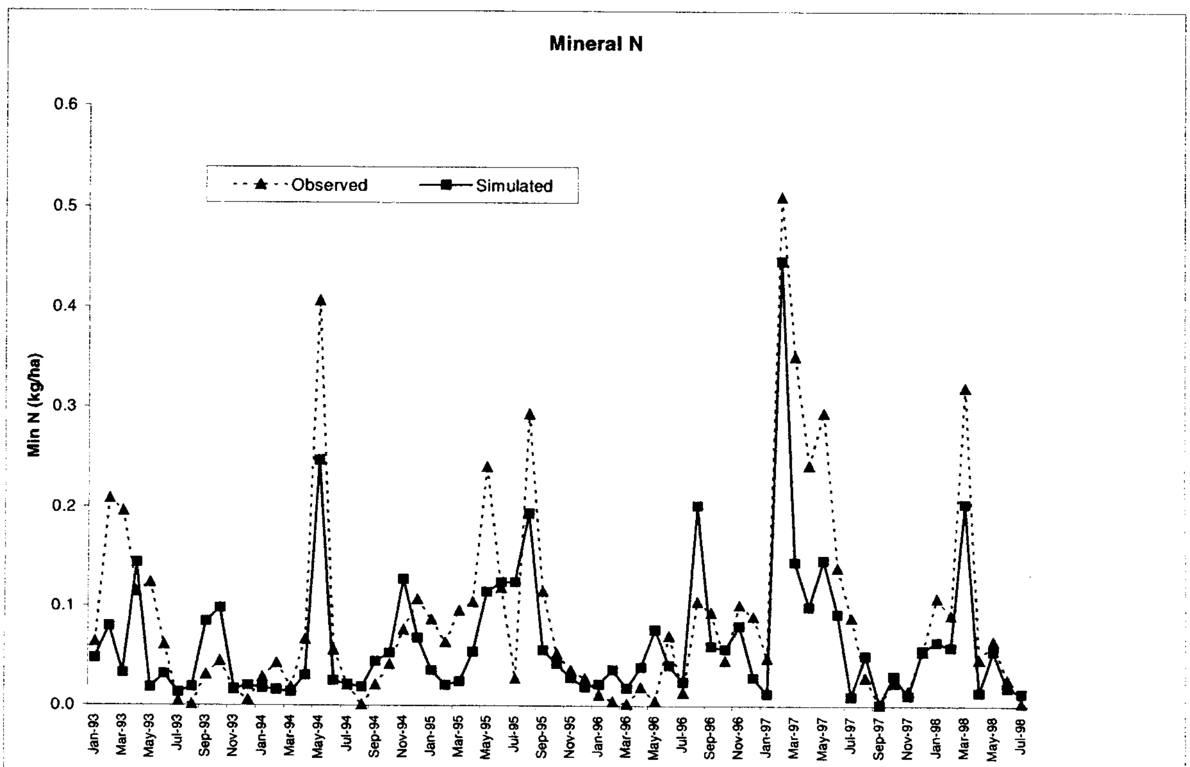

Figure 4e. Sampling Station BO070: Observed and Simulated Nitrate-Nitrogen in UNBR Watershed Using SWAT Within BASINS – Analysis Period January 1993 Through July 1998.

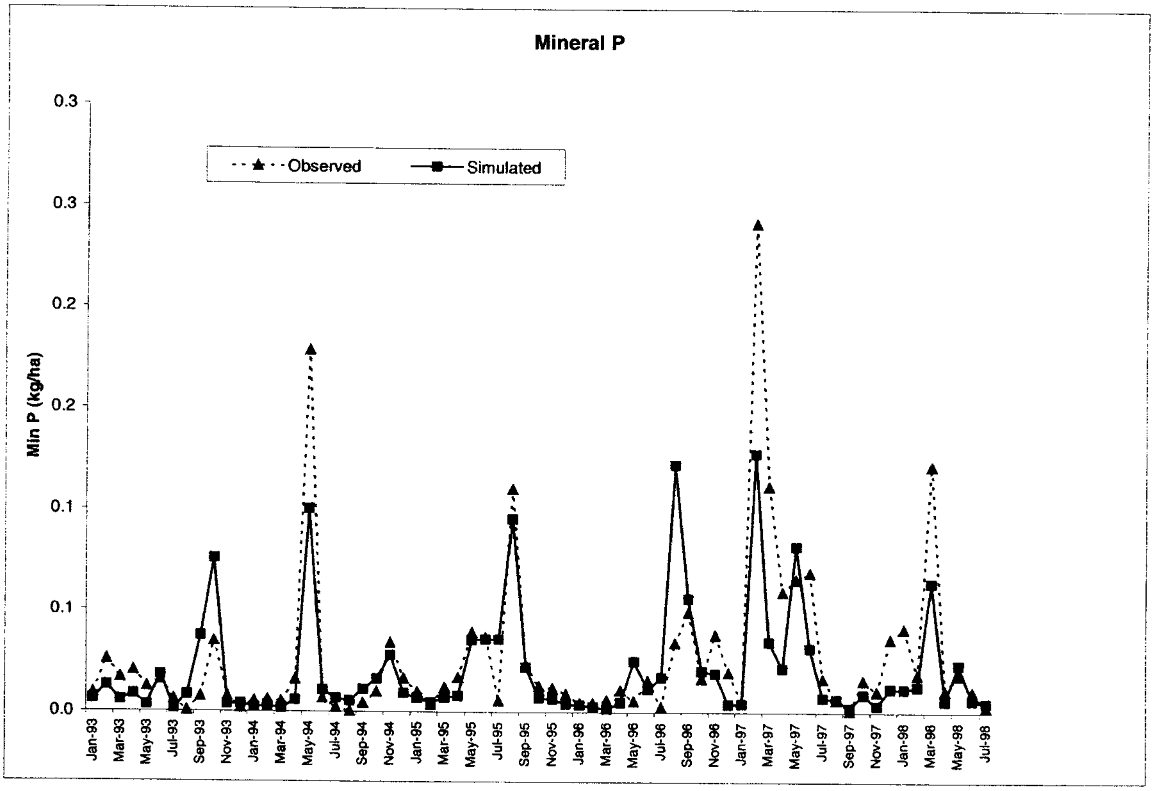

Figure 4f. Sampling Station BO070: Observed and Simulated Orthophosphate Phosphorus in UNBR Watershed Using SWAT Within BASINS – Analysis Period January 1993 Through July 1998.

TABLE 4. Sampling Station BO070: Averaged Observed and Simulated Loading in UNBR Watershed Using SWAT Within BASINS – Analysis Period is January 1993 Through July 1998.

Variable	Observed	Simulated	Nash and Sutcliffe (1970) E (monthly time step)
Water Discharge (m^3/s)	4.43	4.29	0.82
Sediment Yield (t)	4489.90	3625.91	0.78
Organic Nitrogen (kg)	20793.36	15165.59	0.60
Nitrate (kg)	8469.26	6091.20	0.60
Organic Phosphorus (kg)	3699.21	2955.56	0.70
Orthophosphate (kg)	2524.45	1981.84	0.58

estimate the reduction of the elevated fecal coliform levels using efficient dairy waste management systems, a primary objective of the TMDL program for UNBR.

SUMMARY AND CONCLUSIONS

GISs and mathematical, hydrology based simulation models are needed when efficient manipulation of spatially distributed data and an understanding and interpretation of complicated hydrologic processes connected with the water quality assessment on a watershed scale are required. BASINS is a good example of a PC based GIS engine with embedded integrated databases, mathematical simulation models, and utility tools. The 3.0 version of BASINS adopts ArcView as its GIS base and offers a new modular architecture that promotes the development of user's modeling and tool plug-in extensions. As anticipated (Whittemore and Beebe, 2000), the distributed

BASINS 3.0 includes a new optional watershed modeling system that is designed to incorporate state of the art hydrologic GIS raster based tools while being open to the use of any source of data in addition to the distributed basic datasets covering all of the U.S. This system helps the user to segment the watershed, import, and format the supporting data more specifically for the application and calibration of an updates version of SWAT, a hydrologic semidistributed model for the interpretation of the watershed processes associated with the nonpoint sources of pollution and the corresponding loading assessment. The system shares the generated datasets with the other tools and models already in the system or that may be introduced in the future. The reliability, along with the efficiency of obtaining the results of SWAT simulation in the new BASINS 3.0 system (i.e., the illustrative example of the Upper North Bosque River Watershed) promises to be a valuable resource for deploying water quality analysis projects at the watershed level, as well as at single stream segments, a scale required by most TMDL programs.

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