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Agricultural non-point source (AGNPS) water quality modeling in a GIS environment

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ABSTRACT

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This thesis project outlines the development and implementation of a complex GIS project in a government agency. The objective of the project was to integrate a public domain GIS package (GRASS) with a commercial structured query language database in order to undertake Agricultural Non-Point Source (AGNPS) water quality modeling. Three general areas of GIS technology were investigated consisting of technical issues involved in linking GIS; the model; database development; and a discussion of system performance from an institutional perspective.

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Chapter 1: Introduction.

This thesis documents the development and implementation of a complex GIS project in a government agency. The initial project objective was to integrate GRASS, a public-domain GIS software package, with a commercial structured query language database and then to incorporate an Agricultural Non-Point Source (AGNPS) water quality model. In the course of this procedure, three general areas of GIS technology were investigated. These consisted of the technical problems involved in the implementation of linking GIS and the water quality model; database development; and a discussion of system performance from an institutional perspective in particular a reviewing of organizational outcomes arising from the implementation strategy. This report details the results of a single-event erosion prediction tool for field use and program evaluation and presents the experiences of the author in implementing a sophisticated water quality model within a federal institution

Background.

The U.S. Environmental Protection Agency estimates that the United States government spends billions of dollars each year on water quality programs (USEPA, 1994). Most of these public funds are used for wastewater treatment programs at the local level and those treatment programs have certainly improved the overall water quality situation in America. A smaller portion of this total funding is spent by several federal agencies on specific, targeted programs. One common factor among all these specific programs, regardless of agency responsibility, is a general lack of ability to provide any evidence that the water quality goals of the agency are being met. Many agencies are turning to GIS and spatial modeling to develop tools for project evaluation to better address accountability to the taxpayers.

In 1996, the Natural Resources Conservation Service (NRCS) completed a five-year water quality plan and yet had no data to support claims that all the work that had been done had met agency goals. In the NRCS Water Quality Policy statement, policy makers outlined the need for the "development of technical tools necessary to quantify the environmental and economic on- and off-site effects of soil and water conservation measures commensurate with their relative importance" (USDA-SCS, 1990). Although vague, the policy directed responsibility to several levels of the agency structure. In 1988, the agency turned to GIS when the Geographic Resources Analysis and Support System (GRASS) was named the "agency GIS." NRCS staff proceeded to develop interfaces to GRASS, a Structured Query Language (SQL) Database and several available water quality models. As NRCS is the federal agency with primary responsibility for water quality in the agricultural arena, it became critical that the agency demonstrate to the public that it was indeed capable of providing leadership in evaluating the nature and extent of pollution from agriculture. The agency had been interested in water quality models since 1975 when the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model was introduced (Knisel, 1978). Since that time, NRCS has been calibrating and verifying the parameters of several additional water quality models. These models have not been made operational in the field office setting, largely due to the complicated nature of the databases and the need for powerful computers required to run them. Additionally, most of the models being validated by the NRCS had not been subject to wide interdisciplinary review and NRCS was hoping to change this lack of validation capability using GIS technology. It was in this context that a linkage between the Agricultural Non Point Source (AGNPS) water quality model and GRASS GIS was investigated.

The Geographic Setting

The AGNPS-GRASS model integration was tested for a study area in Greenbrier County, West Virginia. The Davis Hollow Basin was selected for this analysis because it is representative of the whole of the Greenbrier Valley. The Greenbrier Valley is located in the southeastern part of West Virginia and makes up about 260,000 acres in Greenbrier County (Figure 1.). The Greenbrier Valley is a large fertile valley primarily lying on the west bank of the Greenbrier River. The valley is made up of many smaller valleys, such as Davis Hollow, and the primary land use is agricultural. Of the farms in the area, 729 are devoted mainly to beef and dairy production making it an important agricultural region in a state with few significant agricultural areas. About 80,000 acres of the valley (31%) is devoted to farm operations supporting livestock populations of about 36,000 cattle, 4600 sheep, 2000 poultry, and 800 hogs (WVDA, 1994). The 27,000 acres (10%) of available cropland is mostly under corn and hay for animal feedstuffs. The valley contains several key elements related to rural water quality problems: a high density of grazing animals on pastures with well-drained soils situated over a limestone karst topography. The fact that the rural population relies on ground water for household consumption makes this study particularly relevant to local needs.

The sample watershed used in this analysis is known locally as The Davis Hollow Basin. The use of the Davis Hollow study area met the requirements of AGNPS by defining a target watershed, which portrayed soil, slope and runoff characteristic of the larger region. The spatial extent of the Davis Hollow Basin is about 1100 Hectares (2715 Acres). It has a mix of agricultural land uses commensurate with the Greenbrier Valley as a whole and shares its topographical characteristics. The successful use of AGNPS-GRASS in Davis Hollow would help assess the potential likelihood of success for the Greenbrier Valley as a whole, while minimizing the workload required to operationalize the system.

Chapter 2: Research Goals and Methods

The principle objective of this project was to enable water quality modeling be undertaken within a geographic information system and to describe the initial success and subsequent failure of implementing a complex GIS operation in the federal sector. The research goals were to specify the computer environment necessary to integrate a single-event erosion prediction model into GIS; develop graphical tools for the operation of the model; and to evaluate the effectiveness of the resulting system for use at the operational level of the field office and NRCS erosion prevention program evaluation.

Research Issues

In order to achieve the overall research objective it was necessary to resolve each of the following steps:

1. Develop an integrated information system to enable the graphical operation of a spatially disaggregated soil erosion model and mapped reporting of results

2. Evaluate the hardware and software requirements for the integrated system
3. Populate the database with a representative data set
4. Implement the system in a NRCS field office setting
5. Observe and evaluate the effectiveness of the implementation
6. Assess the value of the integrated system project.

<u>AGNPS the Model</u>

AGNPS is a straightforward tool in its manual form. The data needed to run AGNPS is readily available to most field workers. The data input requirements are available in most NRCS field offices and consists of data on tillage techniques, fertilizer applications, soils, elevation, drainage, and watershed shape (see pages 6 - 8). AGNPS works on a cell basis and was chosen for integration into GIS for this project because of its simplicity and cell structure which mates nicely to a raster-based GIS like GRASS. AGNPS is a composite of distributed and sequential modeling approaches described by Novotny (Novotny et. al., 1987). In a distributed model, the solution of mass balance equations is carried out simultaneously in all elements. In a sequential model, water and pollutants are routed in a sequence overland and in channels. AGNPS uses a modified Universal Soil Loss Equation (USLE) to predict upland erosion for single storm events. USLE is used extensively by the NRCS for estimating erosion and linking the National Resource Inventory database to erosion estimation. The principal reason for the continued use of AGNPS in NRCS is probably related to its ease of use (Favis-Mortlock, 1994). AGNPS is a series of computer programs that yield data projections of erosion and electrolyte diffusion over a land area. The AGNPS program was designed to generate data on the erosion rates and diffusion rates for phosphates and nitrates which result from rainfall events over the selected study area. A study area can be defined as all land area where overland flow migrates to a single point. This single point is the outlet cell for the entire drainage area.

GRASS GIS

GRASS was developed during the 1970s in the research laboratories of the Army Corps of Engineers in Champaign-Urbana, Illinois. (U.S. Army, 1988) It is a raster-based system built upon modular, open architecture, software design principles, which enable its proogression into increasingly sophisticated uses, analysis, display and applications. GRASS is programmed entirely in the C language and the source code is readily available. This unusual aspect makes GRASS a prime candidate for extension and integration.

Chapter 3 Database Development

The NRCS adopted GRASS as its "official" GIS in 1988. In 1990, the software was linked to a SQL database (INFORMIX) and became the complete package for any agency entity that wanted to integrate GIS into their operations. This was the reason that the data model for this project developed as a two-part structure. Running AGNPS in a GIS environment required two different levels of organizing data: the project level and the simulation level. Simply put, the project level represents a geographical area and the spatial data associated with it. The simulation level represents the various conditions associated with the particular simulation run such as weather or the intensity of the storm event. Within this two-part structure, GRASS manages the geographical data and INFORMIX handles the non-spatial components and the storm event simulation data.

Conceptually, this data model is sound in design and follows the basic rules of spatial data input to GIS for positional data and the associated non-spatial attributes. The creation of a clean, digital database is an important and complex task upon which the ultimate usefulness of GIS depends (Burrough, 1986).

There are three forms of data input developed for this project. These include source data, derived data, and runtime data. The source data (and their associated attribute information) are georeferenced data that had to be compiled, validated, and digitized for the watershed in question. These inputs included the soil survey data, the farm field boundaries, the digital elevation model, the watershed boundaries, the drainage network, and ponds. The derived data are those data that can be derived entirely from the source data using GIS operations either in the GRASS environment or by an SQL query. The runtime data is that data which the user wants to use for a particular condition. Examples of runtime data are the initial conditions or the output options. The platform requirements for this project was a SUN Sparc Station with GRASS version 4.0 and INFORMIX version 4.0, standard engine (SE) and structured query language (SQL) runtime modules. The data types for this project involved line, point, and polygon vector data types. The spatial data was compiled and digitized on 1:24000 orthophotography in vector format. The USGS 30-meter elevation matrix was used in raster format. The relational table required by INFORMIX is a pipe-delimited file, which was created manually using the UNIX vi editor. A pipe delimited file is one that has a pipe character (|) separation between fields of data.

Source Data

To run the AGNPS model in the GIS environment, the following source data was collected and transformed:

- Soils Data. The digitized spatial soils data includes the soil map unit identifier (MUID) as the area label category. The attribute database (the relational table) includes the MUID plus the related attribute information to calculate the soils-related parameters needed for AGNPS. Entering the soil data coverage was the most time consuming part of data development (See Figure 2.). Soils were compiled to a stable, orthographic base map and then digitized using GRASS MAPDEVsubsystem. The attribute data for soils provides the non-layer soil information for the areas within the watershed. The parameter "map unit id" is the pointer to the simulation table. Contents of the attribute table for the soils coverage include were obtained from the State Soil Survey Database for West Virginia and included the following information:

  - K Factor. Representative value of soil erodibility used by USLE.
  - Layer Depth. Numeric value of each soil horizon depth in inches
  - Hydrologic Grouping. Value for estimated infiltration before runoff based on soil type.
  - Organic Carbon. Value given in percent of carbon in horizon.
  - Sand, silt, and clay. Determined by soil particle size analysis in standard sieves used by NRCS.

- Elevation Data. Digital elevation Model from USGS was utilized for the elevation coverage. This data is at 30-meter resolution. The data was reviewed for error and used without change.

- Field Data. These data serve essentially as a land use coverage and was compiled and digitized specifically for this project. The coverage is illustrated in Figure 3. It includes the field map unit identifier (FDID) as the area label category. The coverage is a vector file of the farm field boundaries and other areas of land use (in this case forest). The relational table includes all field data and related information needed to calculate the field related parameters to including hydrologic condition, tillage practices, and fertilizers used. The field area identifier links to a field application table constructed solely for AGNPS. The field application tables required for the field data are:

  - Cropland operations application (COID). This relational table contains information on crop name, number of years in rotation, date of planting, plant residue remaining, and planting method.
  - Non-cropland application (NCID). This table contains the C and P-Factor for USLE. The C factor is a value given for "type of crop" and the P factor is a value for the practice being applied (obtained from USLE).
  - Fertilizer application (FTID). This table contains fertilization compounds, dates applied, crop name, and application rates. The information is based on fertilizer type and chemical composition.

- Pesticide application (PEID). This table contains attributes for pesticide date, crop name, application rate, and pesticide used. Types of pesticides are grouped according to chemical composition and half-life

- Watershed System Data (WSID). This data is a critical part of the total database for AGNPS and includes the watershed area data and the geomorphic region data. Fluvial geomorphology principles applicable to natural channels were measured in the field. AGNPS requires data on side slope of channel cross-section, Manning's "n" value, bankfull flow depth, top width at bankfull and D_{90} data (the exponential curve for the bed material particle size passing the D (diameter)$_{90}$ sieve). Cross sections were measured in the field using cloth tape, hand level, rod, and were geo-referenced using Global Positioning System (GPS) equipment. Figure 4. shows the subdivisions within the watershed.

- Drainage Network. Streams were compiled, digitized, and labeled according to the USGS topographic 7.5-minute series and the orthophotography. Small channels were extended up to the headwaters of every tributary and branch. AGNPS requires each grid cell to be linked to an adjacent cell for drainage.

- Derived Data and Associated Databases. The AGNPS model to derive information necessary to produce output utilizes the data listed above.

- **Soils**. AGNPS derives two data attributes from soil physical properties. These are soil bulk density-oven dry (g/cc) and porosity in inches.

- **Field Data.** The spatial field data runs in AGNPS as entered in the attribute table.

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- **Elevation Data.** The 30 meter DEM requires no derivation, only inspection to check for errors.

- **Watershed System Data.** Derived data for the watershed are used to create sub-watershed boundaries and respective drainage areas specific to the particular location. This calculation is essentially a calculation of the size of the drainage area and the subarea.

- **Stream System Data.** This derived data is used to augment the elevation data and derive the stream channel system. Derived data attributes include Manning's "n"value for the channel and overland flow, stream segment length, and drainage area.

Runtime Data Requirements

AGNPS permits the running of different scenarios. Runtime data requirements are the unique conditions that are subject to change in order to simulate specific scenarios. For AGNPS, the runtime parameters are quite simple. They include 24 hour rainfall by frequency (inches), rainfall erosion index (EI, (a mean of rainfall intensity), month of year, and the day the simulation begins. The user enters the runtime data before running the program.

Chapter 4. System Performance

System performance is reviewed in three general ways for this project. First, the user interface design is outlined and reviewed. The next step in the work involves an overview of machine performance. Finally, consideration is given to output from the model operating on actual field data.

The User Interface. The user interface for this tool was developed using Motif and is designed to give the user a logical, integrated set of commands that are easily understood and enable accurate entry of runtime data. Developed and distributed by Integrated Computer Solutions, Motif is an interface specification with a set of development libraries with reusable library objects. Motif works well with the Sun Operating System particularly the sharing of X11 libraries where any X11R5-compliant sets are compatible.

The first consideration of this project was to facilitate the system user and the structure of the organization. For this project the user is assumed to be an inexperienced computer user in a field office situation. Therefore, a straightforward, easily understood logic had to be designed into the GIS interface so that the user could work through the functions of the software without confusion or error. There are a variety of Motif tools available to produce menu action screens. In designing an interface, consideration had to be given to programming, graphic design, cognitive psychology, and in this project, overcome limitations of the processor to handle all the processes for the model to successfully execute. Many developers use scheme diagrams for "sketching" the requirements of the command bar or user interface (Laurel, 1990). The user view of the command window is shown in Figure 6.

In testing the user interface, two approaches were used. First, an experienced GIS specialist with development experience moved through the menus to complete a simulation with the interface. Next, a recently hired soil conservationist was requested to interact with the menubar and command line for the tool. The soil conservationist was observed using the interface and the results of each task are noted below. The experienced GIS specialist moved through the creation of a simulation with minimal problems. The inexperienced field specialist had problems using the menus. She struggled somewhat with the distinction between defining and running a procedure. While it is easy to shift operational modes between simulation and projects, entry and exit from a particular mode of operation is not always clear. For example, the field specialist had several simulations running at one time but did not know how or why. Not only did she stack up several simulations but corrupted the data in one case. One major discovery here is that entry and exit from operational modes on a command bar must be very explicit. The user's understanding of the interface will improve with experience. It is also recommended that a user be familiar with the local area when reviewing results from the simulation. The Runtime Screen as it appears to the user is shown in Figure 7. Figures 8 and 9 show output from the tool based on a 100-year storm event and a baseline condition, respectively.

Machine Performance.

A common factor between the experienced and inexperienced user is that of the limited processing power of the computer hardware. In most cases, a simulation took several hours to run and many times had to be done overnight. Where raster size was less than five hectares, the simulation failed due to insufficient Random Access Memory (RAM).

The interface and data manipulation requirements proved to be more than the Sun Sparc Station with 128 Megabytes of RAM could process efficiently. Simulations were limited to a raster size of about 200 meters. The data was developed to a spatial resolution of 30 meters. In seeking to run simulations on a raster size of 30 meters, the machine could not complete the process. Moreover, using the Solaris-based scripts, there was no warning or error message to indicate this problem The inability of the processor to handle the processing load is a prime example of how the system was unable to answer the most important question for NRCS: how can we show progress on understanding environmental processes?

The next section examines the three areas of implementation: institutional barriers, cultural barriers, and machine limitations.

Chapter 5. Implementation from the Organizational Perspective.

Those who advocate the use of Geographic Information Systems frequently claim that at the initiation of a project that the organization should realize benefits in increased productivity, quick responses to questions, and better quality information. There are a number of obstacles that prevent the successful completion of a GIS project, many of which are institutional rather than technological. Any organization must fully appreciate and integrate the realization that successful GIS implementation takes large investments of time, money, and people. Recent research in technology implementation suggests that organizational and management concerns are critical factors for success. The literature in this area is rich in successes and failures in implementing GIS, but information on actual performance of established systems are less widely available (UCGIS, 1998).

Organizational Context

There is a need in GIS research for more studies that evaluate the technology in an organizational context. The benefits realized by the agency or organization is many times the "indicator of success". For example, it is easy to submit cost-benefit studies to show how GIS will benefit the organization, but once the system is installed these cost-benefit studies are many times forgotten. Eason (1988) noted three general areas of benefit that an agency could gain from information technology such as GIS. He outlined these as: a) an improved cost efficiency, b) improved decision support, and c) overall agency improvement. Brown and Brudney (1993) also listed three general areas where public organizations could benefit from the implementation of GIS technology: a) productivity, b) decision making, and c) customer service. It has been the experience of the author that there are three general barriers that exist when any organization moves to implement GIS technology. These may be referred to broadly as institutional, cultural, and state of the industry (state of the technology). This project examines these barriers in a case study where an organization attempts to integrate complex technology that ultimately fails to be implemented. Other workers have described similar barriers. Sivertun, 1993 noted the "four legs" of GIS creation as GIS, humans, databases, and hardware/ software, each of which must stand if the project is to succeed.

The current literature in GIS contains many stories of well-intentioned projects that ultimately failed due to one or all of the above barriers. For example, the Land Use and Natural Resources (LUNR) system of the state of New York failed mainly because of poor design and a general failure to anticipate the special technical problems encountered in the processing of large volumes of data (Peuquet, 1990). The current report details the attempts of a federal agency to develop a complex water quality tool for field use. The case study involved the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA). In 1995, the NRCS sought to develop a water quality tool that could be used to provide data on the results of applied conservation practices applied on a watershed basis. The target date for implementation was 1999. At the time, the agency had no information on whether or not their watershed programs were effective in reducing nutrient transport from farm fields to streams. Conceptually, this project was designed to help answer these questions. Decision support was the first goal of the GIS/model project. The critical resource question being addressed was 'how can the agency account for and promote water quality programs without a system to assist in determining their overall effect?'

Institutional barriers.

Numerous barriers limiting GIS implementation strategies are often imposed by the institution actually implementing the project. Large federal agencies, with their inherent bureaucratic structure, often create barriers and a political climate that does not reflect the best interest for the project or the public need in general. Institutional barriers affecting the development and successful implementation of this project were mainly associated with the phases of conceptual development and testing taking place on an administrative level far removed from the field office setting where the tool would ultimately be used.

The development was at the national level at the Information Technology Center located in Ft. Collins, Colorado. The agency headquarters continually moved on to more complex operations and new model requirements before the field developers were efficient in implementing and using the previous release. The project moved from using AGNPS alone to more complex models such as Groundwater Loading Effects of Agricultural Management Systems (GLEAMS), Simulator for Water Resources in Rural Basins-Water Quality (SWRRB), and Erosion Productivity Impact Calculator (EPIC). Data requirements changed and increased with the models and the data became increasingly complex and time-consuming to gather. The cascade of differing model data requirements created confusion for the field data collectors. In retrospect, the agency was naïve in believing that the successful implementation of four water quality models in one tool could be accomplished, particularly in view that the technology development resided in a small, elite development staff at Ft. Collins and a few, well-trained field personnel. Moreover, developing four models simultaneously with field staff working on one but not the other created a sense of fragmentation, lack of common goals, and inefficiency. As a field developer for the AGNPS tool, this writer had little communication with other developers and therefore very little knowledge of what the other developers were doing. Prolonged testing created another institutional barrier and evaluation that continued through several annual budget cycles which eventually resulted in a loss of funding support for the project at the national level. In many ways, the NRCS failed to realize the full scope and requirements of the GIS application with respect to computer processing capability, the geographic extent and size of the numerous parameters, and the difficulty for field personnel to grasp the fundamentals of GIS use in the field office setting.

Cultural Barriers.

Cultural barriers are not as easily defined and evaluated as those considered institutional or structural, but their effects can be substantial. Cultural barriers are those factors in the organization that affect GIS implementation as a result of the perceptions, beliefs, and actions of people making up the organization. This includes, but not is limited to, educational background, median age of the staff, attitudes toward technology, and the current state of corporate knowledge of GIS. Many authors mention the steep learning curve related to GIS technology implementation and this is exacerbated by diversity of staff abilities and attitudes. Cultural barriers had a profound effect on the outcome of this project and were a major contributor to the failure in implementing the tool.

In an evaluation of the database structure of the soil survey data system this writer reported that NRCS personnel are generally unsophisticated when approaching computers (Carpenter, 1988). At the time, the agency (then the Soil Conservation Service) was using the Bell Laboratory's System V UNIX operating system and a Prelude table structure for storing data. This cultural barrier (that of lack of technical or computational sophistication) still persists today after over a decade of development and growth in data processing technology. It may be termed "computer illiteracy" or may be a resistance to technical innovation. The general staff of NRCS still uses the Universal Soil Loss Equation-Revised (RUSLE) in erosion prediction largely due to its simplicity but there is no provision for analysis and display of spatial information under different management scenarios. AGNPS uses USLE for sediment delivery calculations. NRCS personnel are familiar with USLE but in briefing the staff on GIS-driven AGNPS (USLE) project for Greenbrier County in West Virginia, this writer received no questions or comments. The implications of this fact are quite clear: AGNPS is capable of providing useful values without the use of GIS, even though the process takes longer and does not necessarily yield data on the whole watershed. The field staff were not using AGNPS even in analogue form. The cultural barrier is also manifest in the requirement for training even in the most elementary topics of GIS.

State of the Industry (technology)

Dealing with an ever-changing landscape of new innovation is one of the most challenging areas of GIS implementation. For the purposes of this project, system development was completed on a complex combination of software and hardware. The computer code for this project was compiled from the FORTRAN language to run on a Solaris-based SUN SparcStation 20 with the Geographic Resources Analysis Support System (GRASS), and Informix SQL. By the time the tool was ready for prototype testing (1999), the agency had selected Microsoft Windows NT as the platform of choice for all field locations. Dealing with the rapid movement of technology proved to be one of the most powerful factors affecting the outcome of the project. This raises several serious questions related to the implementation of GIS technology in organizations. For example, has GIS lived up to its potential? How does one deal with technology aas a continuously moving target? There is considerable debate on this issue within the NRCS at this particular time and the conclusions are mixed.

Chapter 6. DISCUSSION

GIS capability (both software and data) for this project took over two years to develop. Relational tables had to be constructed using the UNIX vi editor and the soil survey and land use coverages had to be manually compiled to a stable base for digitizing. After all required coverages were developed, two simulations were tested for review. One simulation was designed to show baseline conditions under normal rainfall. Another simulation was developed for comparison to record a 100-year storm event. The results of these two simulations are given in Table 1. below.

Table 1. Comparison of Simulations (Losses to Water per Acre per Year)

Simulation	Phosphorus	Nitrogen Levels	Total Erosion
Baseline Condition	0.0300 lbs./acre	0.45 lbs./acre	303 Tons
100 year Storm	1.46 lbs./acre	0.56 lbs./acre	3674 Tons

These values appear to be within expected thresholds of sedimentation and nutrient yield. These values are calculated for the entire watershed area. The values shown in Table 1 are for soluble Nitrogen and Phosphorus loading in runoff for the entire watershed. Total erosion is the total sediment load at the outlet for the watershed. The contrasts in these simulations reveal the shortcomings of a single event model such as AGNPS.

Soil erosion is the primary vehicle for pollutants and subsequent agricultural water quality problems in the United States. All geographers must realize and accept this fact when considering pollution from agriculture. An international conference was held in the United Kingdom in 1972 to discuss water pollution from agriculture (Cooke and Williams, 1973). The conclusions of the conference were that erosion control is the primary concern for minimizing pollutant runoff. Twenty-five years later, scientists were still making the same recommendations (Sharpley, 1997). NRCS utilizes the revised Universal Soil Loss Equation (USLE-R) for conservation planning which is a viable tool on most of the major cropland areas of the United States. Since the USLE was developed on medium textured, moderately sloping soils in the Midwest, it returns acceptable values on erosion rates for the soils in this area. As previously pointed out, it is also easy for field staff to use. However, USLE's sensitivity to slope and length of slope make estimations on erosion from landscapes in Appalachia questionable. Many resource planners in NRCS dismiss erosion values from USLE on steeper slopes as unreliable. It is critical that a method to estimate erosion on steeper slopes be developed. Chaos theory applied to erosional surfaces in Appalachia has promising potential. This should be pursued.

NRCS is currently unable to use GIS for erosion prediction at the local level. The agency's move from a UNIX-based system to a WindowsNT environment has delayed

GIS operations for many programs and for all practical purposes postponed the goal of putting GIS into the hands of field personnel. The agency has two options in the opinion of this writer. They can integrate the models in a Visual Basic Code for ArcView (to use in a WindowsNT environment) or they can use the advantages of Reduced Instruction Set Code (RISC) in a UNIX environment by employing UNIX-based servers for the WindowsNT environment. Based on the amount of completed work in coding the models for this project, the option of using the Unixware servers seems the most viable route. It is disappointing to suggest that all the development in the UNIX environment will be lost to a shift in technology. In most cases however, the administration of such a system would be difficult for NRCS due to a shortage of skilled technicians. In reviewing a revised conceptual framework for this project, it is clear that a more efficient approach would have been to use the GRASS-GIS program without the AGNPS program code thus eliminating processor load in running the three-loop process for AGNPS. Using the compiled AGNPS code created a major processing load on the machine with the three-loop process of calculating flow from each cell (raster). In reviewing recent work in this area, the Watershed Module in GRASS can be used to handle most of the calculations required for this type of analysis within the GRASS software.

Conclusion

Future research on developing an erosion model is recommended for the complex landscapes typically found in Appalachia. AGNPS, which employs the USLE-R, does not deal effectively with steep areas with long slope lengths. It is not exactly clear what type of model would adequately address the multi-faceted, steep slopes in the Appalachian region. Researchers should pay particular attention to simulating continuous activity over time (AGNPS currently is a single-event model). It is further recommended that government agencies should obtain "off-the-shelf" software for complex tasks such as water quality analysis. There was much waste and delay involved in the NRCS developing its own model interfaces, particularly considering that, by programming the model in the C computer language, GRASS-GIS could have been used alone for this application. Moreover, GRASS-GIS is public domain software available at no cost to the user. At the time of initiation, the integration of AGNPS with GRASS-GIS was an innovative idea. The fact that the rapid development of hardware and software would overtake model development was not anticipated. In the event, the requirement of running three separate processes for AGNPS, GRASS, and the SQL proved too much for a single processor computer and for the technical competence of the average field office staff. The system ultimately failed due to institutional, cultural, and technological constraints. Operational GIS technology in the hands of NRCS field users remains an illusive, moving target for agency managers. This is a major concern for the NRCS considering that all their work is related to spatial processes on the landscape.

In the final analysis, AGNPS and GRASS-GIS were successfully integrated into a SUN Solaris environment but the result was seriously limited by both machine performance and complexity to be of value for field users. Figure 10 suggests a revised conceptual framework for this type of model integration where GRASS runs all of the AGNPS routines within the Watershed Module. More recently on a positive note, Purdue University has developed a UNIX version of AGNPS-GRASS which operates within the Watershed Module of GRASS. This successful integration eliminates the processing load for running the AGNPS program as a separate process and optimizes the robust raster capability of GRASS. The source code is available for distribution on the Internet at www.purdue.edu.

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Figure 1.

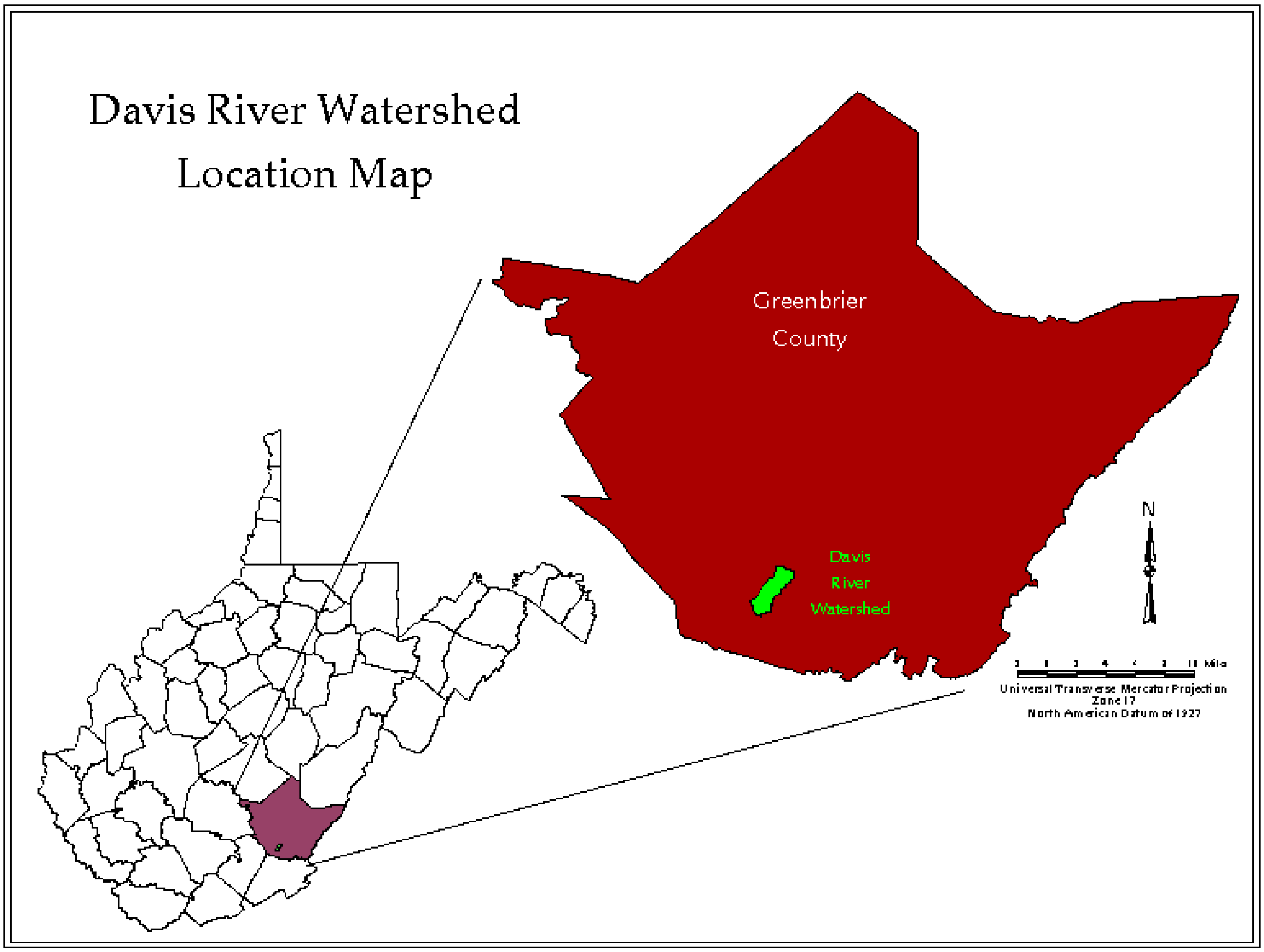
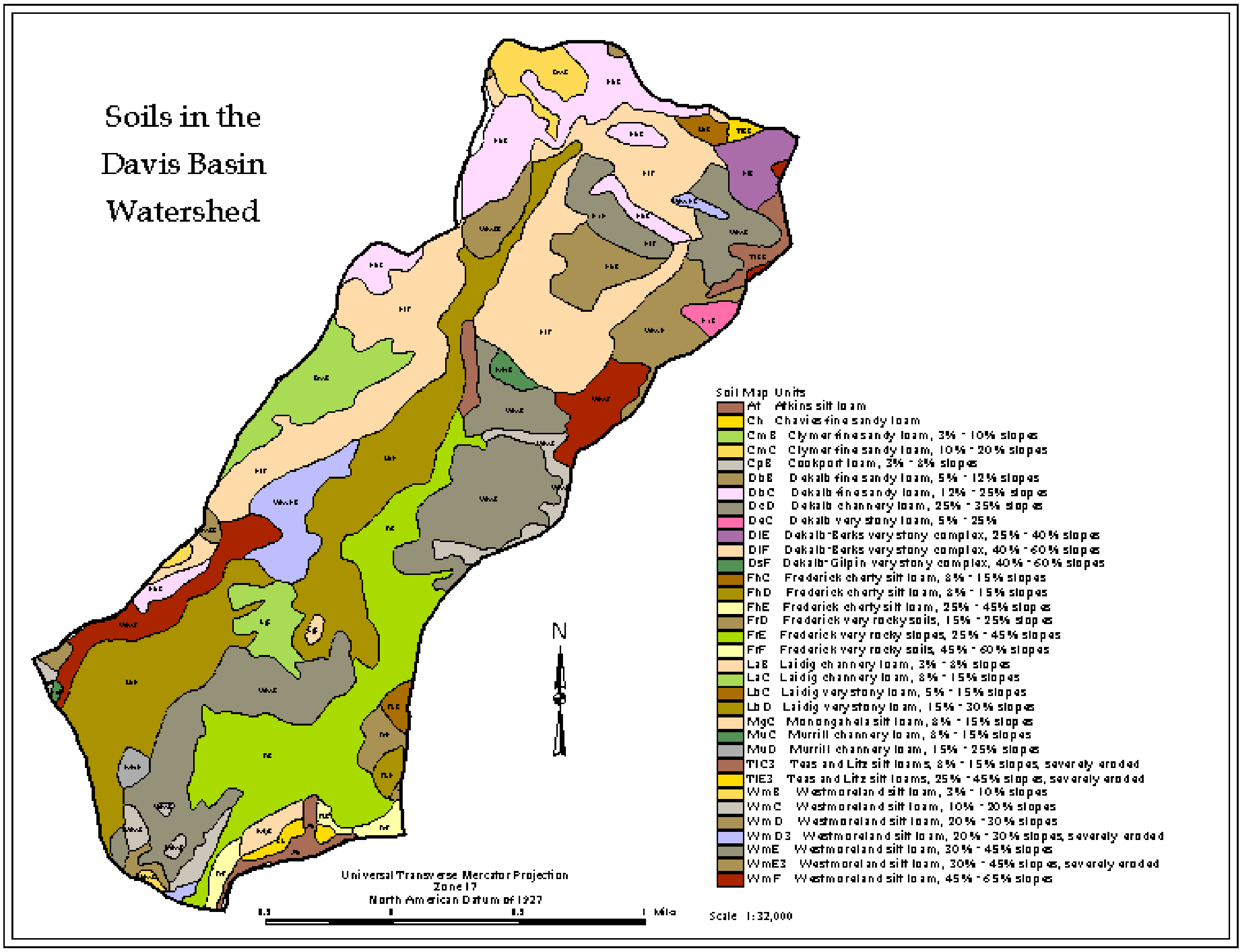
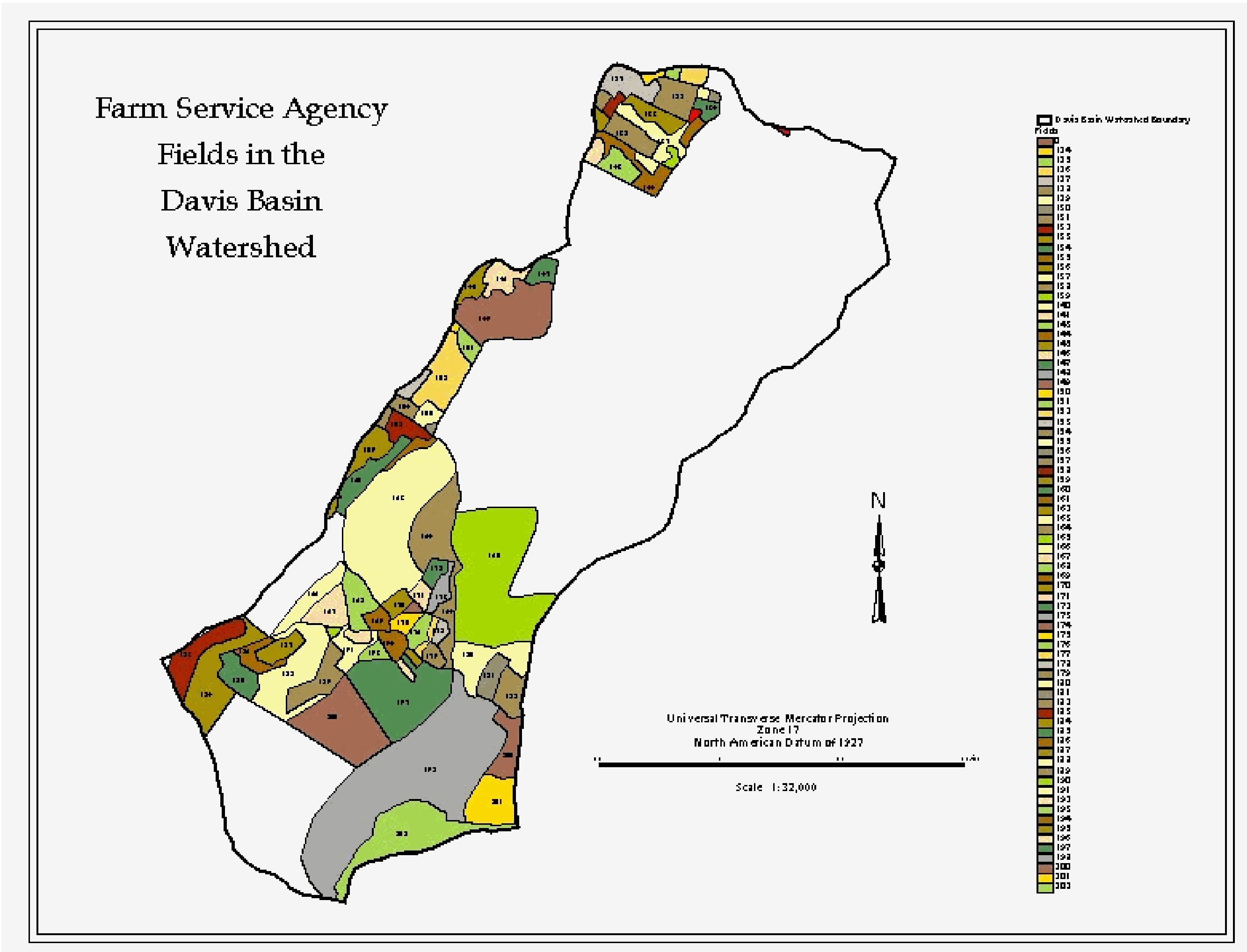

Davis River Watershed
Location Map
Greenbrier
County
Davis
River
Watershed
N
4
Universal Transverse Mercator Projection
Zone 17
North American Datum of 1927

Figure 2



Soils in the Davis Basin Watershed
Soil Map Units
At Atkins silt loam
Ch Chavies fine sandy loam
CmB Clymer fine sandy loam, 3% - 10% slopes
CmC Clymer fine sandy loam, 10% - 20% slopes
CpB Cookport loam, 3% - 8% slopes
DbB Dekalb fine sandy loam, 5% - 12% slopes
DbC Dekalb fine sandy loam, 12% - 25% slopes
DcD Dekalb channery loam, 25% - 35% slopes
DeC Dekalb very stony loam, 5% - 25%
DlE Dekalb-Berks very stony complex, 25% - 40% slopes
DlF Dekalb-Berks very stony complex, 40% - 60% slopes
DsF Dekalb-Gilpin very stony complex, 40% - 60% slopes
FhC Frederick cherty silt loam, 8% - 15% slopes
FhD Frederick cherty silt loam, 8% - 15% slopes
FhE Frederick cherty silt loam, 25% - 45% slopes
FrD Frederick very rocky soils, 15% - 25% slopes
FrE Frederick very rocky slopes, 25% - 45% slopes
FrF Frederick very rocky soils, 45% - 60% slopes
LaB Laidig channery loam, 3% - 8% slopes
LaC Laidig channery loam, 8% - 15% slopes
LbC Laidig very stony loam, 5% - 15% slopes
LbD Laidig very stony loam, 15% - 30% slopes
MgC Monongahela silt loam, 8% - 15% slopes
MuC Murrill channery loam, 8% - 15% slopes
MuD Murrill channery loam, 15% - 25% slopes
TlC3 Teas and Litz silt loams, 8% - 15% slopes, severely eroded
TlE3 Teas and Litz silt loams, 25% - 45% slopes, severely eroded
WmB Westmoreland silt loam, 3% - 10% slopes
WmC Westmoreland silt loam, 10% - 20% slopes
WmD Westmoreland silt loam, 20% - 30% slopes
WmD3 Westmoreland silt loam, 20% - 30% slopes, severely eroded
WmE Westmoreland silt loam, 30% - 45% slopes
WmE3 Westmoreland silt loam, 30% - 45% slopes, severely eroded
WmF Westmoreland silt loam, 45% - 65% slopes
N
Universal Transverse Mercator Projection
Zone 17
North American Datum of 1927
1 Mile
Scale 1:32,000

Figure 3.



Farm Service Agency
Fields in the
Davis Basin
Watershed
Davis Basin Watershed Boundary
Fields
N
Universal Transverse Mercator Projection
Zone 17
North American Datum of 1927
Scale 1:32,000

Figure 4.

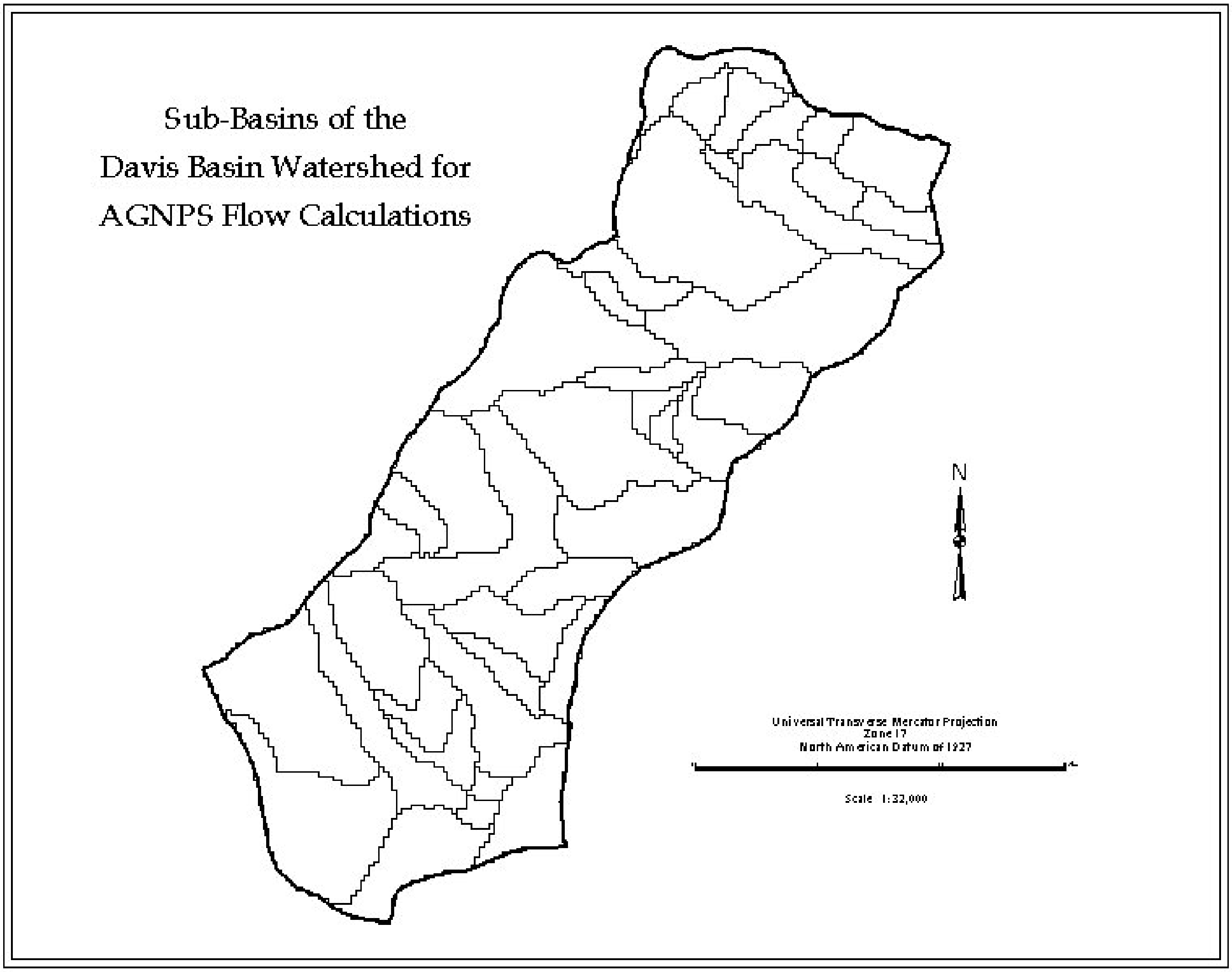

Sub-Basins of the
Davis Basin Watershed for
AGNPS Flow Calculations
N
Universal Transverse Mercator Projection
Zone 17
North American Datum of 1927
Scale 1:32,000

Figure 5.

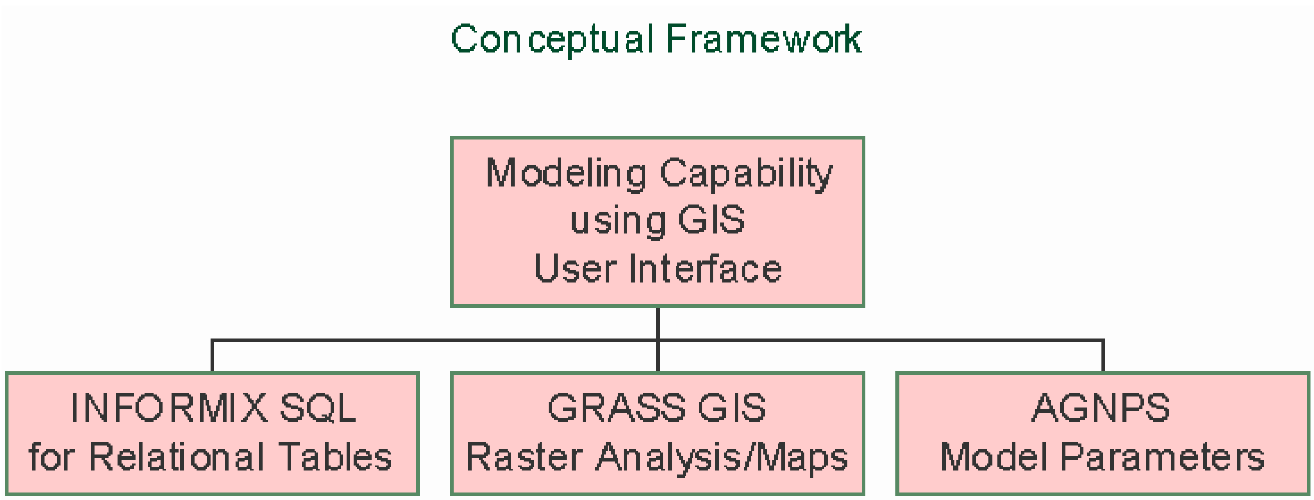

Conceptual Framework
Modeling Capability using GIS User Interface
INFORMIX SQL for Relational Tables
GRASS GIS Raster Analysis/Maps
AGNPS Model Parameters

Figure 6.

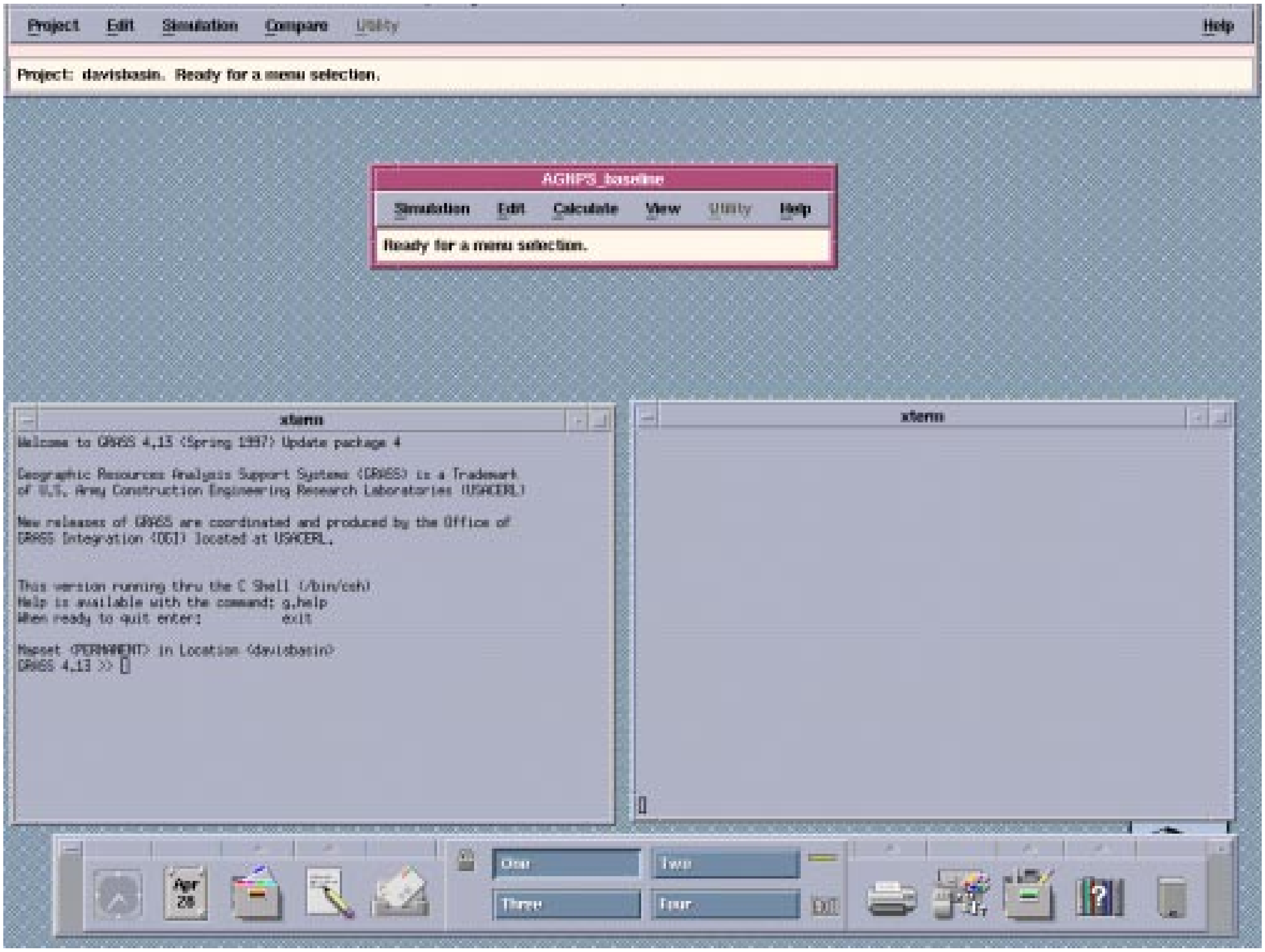

Project
Edit
Simulation
Compare
Utility
Help
Project: davisbasin. Ready for a menu selection.
AGNPS_baseline
Simulation
Edit
Calculate
View
Utility
Help
Ready for a menu selection.
xterm
Welcome to GRASS 4.13 (Spring 1997) Update package 4
Geographic Resources Analysis Support System (GRASS) is a Trademark
of U.S. Army Construction Engineering Research Laboratories (USACERL)
New releases of GRASS are coordinated and produced by the Office of
GRASS Integration (OGI) located at USACERL.
This version running thru the C Shell (/bin/csh)
Help is available with the command: g.help
When ready to quit enter: exit
Mapset <PERMANENT> in Location <davisbasin>
GRASS 4.13 >>
xterm
One
Two
Three
Four

Figure 7.

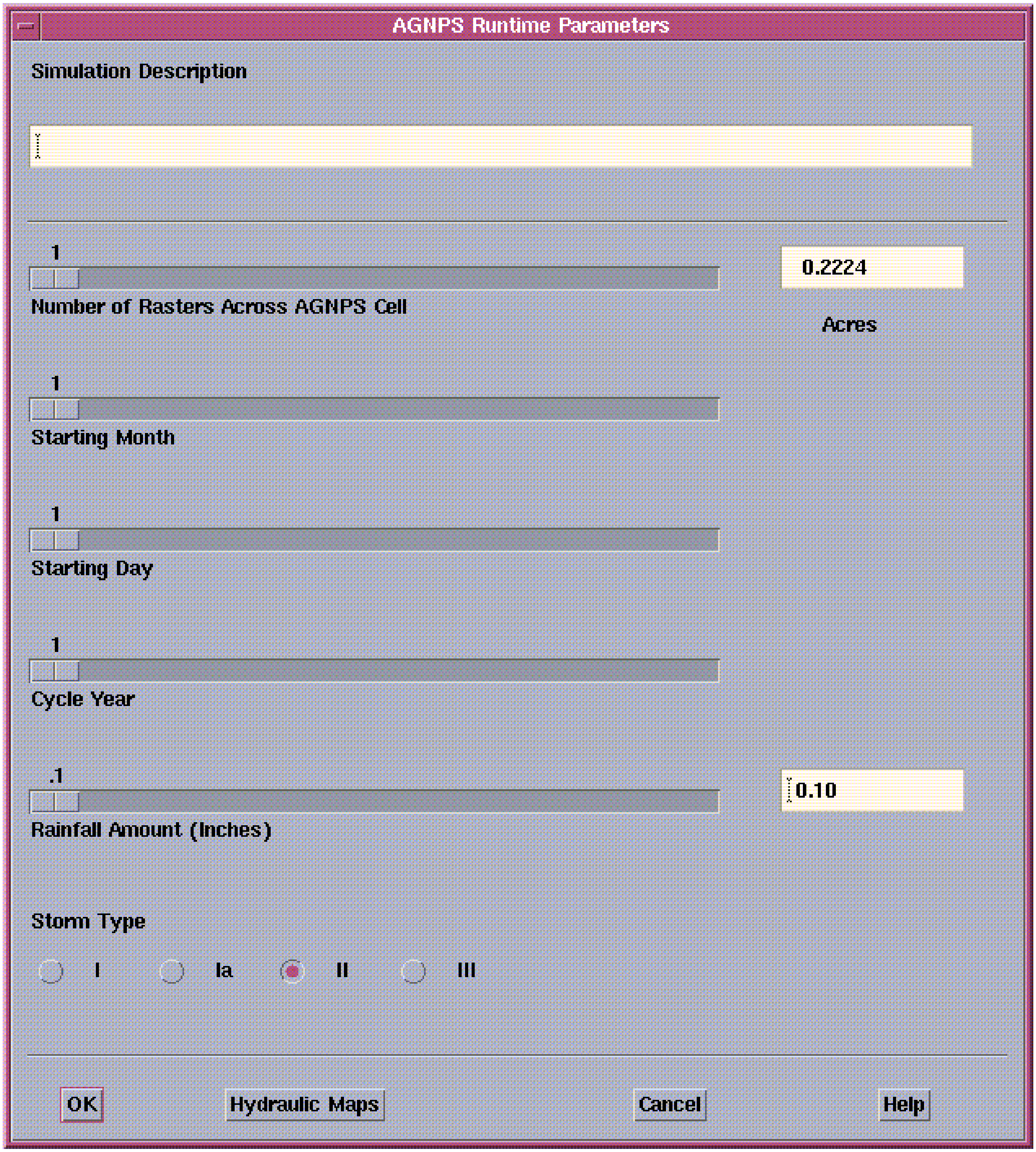
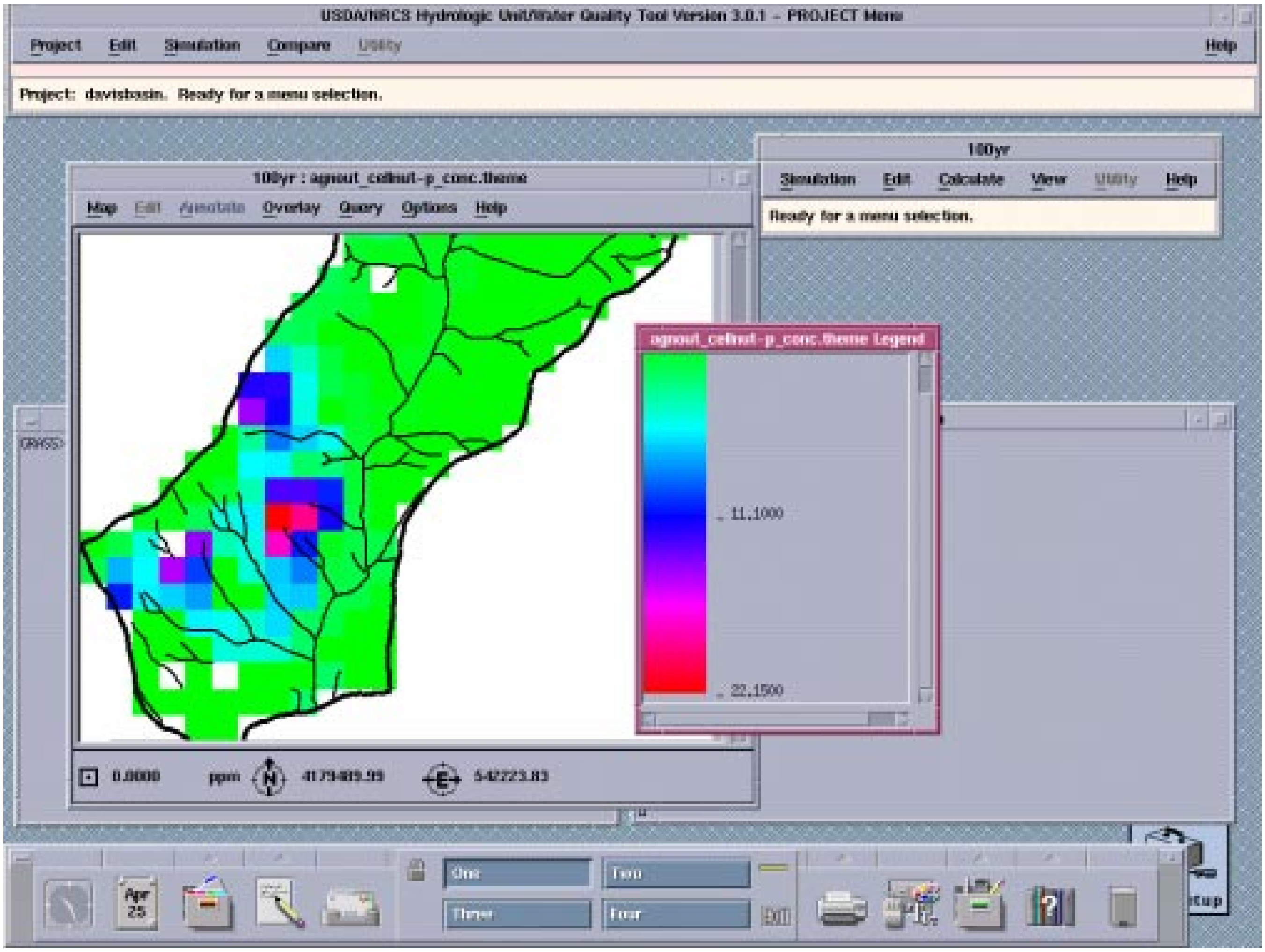
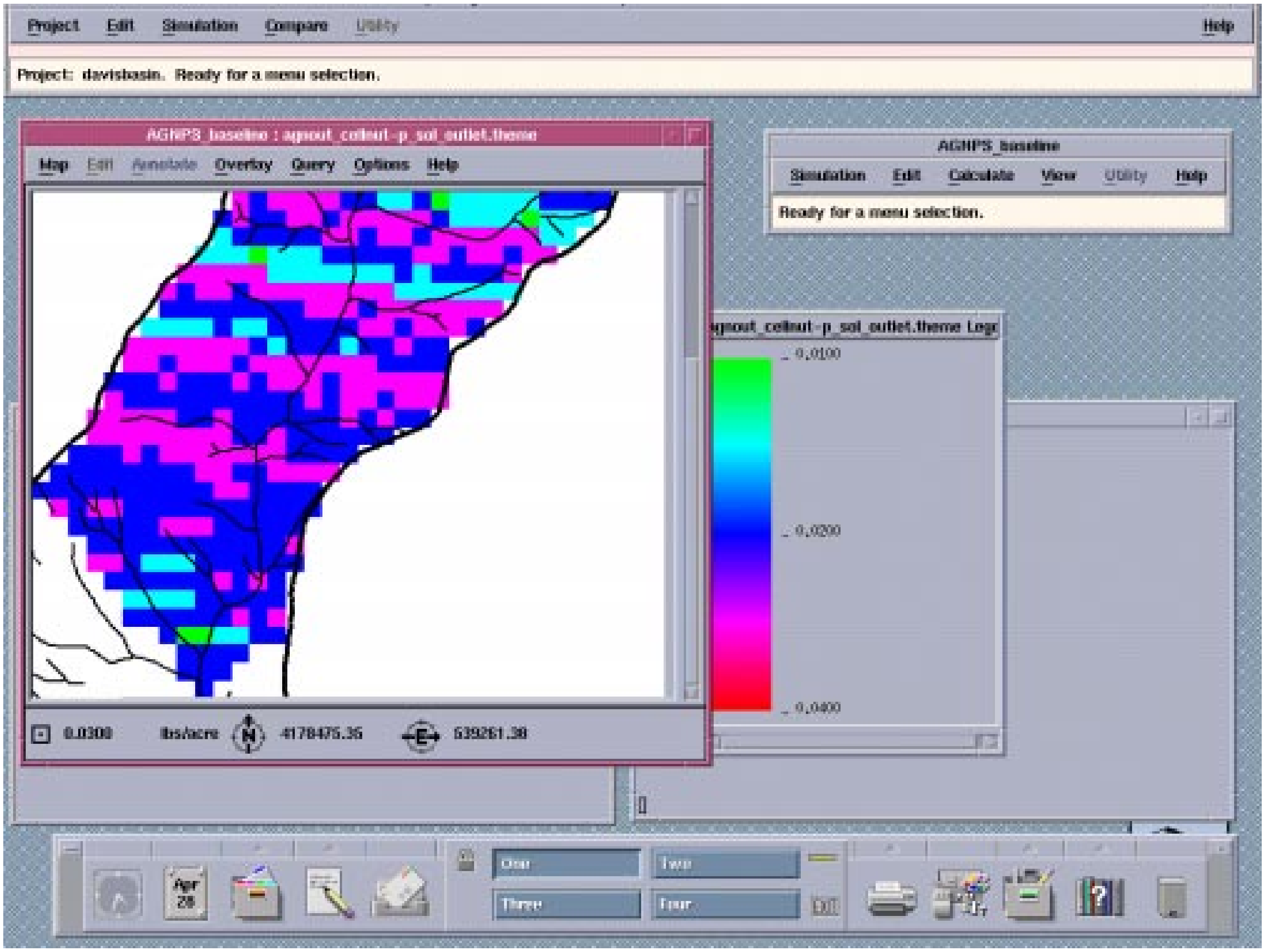

AGNPS Runtime Parameters
Simulation Description
1
Number of Rasters Across AGNPS Cell
0.2224
Acres
1
Starting Month
1
Starting Day
1
Cycle Year
.1
Rainfall Amount (Inches)
0.10
Storm Type
I
Ia
II
III
OK
Hydraulic Maps
Cancel
Help

Figure 8.



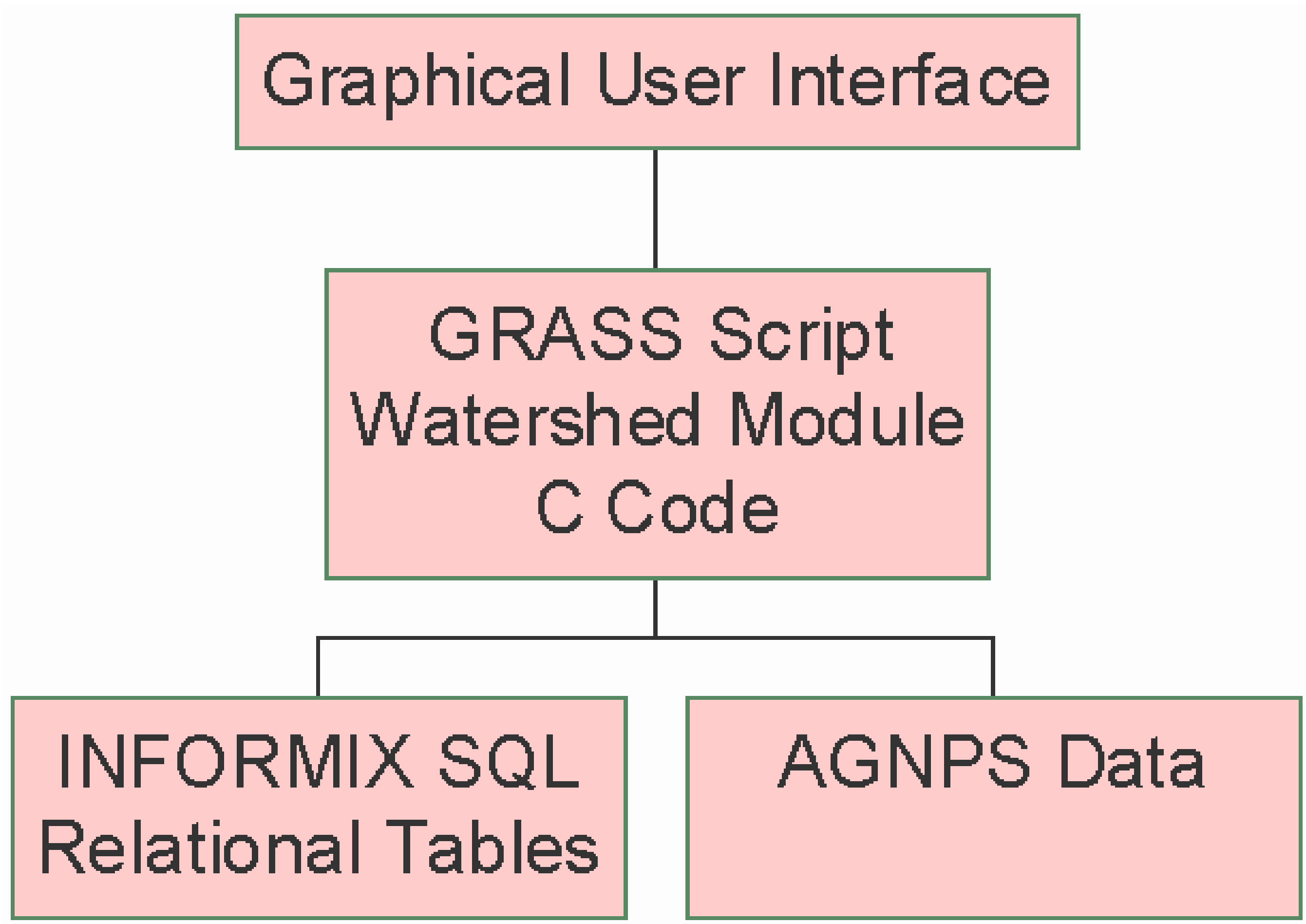
USDA/NRCS Hydrologic Unit/Water Quality Tool Version 3.0.1 – PROJECT Menu
Project Edit Simulation Compare Utility Help
Project: davisbasin. Ready for a menu selection.
100yr
Simulation Edit Calculate View Utility Help
Ready for a menu selection.
100yr : agnout_cellnut-p_conc.theme
Map Edit Annotate Overlay Query Options Help
agnout_cellnut-p_conc.theme Legend
11.1000
22.1500
0.0000 ppm
One
Two
Three
Four

Figure 9.



Project Edit Simulation Compare Utility Help
Project: davisbasin. Ready for a menu selection.
AGNPS_baseline : agnout_cellnut-p_sol_outlet.theme
Map Edit Annotate Overlay Query Options Help
AGNPS_baseline
Simulation Edit Calculate View Utility Help
Ready for a menu selection.
0.0100
0.0200
0.0400
0.0300 lbs/acre 4178475.35 539261.38
One Two Three Four

Figure 10.


Graphical User Interface
GRASS Script
Watershed Module
C Code
INFORMIX SQL
Relational Tables
AGNPS Data