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Upper Auglaize Watershed AGNPS Modeling Project Final Report

Prepared For:

U.S. Army Corps of Engineers—Buffalo District

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GLOSSARY OF ACRONYMS

Acronym	Description
AGNPS	Agricultural Non-Point Source Pollution Model, a suite of computer models used for watershed-scale best management practice analyses.
Agua_GEM	Computer program used to create custom climate statistics used by GEM.
AnnAGNPS	Annualized Agricultural Non-Point Source Pollution Model, a computer program used to determine pollutant yields and loadings anywhere in the watershed.
ArcView	Proprietary, commercially available GIS software.
ARS	Agricultural Research Service
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BMPs	Best Management Practices
CCHE1D	National Center for Computational Hydroscience Engineering 1-Dimensional Model
CEAP	Conservation Effects Assessment Program
CONCEPTS	Conservational Channel Evaluation and Pollutant Transport System Model
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CSV Files	Standardized comma separated variable files
DEM	Digital Elevation Model
DLG	Digital Line Graph
EGEM	Ephemeral Gully Erosion Model
EQIP	Environmental Quality Incentive Program
ERDAS	Software used to analyze LANDSAT imagery.
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
GEM	Generation of Weather Elements for Multiple Applications Computer Model
Genpar6	Computer program used to create custom climate statistics used by GEM.
GIS	Geographic Information System
LANDSAT	Databases from satellite imagery.
LEASEQ	Lake Erie Agricultural Systems for Environmental Quality
LTMS	Long-Term Management Strategy
LULC	Land Use/Land Cover
NASIS	National Soil Information System
NAWQA	National Water Quality Assessment Program
NRCS	Natural Resources Conservation Service
ODNR	Ohio Department of Natural Resources, Division of Soil and Water Conservation
Ohio EPA	Ohio Environmental Protection Agency
PC	Personal Computer
POW	Plan of Work
RAM	Computer random access memory
REMM	Riparian Ecosystem Management Model
RUSLE	Revised Universal Soil Loss Equation
SIDO	Sediment Intrusion and Dissolved Oxygen Model
SNTEMP	Stream Network Water Temperature Model
SSURGO	Soil Survey Geographic Database
SWCD	Soil and Water Conservation District
TKN	Total Kjeldahl nitrogen
TMDLs	Total Maximum Daily Loads
TOPAGNPS	A computer model which is a subset of TOPAZ written for AGNPS.
TOPAZ	Topographic Parameterization Computer Model
USACE	U. S. Army Corps of Engineers
USDA	U. S. Department of Agriculture
USGS	U. S. Geologic Survey
UT	University of Toledo

Executive Summary

The Upper Auglaize Watershed agricultural non-point source modeling project was an interagency effort to use a Geographic Information System (GIS)-based modeling approach for assessing and reducing pollution from agricultural runoff and other non-point sources. This project applied the U.S. Department of Agriculture (USDA), Agricultural Research Service's AGricultural Non-Point Source (AGNPS) suite of models to the Upper Auglaize River Watershed, a major watershed within the Maumee River Basin. This modeling project was conducted by an interagency team consisting of a partnership between the: (1) USDA, Agricultural Research Service (ARS); (2) USDA, Natural Resources Conservation Service (NRCS); (3) U.S. Army Corps of Engineers (USACE); (4) U.S. Geological Survey (USGS); (5) Ohio State University; (6) University of Toledo (UT); (7) Heidelberg College; (8) Ohio Department of Natural Resources (ODNR), Division of Soil and Water Conservation; (9) Ohio Environmental Protection Agency (OEPA); and (10) Allen, Auglaize, Van Wert, and Putnam Soil and Water Conservation Districts. The partnership was the first step in a process to eventually apply the model in a portioned subset of watersheds for the Maumee Basin, and then to link them to form a comprehensive basin-wide model This work was performed under the authority of Section 516(e) of the Water Resources Development Act (WRDA) of 1996, as amended, for the purpose of assisting State and local watershed managers with their evaluation, prioritization and implementation of alternatives for soil conservation, sediment trapping and non-point source pollution prevention in the Upper Auglaize River watershed.

The project team, working in a cooperative effort, used the models to determine sediment sources, contributing locations, and the effect of application of best management practices (BMPs) on rates of sediment delivery to the mouth of the watershed. The results will be used to guide conservation incentive and land treatment programs. The team relied heavily on Geographic Information System (GIS)-based applications to expedite the application of the model.

The results of the analysis demonstrated that the application of BMPs would have a positive effect on reducing the loadings of sediment leaving the mouth of the Upper Auglaize Watershed. An application of 17 percent new no-till acres and eight percent new grassland acres, when randomly applied to the watershed, reduced loadings at the mouth to 82 percent of the simulated existing condition loadings. No-till, conversion of cropland to grassland, other uses including grass buffers, and reforestation of parts of the watershed, were all shown by the model to have a measurable effect on reducing sediment loads. Conversion of all of the cropland in the watershed to no-till would reduce the average unit load (tons of sediment per acre) leaving the mouth of the watershed to a level that is 42 percent of the simulated existing condition load.

Ephemeral gullies were found to be the primary source of erosion (72 percent), sediment yield (73 percent), and sediment loading (73 percent). Controlling sediment load means controlling gully erosion and possibly trapping sediment yield before it reaches the stream system. Most BMPs (e.g., no-till, conversion of cropland, etc.) that reduce sheet and rill erosion and its sediment yield will also reduce gully erosion and its sediment yield. However, grassed waterways, which have no effect on sheet and rill erosion, are frequently an effective BMP to prevent ephemeral gullies. And, of course, riparian vegetation and sediment traps would reduce the delivery ratios of all types of landscape erosion.

New techniques were developed by the team to quantify the ephemeral gully erosion within the model. When calibrated to available stream gage data the model suggests that more (73% in the existing condition simulation) of the sediment load originates from ephemeral gully erosion than from traditional sheet and rill erosion.

The model quantified the value of tile drainage in reducing the sediment load from the watershed. Loadings under drained conditions were always less than loadings under undrained conditions for otherwise identical land uses. The average sediment load of all alternatives for drained loadings was 89.2 percent of the load for the corresponding undrained loadings. The model established that while many conservation incentive programs treat tile drainage as a production practice, significant erosion and sediment control benefits are provided by the practice in comparison to cultivation in an undrained state.

MAUMEE RIVER BASIN: UPPER AUGLAIZE REPORT

I. INTRODUCTION

A. OVERVIEW

Under the authority of Section 516(e) of the Water Resources Development Act (WRDA) of 1996, as amended, the US Army Corps of Engineers (USACE) is directed to develop sediment transport models for tributaries to the Great Lakes that discharge into Federal navigation channels or Areas of Concern (AOCs). These models are developed to assist State and local watershed managers with their evaluation, prioritization and implementation of alternatives for soil conservation, sediment trapping and non-point source pollution prevention. On average, the USACE and the Port of Toledo spend approximately $2.2 million each year to dredge a long-term average of 850,000 cubic yards of sediment from Toledo Harbor. Environmentally acceptable alternatives may be less costly than dredging. A significant amount of the sediment dredged originates from farm fields in northwest Ohio and portions of Indiana and Michigan within the Maumee River Basin. A long-term goal has been established to reduce sediment loadings by 15 percent through the increased use of soil erosion control techniques. In addition, the Lake Erie Protection and Restoration Plan established a goal of reducing agricultural sediment loading from the Lake Erie watersheds by 67 percent.

Although the causes of soil erosion and the methods of control are well known at the farm field scale, less is known about the transport of eroded soil and sediment through the stream system at the watershed scale. The Upper Auglaize Watershed Modeling Project is a conservation partnership to reduce erosion in the Maumee River Basin and to determine ways to reduce sediment delivery to Toledo Harbor. The project team applied the U.S. Department of Agriculture (USDA), Agricultural Research Service's (ARS) AGricultural Non-Point Source pollution model (AGNPS) to measure erosion, sediment delivery pathways, and sediment delivery yields and loads; and to develop effective conservation treatment strategies and best management practices (BMPs) for the watershed. The application of AGNPS will fill gaps in the current scientific knowledge base. Figure I-1 and Figure I-2 show dredging of the Toledo Harbor.

Figure I-1: Dredging of Toledo Harbor

Figure I-2: More dredging of Toledo Harbor

B. PARTICIPATING AGENCIES

The Upper Auglaize AGNPS Project is a partnership of the following participating agencies and organizations:

- U.S. Army Corps of Engineers (USACE)
- USDA Natural Resources Conservation Service (NRCS)
- U.S. Geological Survey (USGS)
- USDA Agricultural Research Service (ARS)
- University of Toledo (UT)
- The Ohio State University
- Heidelberg College–Water Quality Lab
- ODNR Division of Soil and Water Conservation (ODNR)
- Ohio Environmental Protection Agency (Ohio EPA)
- Allen, Auglaize, Van Wert and Putnam Soil and Water Conservation Districts (SWCD's)

C. HOW PROJECT WAS ORGANIZED & TEAM OPERATED

The project operated via a team approach. The project was initiated as an outgrowth of the Toledo Harbor Long-Term Management Strategy (LTMS) process. NRCS, USGS, Ohio EPA and the USACE recognized the need for modeling data to quantify the effects that accelerated land treatment programs would have on the Toledo Harbor. This core group developed a project proposal that was funded by USACE via Section 516(e) of the Water Resources Development Act of 1996. The project proposal identified the needed expertise, the agencies that could provide that expertise, and project costs to do this work. Once the project was funded the agencies assigned individuals to represent them and to assist the team.

The first task of the team was to receive training in the AGNPS model. Simultaneously a project work plan was developed, which identified necessary tasks, responsibilities, and timelines for each task. ARS led this effort, which commenced in May of 2002.

The group operated as a self-directed work team and work was distributed appropriately among the agencies and by tasks as outlined in the work plan. NRCS provided coordination and team leadership to call meetings, enhance team communication, etc. NRCS provided storage space on a common server where all team members could go to deposit, view, or check out work products, data, or databases that were developed. A group e-mail listing was also developed. Both of these tools proved invaluable to enhance communication and make it easy for team members to work together even though they were physically housed over many parts of the country. Face to face meetings were also held at various milestones during the process to share work, edit, troubleshoot, and make decisions.

The team approach had some disadvantages. Since everyone was participating as a collateral duty, other agency work needs took priority and slowed progress. Due to this and the fact that this effort was modeling a very large watershed, the project took more time than planned and stretched out the timelines as shown in the original plan of work (POW). In spite of this, the team approach had a huge benefit, which outweighed any shortcomings. Each organization brought to the table specialized expertise, not available in all agencies. No one entity could have had all the skills or resources needed to complete this effort alone. In the process, the team developed new and efficient techniques for using remote sensing and the GIS interfaces to automate the population of some of the model data bases. Without these automated techniques, it is improbable that a watershed this size could have been effectively modeled with the resources and time available.

D. Responsibilities of Various Agencies

Each team member assisted the project as follows:

U.S. Army Corps of Engineers (USACE) (Buffalo District) provided funding for the project, assigned a staff member to work with the project team, and reviewed the final report.

USDA Natural Resources Conservation Service (NRCS) (Ohio) provided administrative leadership, agronomic, engineering, soils, and resource conservation assistance to the team. NRCS housed the model and provided a hydrologist to make the more than 19 different runs of the model. It also developed the digital soils information, crop management system data bases, and conservation-tillage transect data. It assisted the University of Toledo (UT) in refining the land use remote sensing findings. NRCS developed the alternative conservation treatment scenarios that were used for the various model runs. NRCS provided the common server for use by the team members and prepared & printed the final report.

USDA Natural Resources Conservation Service (NRCS) (National Water & Climate Center) assisted with training the team, in developing new techniques & routines to quantify the ephemeral gully issues, in troubleshooting problems, and in writing & editing the final report.

U.S. Geological Survey (USGS) conducted field surveys, developed the hydraulic geometry data needed for the model, assisted UT in the digital elevation module generation, and developed the climate data input. The climate data work included development of specialized techniques to adapt available climate station data to the watershed. They also provided reference data from previous studies on the Upper Auglaize Watershed and assisted with resolving validation and calibration issues.

USDA Agricultural Research Service (ARS) provided the model, provided leadership to develop the work plan and train the team members in use of the model, troubleshot problems, and assisted in writing the final report. They also have initiated work on new coding to add a riparian component to the AGNPS suite of models.

University of Toledo (UT) developed and refined new remote sensing techniques to develop the land use data in a digital form that could be read by the GIS interface in the model. They also developed an innovative technique to use remote sensing data to develop four-year crop rotations for each crop field in the watershed, and digitally automate the process of populating the cells with this data. The university also generated the Digital Elevation Model (DEM) with the assistance and help of USGS.

The Ohio State University provided data and assistance to UT in the remote sensing process via a subcontract between the University of Toledo and the Ohio View Consortium.

Heidelberg College–Water Quality Lab provided historical sediment and water quality monitoring gage data and analysis for the Maumee that was used as a reference for typical unit area loads for the Maumee River Basin. They assisted in developing statistical routines to extrapolate that data to the Upper Auglaize for validation and calibration considerations. They assisted in the validation and calibration process to help verify model results.

Allen, Auglaize, Van Wert & Putnam SWCD's publicized the project with local landowners, provided conservation-tillage transect data records, assisted the UT in field checking the remote sensing land use data. They will also be using the model results and maps in the conservation treatment programs in the watershed areas within their counties.

Ohio Environmental Protection Agency (Ohio EPA) will provide pollutant load data from point sources and large feedlots if the project is expanded to include nutrients modeling.

II. BACKGROUND

A. WATERSHED DESCRIPTION

The Upper Auglaize Watershed is located in portions of Auglaize, Allen, Putnam, and VanWert counties in the southern portion of the Maumee River Basin. The watershed encompasses 211,956 acres upstream of the USGS Fort Jennings gaging station. Land use is predominately agricultural with 74.2 percent cropland, 10.8 percent grassland, 6.2 percent woodland, and 8.8 percent urban and other land uses. Corn and soybeans are the predominate crops grown in the watershed and together account for an estimated 83 percent of the agricultural cropland in cultivation and 62 percent of the total watershed area. The Auglaize River transverses the watershed originating southeast of Lima, flowing southwest through the town of Wapakoneta, and then north through the Village of Fort Jennings.

The entire Upper Auglaize Watershed lies within the Central Lowland physiographic province. The lower one-third of the Upper Auglaize Watershed lies within the Maumee Lake Plains section. The upper two-thirds of the watershed lies within the Central Ohio Clayey Till Plains section and is intersected by alternating bands of ground and end moraines created by successive advances and retreats of the last glacier. Figure II-1 shows the major subbasins within the Maumee River Basin. Figure II-2 shows the Upper Auglaize Watershed and the drainage network within the Maumee River Basin.

Continental glaciers have covered the watershed several times. Wisconsin-age glacial drift presently covers most of the watershed at thicknesses ranging from a few feet to several hundred feet. The glacial drift overlies limestone bedrock of Silurian age. The Wisconsin-age glacial drift includes till, outwash, loess, lacustrine deposits, and alluvium (U.S. Department of Agriculture, 1981).

Land-surface elevations in the Upper Auglaize Watershed range from about 710 to 1,100 feet above sea level. Most soils in the Upper Auglaize Watershed are nearly level to gently sloping; however, moraine areas and areas near streams can be steeper. In general, soils in the lower one-third of the watershed tend to be appreciably flatter than those in the upper two-thirds of the watershed.

Blount and Pewamo are major soil types in the watershed. These soils are characterized as somewhat poorly to very poorly drained with moderately slow permeability. Farm fields in the watershed are extensively tile drained and the area has a very extensive network of man-made or man-altered drainage ditches. Common conservation practices applied in the watershed include grassed waterways, tile and surface drainage, conservation-tillage and no-tillage, grass filter strips, and erosion control structures. Soils are among the most productive in Ohio and fields not still in woodland or USDA set-aside cover are intensively farmed. At the present time no-tillage (no-till) is practiced on 51 percent of the cropped fields and mulch tillage on 17 percent. Most natural fencerows have been removed. There is a modest amount of livestock in the watershed, most of which is in confined feeding setups with very few animals on pasture. Figure II-3 shows the Auglaize River carrying sediment after a major storm (June 2003) in the Upper Auglaize Watershed.

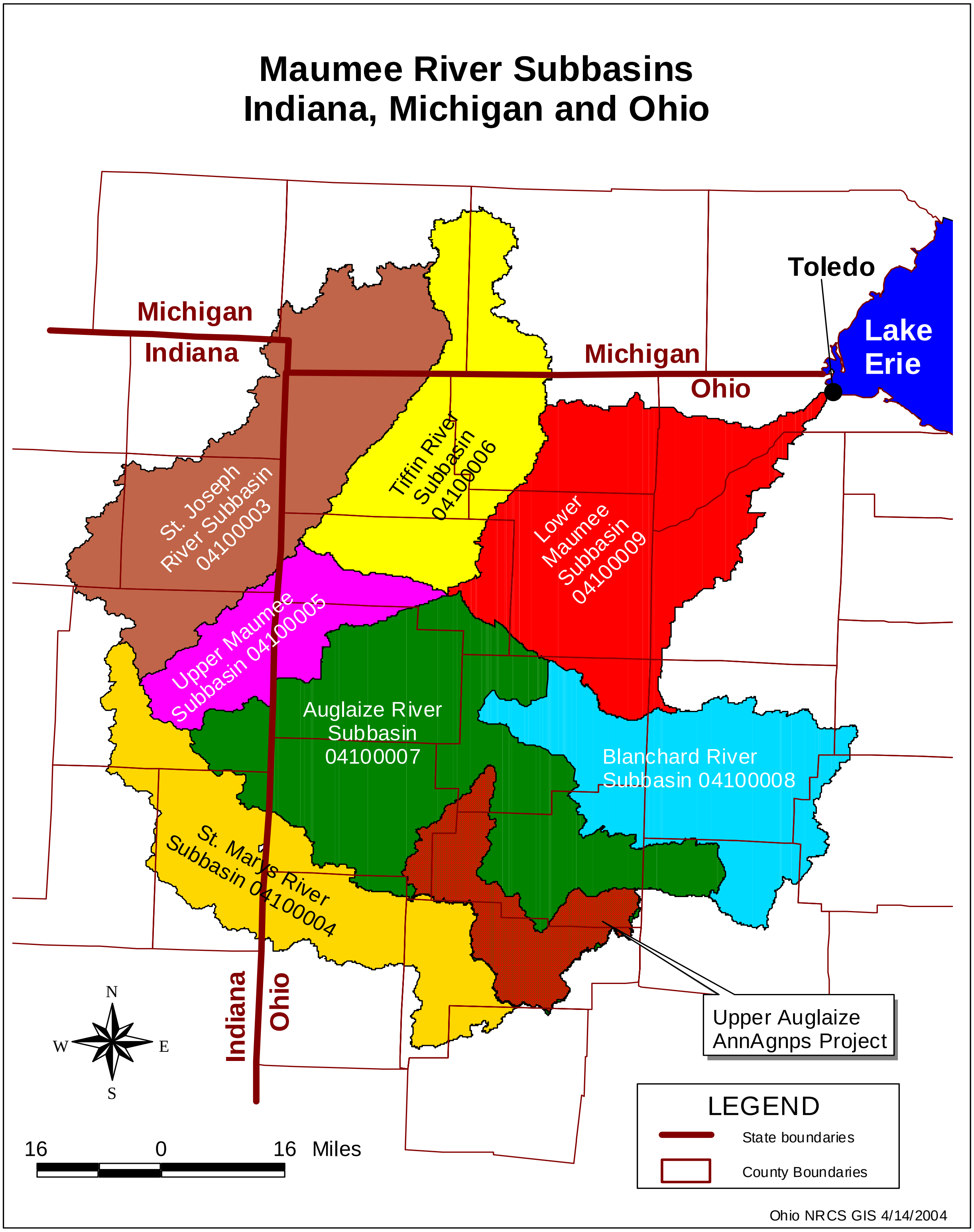

Figure II-1: Maumee River basin portioned into subbasins and showing the Upper Auglaize watershed.

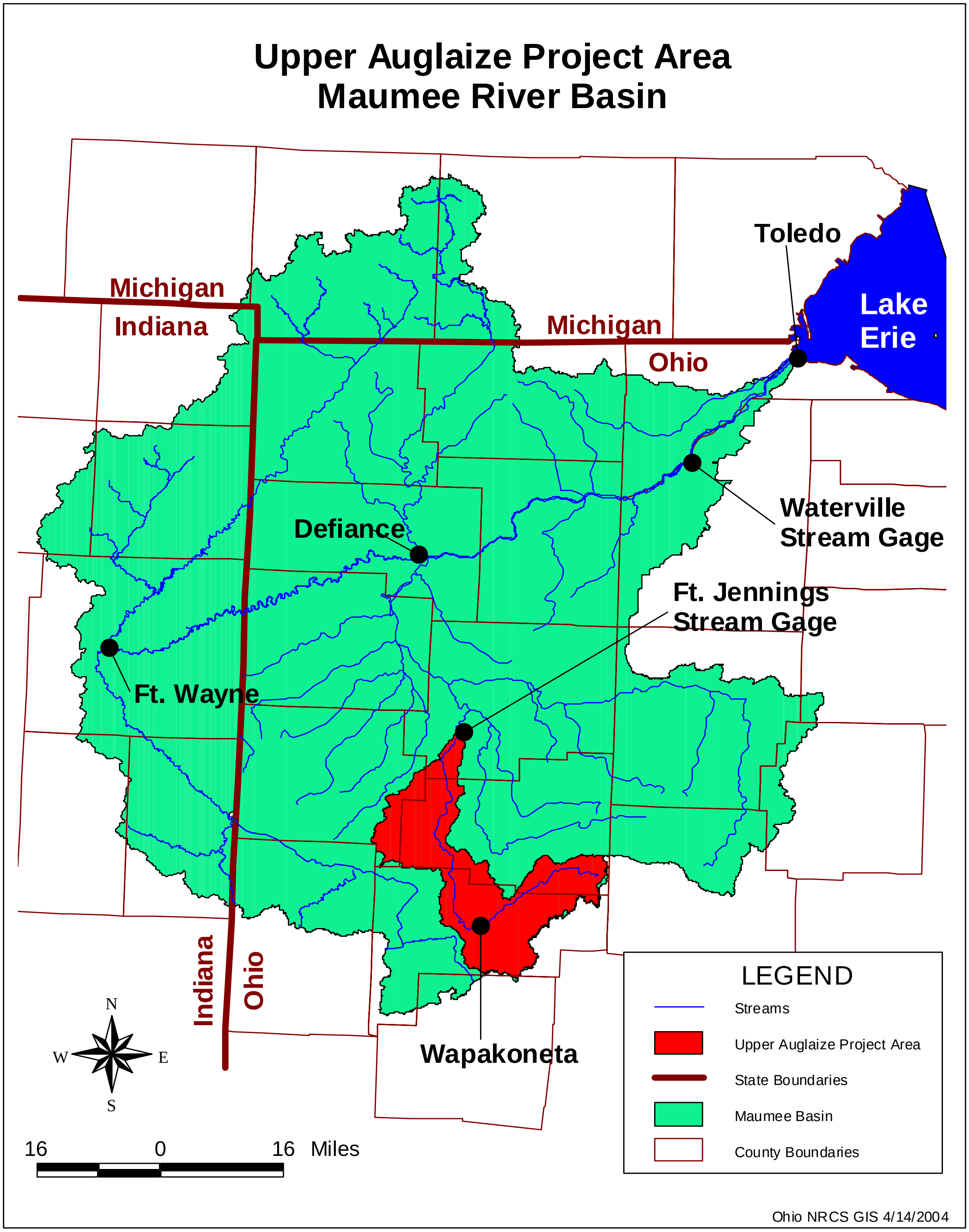

Figure II-2: The Maumee River basin drainage network and the Upper Auglaize watershed.

Figure II-3: Auglaize River carrying sediment after a major storm (June 2003) in the Upper Auglaize Watershed.

B. WHY UPPER AUGLAIZE WATERSHED WAS SELECTED

Due to the large size of the Maumee River Basin, the vision of the partnership was that the major watersheds would each be modeled independently and then linked together with a mainstem channel model for the entire Maumee Basin. The Upper Auglaize Watershed was selected as the watershed with which to start this process. The Upper Auglaize was selected for this study for a variety of reasons:

1. The watershed has been identified as a significant contributor of sediment to the Maumee River that is then transported to Toledo Harbor. The 2000 USGS Report "Status and Trends in Suspended-Sediment Discharges, Soil Erosion, and Conservation-tillage in the Maumee River Basin" identified this watershed as being among those with the highest delivery ratios and sediment yields (unit-area) in the Maumee Basin.

2. The watershed contains soils, topography, and landforms highly typical of the Maumee River Basin as a whole, including both sloping glacial end moraine areas in the upstream reaches and areas of flat lacustrine soils and topography in the downstream reaches. Therefore the knowledge gained in modeling this sub-watershed would likely be applicable to modeling efforts in the rest of the Maumee River Basin. Likewise, the results and recommendations resulting from modeling this sub-watershed are likely to scale up nicely to the Maumee River Basin as a whole.

3. There was significant data concerning this watershed already available and in place, including a USGS gaging station at the mouth, previous USGS sediment work done in the watershed, available soils data, and

other needed information. The agency infrastructure was in place to provide the technical expertise, data, and staff resources needed to tackle this project.

4. The watershed was large enough to provide useful results to environmental managers, but small enough to be more manageable than starting with the entire Maumee. At the time this project was initiated, it was thought to be one of the largest applications ever attempted with the AGNPS model

C. Previous Studies

The Maumee River is the largest U.S. tributary to Lake Erie, in terms of both drainage area and annual discharge. It delivers the largest loads of sediment and nutrients to Lake Erie. It drains into Maumee Bay in Toledo, at the western end of the Western Basin of Lake Erie. Sediment derived from the watershed settles in Maumee Bay and the lower reaches of the river. The deposited sediment interferes with shipping and other commerce and adversely impacts the Maumee Bay and Lake Erie ecosystems. Partly as a consequence of contaminants transported in the river, the Toledo area has been designated as an Area of Concern by the International Joint Commission. For these and other reasons, the Maumee River has been the site of many water quality studies in the past.

The Water Quality Laboratory at Heidelberg College has collected daily and sometimes more frequent water quality samples at Waterville since 1975, with a hiatus during 1979-1981. This database contains some 12,000 samples analyzed for suspended sediment, nutrients, metals, and pesticides. These and other data were recently analyzed during the USDA-funded Lake Erie Agricultural Systems for Environmental Quality (LEASEQ) study (Richards et al., 2002). The study evaluated changes in land use and agricultural management practices in the Maumee Basin during the period 1975-1995, as well as changes in water quality in the Maumee River at Waterville. The study found that the percent of agriculture in the basin changed only slightly during the study period. Soybeans increased at the expense of corn among row crops. Fertilizer applications, especially of phosphorus, declined after reaching a peak about 1980. Applications of manure declined throughout the study period. No-till and conservation-till agriculture increased dramatically, especially after 1990, to about 50 percent by 1995. These changes on the land were accompanied by statistically significant reductions in concentrations and loads of suspended solids (18 percent), total phosphorus (42 percent), soluble reactive phosphorus (85 percent), and total Kjeldahl nitrogen (28 percent). Nitrate increased (21 percent), although the change per year was not statistically significant. Twelve papers reporting the detailed results of the LEASEQ project were published in the Journal of Environmental Quality in January-February 2002.

The Water Quality Laboratory also performed a study of grain size of suspended sediment, which was funded by Ohio Sea Grant and the Lake Erie Protection Fund. The study included analysis of 51 samples from the Maumee River under different flow conditions and during different seasons. This study determined that most of the suspended sediment in transport during storm runoff events is in the clay size range.

The USGS historically has conducted routine and special studies resulting in the collection of a variety of types of surface-water and water-quality data in the Upper Auglaize River Watershed. The USGS has operated a streamflow gaging station on the Auglaize River near the city of Fort Jennings, Ohio, for many years. The gage, located about 200 feet upstream from where Ohio State Route 224 crosses the Auglaize River, has been in operation since August 1921, with a break in the record from December 1935 through October 1940, and as of January 2005 was still in operation as a real-time gage. Periodic suspended-sediment data were collected at the gage during the 1970s as part of a study to characterize fluvial sediment in Ohio streams (Antilla and Tobin, 1978) and again since 1996 as part of the National Water Quality Assessment (NAWQA) Program in the Lake Erie-Lake St. Clair Basins (U.S. Geological Survey, 2003a). Suspended sediment data collected for the NAWQA study were summarized by Myers et al. (2000) in a report on status and trends in suspended sediment discharges, soil erosion, and conservation-tillage in the Maumee River Basin. In addition to streamflow and sediment data, the USGS has collected data in the Auglaize River sub-basin on freshwater mussel and clam species, stream habitat characteristics, and a variety of physical, chemical, and biological measures. Those data can be obtained through the USGS' NWISWeb system (U.S. Geological Survey, 2003b) and summaries of selected data are available on the World Wide Web (U.S. Geological Survey, 2003c). Figure II-4 shows the USGS stream gage downstream from Fort Jennings.

Figure II-4: USGS stream gage downstream from Fort Jennings

D. MONITORING AND OTHER AVAILABLE INFORMATION

A modeling project of this scope cannot take place in a vacuum. Many kinds of data are needed as input to different layers of the Geographic Information System (GIS) database used to populate the model. These data include land surface topography, stream network, weather and climate information, soils data, and land use information. Many of these kinds of data must be spatially defined across the study area, and in sufficient detail to permit the model to accurately reflect the real landscape it represents. Some data, such as soils information, are relatively static through time. Other data are temporally dynamic, changing annually (crops) or even daily (weather, soil moisture, and tillage operations).

In addition, it is important to have some knowledge of the outputs of the landscape being modeled—sediment and water yields, for example, in order to determine whether the model is providing realistic simulations of known conditions. If the model is not known to be capable of mirroring real conditions, it cannot be counted on to provide useful perspectives on hypothetical conditions such as possible management goals.

This project was fortunate to have access to a rich database of information from which the needed information layers could be drawn or developed. Table II-1 and Table II-2 summarize these information types and their sources.

Table II-1: Data for model development

Information Type	Source	Scale/Spatial Resolution	Temporal Resolution	Comments
Surface topography	DEM computed from USGS DLG	20 m	invariant	
Model cell boundaries	computed from DEM	variable; version with highest resolution divides U. Auglaize into 1833 cells averaging 116 acres	invariant	
Drainage network	computed from DEM		invariant	
Drainage network	US EPA Reach files, USGS DRGs		invariant	used for comparison with computed drainage network
Soils	SSURGO OCAP	1:12,000 resolution	invariant	integrated for the project by NRCS
Soil attributes	NRCS-NASIS		N/A	Enhanced to provide missing data items
Hydraulic geometry	USGS	18 locations of different sizes used to generate power curves	invariant	used for flow routing
Land use	LANDSAT 7	30 meter raster	1999-2002, 16 images	Image processing at U. Toledo
Land Cover	LANDSAT 7	30 meter raster	1999-2002, 16 images	Image processing at U. Toledo
Crop rotations	Land cover data	40 meter grid	one 4-year set, 1999-2002	Developed by systematic sub-sampling of land cover maps
Tillage Transect Data	NRCS/SWCD field offices	Approximately 400 points 1 mile apart on co road systems	4 year set, 1999 - 2002	One year of tillage data missing
Climate (historical)	NOAA	Precipitation and temperature from Findlay, other parameters from Dayton	daily	
Climate (synthetic)	ARS synthetic weather generator	assumed uniform over model domain	daily	
Potential gross erosion	RUSLE	N/A	invariant	Developed common mgt systems date (crop rotations, tillage practices, and operation dates) for sheet and rill erosion calculations within model
Ephemeral gully erosion	NRCS EGEM model	N/A	event driven	observations at selected sites and times
Point sources	OEPA	N/A	N/A	not modeled
Feedlots	OEPA	N/A	N/A	not modeled

Table II-2: Data for model evaluation

Information Type	Collection Agency	Data Source Originating From	Temporal Resolution	Comments
Stream hydrology	USGS	Gaging station on Upper Auglaize at Fort Jennings: USGS 04186500	Mean daily flows; finer resolution available in principle	
Suspended sediment concentrations	USGS	4 sites: (1) Maumee @ Waterville (MW); (2) Maumee @ Defiance (MD); (3) Auglaize @ Defiance (AD); (4) U. Auglaize @ Ft. Jennings (UA)	Daily to intermittent. Samples: MW: 14,415 MD: 730 AD: 52 UA: 88	Directly applicable to a larger basin model only, except for Auglaize @ Ft. Jennings which corresponds to the U. Auglaize.
Suspended sediment concentrations	Heidelberg College WQL	1 site at Waterville	Daily and more frequent, 1975-present. 12,000+ samples.	Directly applicable to a whole Maumee Watershed model only.
Suspended sediment particle sizes (Sieve: 4 particle sizes finer than 0.5 mm; fall diameter: 4 particle sizes finer than 0.031mm)	USGS	Maumee River at Waterville	MW: 10 sieve and fall MD: 0 AD: 10 s, 10 f UA: 10 s, 10 f	Particle sizes should be broadly representative of U. Auglaize subwatershed.
Suspended sediment particle sizes (Malvern Mastersizer: 92 particle size classes finer than 2 mm)	Heidelberg College WQL	1 site at Waterville	51 samples from storm events in 1997 and 1998	Particle sizes should be broadly representative of U. Auglaize subwatershed as well.
Nutrient concentrations	USGS	1 site: Auglaize at Fort Jennings	about 70 analyses since 1990	Appropriate for this model but limited in number
Nutrient concentrations	Heidelberg College WQL	1 site at Waterville	Daily and more frequent, 1975-present. 12,000+ samples.	Directly applicable to a whole Maumee Watershed model only.

Some summary results from the Heidelberg College Water Quality Lab sampling program are presented in Table II-3. Presented are selected percentiles from the distribution of annual discharges and unit area loads for the water years 1990 to 2003, based on 6,604 samples. The area of the watershed was calculated as 4.2 million acres. Much of this data is available from the US Environmental Protection Agency (EPA) Storage and Retrieval (STORET) database; the rest can be accessed by contacting the Water Quality Lab. Documents describing various aspects of the sampling program and its results can be accessed at http://www.heidelberg.edu/WQL/publish.html#reports.

Table II-3: Summary water quality results from the Water Quality Laboratory sampling program on the Maumee River at Waterville, Ohio.

Percentile of Samples	Discharge [in]	Suspended Sediment [t/ac]	Total Phosphorus [lb/ac]	Dissolved Reactive Phosphorus [lb/ac]	Nitrate [lb/ac]	Total Kjeldahl Nitrogen* [lb/ac]
minimum	9.7	0.09	0.5	0.05	10.2	2.8
25th	11.9	0.15	0.7	0.11	13.9	3.0
median	16.4	0.25	1.1	0.15	15.4	4.8
75th	18.2	0.32	1.5	0.23	20.7	5.9
90th	20.9	0.50	1.6	0.26	22.2	6.4
maximum	23.7	0.62	1.8	0.30	22.8	6.9

*Total Kjeldahl nitrogen (TKN) is a chemical measurement that includes both ammonia and organic nitrogen. In the Maumee River, most of the TKN is organic nitrogen.

Table II-4 shows summary statistics for sediment grain size distribution in 51 suspended sediment samples from the Maumee River at Waterville, Ohio. The values shown are derived from the distributions of the parameters listed at the head of the table. For example, each grain size analysis produces a value for the percent of fine clay in the sample. The value reported for the median is the middle value of percent of fine clay, when the 51 values are ranked from lowest to highest. Half the samples had more than 37.3 percent fine clay, and half had less than 37.3 percent fine clay. Similarly, three-quarters of the samples had less than 29 percent of the sample in the fine silt size range, and one quarter had more than 29 percent of the sample in that size range.

Samples were analyzed by the Water Quality Lab using a Malvern Mastersizer Plus Particle Size Analyzer following sonication to separate flocs into primary particles. Summary statistics are based on 51 samples collected between 1997 and 1999. Rows do not sum to 100 percent because generally the numbers that correspond to a given percentile do not come from the same sample. A description of this project and its results (Richards and Baker, 2000) can be obtained from the Ohio Lake Erie Office by calling (419) 245-2514.

Table II-4: Summary statistics on sediment grain size distribution in suspended sediment samples from the Maumee River at Waterville, Ohio.

Percentile of Samples	Fine Clay [% <1μ]	Coarse Clay [% 1-4μ]	Fine Silt [% 4-16μ]	Coarse Silt [% 16-63μ]	Fine Sand [% 63-250μ]	Medium to Coarse Sand [% 250-1000μ]
minimum	20.9	18.3	4.4	0.0	0.0	0.0
25th	32.6	24.9	20.8	3.2	0.0	0.0
median	37.3	29.5	25.9	5.1	0.1	0.0
75th	45.3	33.9	29.0	8.8	0.7	0.0
90th	52.1	35.0	31.1	14.4	1.9	0.0
maximum	71.1	38.5	41.2	19.7	5.5	4.4

III. AGNPS MODEL—BRIEF OVERVIEW

AGNPS is a joint ARS and NRCS suite of computer models developed to predict nonpoint source pollutant loadings within agricultural watersheds. It includes a continuous-simulation, surface-runoff computer model called Annualized AGricultural Non-Point Source Pollution Model (AnnAGNPS). AnnAGNPS is designed to assist with determining BMPs, the setting of Total Maximum Daily Loads (TMDLs), and for risk and cost/benefit analyses. The set of computer programs consist of: (1) input generation and editing as well as associated databases; (2) the "annualized" science and technology pollutant loading model for agricultural-related watersheds (AnnAGNPS); (3) output reformatting and analysis; and (4) the integration of more comprehensive routines—National Center for Computational Hydroscience Engineering 1-Dimensional (CCHE1D) for the stream network processes; (5) a stream corridor CONservational Channel Evaluation and Pollutant Transport System model (CONCEPTS); (7) an instream water temperature model, Stream Network Water TEMPerature Model (SNTEMP); and (8) several related salmonid models (Sediment Intrusion and Dissolved Oxygen (SIDO), Fry Emergence, Salmonid Total Life Stage, and Salmonid Economics). Not all of the models are electronically linked but there are paths of common input/output that, with the use of standard text editors, can be linked.

Figure III-1 is a system diagram for the suite of AGNPS computer models.

The input programs include: (1) a GIS-assisted computer program (TOpographic PArameteriZation (TOPAZ) with an interface to AGNPS) to develop terrain-following cells with all the needed hydrologic and hydraulic parameters that can be calculated from readily available DEM's; (2) an input editor to initialize, complete, and/or revise the input data; and (3) an AGNPS-to-AnnAGNPS converter for the input data sets of the old single-event versions of AGNPS (4.03 and 5.00).

AnnAGNPS includes up-to-date technology–e.g., Revised Universal Soil Loss Equation (RUSLE) and pesticides–as well as the daily features necessary for continuous simulation in a watershed. Additional features of AnnAGNPS include:

1. The capability to produce output related to soluble and attached nutrients (nitrogen, phosphorus, and organic carbon) and any number of pesticides.
2. Water and sediment erosion, yield, and load by particle size class and source are calculated and determined to any point in the watershed channel system.
3. A field pond water and sediment loading routine is included for rice/crawfish ponds that can be rotated with other land uses.
4. Nutrient concentrations from feedlots and other point sources are modeled. Individual feedlot potential ratings can also be derived using the model.
5. The applications of CCHE1D for stream networks and CONCEPTS for stream corridors include more detailed science for the channel hydraulics, morphology, and transport of sediments and contaminants.

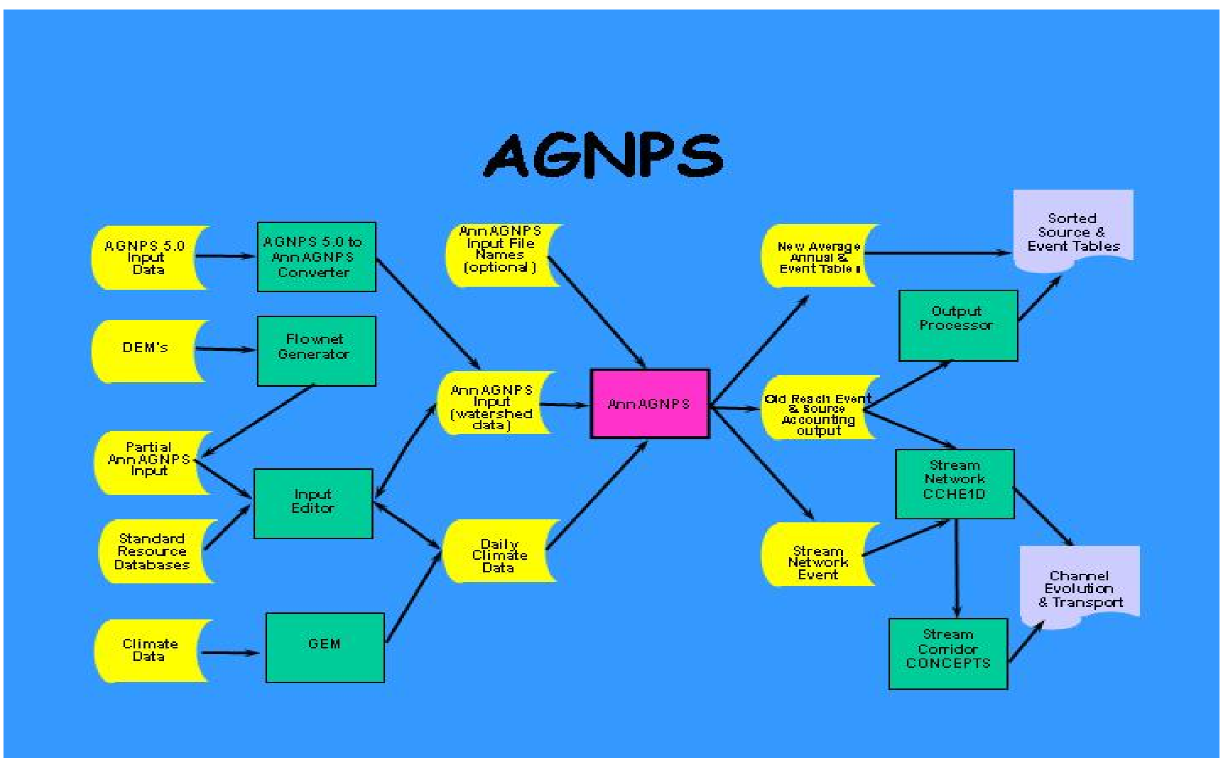

Figure III-1: AGNPS system diagram.

A. How to use the AGNPS Model

The AGNPS watershed simulation model (Bingner and Theurer, 2001a) has been developed as a tool for use in evaluating the pollutant loadings within a watershed and the impact farming and other activities have on pollution control. Various modeling components have been integrated within AGNPS to form a suite of modules. Each module provides information needed by other modules to enhance the predictive capabilities. The modules include: (1) the pollutant loading module within AGNPS that is critical to the Upper Auglaize Watershed analyses is AnnAGNPS Version 3.3 (Bingner and Theurer, 2001b) which is a watershed-scale, continuous-simulation, pollutant-loading computer model designed to quantify and identify the source of pollutant loadings anywhere in the watershed for optimization and risk analysis; (2) CONCEPTS (Langendoen, 2001), a set of stream network, corridor, and water quality computer models designed to predict and quantify the effects of bank erosion and failures, bank mass wasting, bed aggradation and degradation, burial and re-entrainment of contaminants, and streamside riparian vegetation on channel morphology and pollutant loadings; (3) SNTEMP (Theurer et al, 1984), a watershed-scale, stream network, water temperature computer model to predict daily average, minimum, and maximum water temperatures; (4) SIDO (Alonso et al, 1996), a set of salmonid life-cycle models designed specifically to quantify the impact of pollutant loadings on their spawning and rearing habitats as well as include other important life-threatening obstacles; and (5) an economic model that determines the net economic value of Pacific Northwest salmonids restored to either the commercial or recreational catch (see AGNPS web site).

AnnAGNPS is an advanced technological watershed evaluation tool, which has been developed through a partnering project with the ARS and NRCS to aid in the evaluation of watershed response to agricultural management practices. Through continuous simulation of surface runoff, sediment, and chemical non-point source pollutant loading from watersheds, the impact of BMPs on TMDLs can be evaluated for risk and cost/benefit analyses.

AnnAGNPS is a continuous simulation, daily time-step, pollutant-loading model and includes significantly more advanced features than the single-event AGNPS 5.0 (Young *et al.*, 1989). Daily climate information is needed to account for temporal variation in the weather. Spatial variability within a watershed of soils, land use, and topography, is accounted for by dividing the watershed into many homogeneous drainage areas. These simulated drainage areas are then integrated together by simulated rivers and streams, which route the runoff and pollutants from each individual homogeneous area to downstream. From individual fields, runoff can be produced from precipitation events that include rainfall, snowmelt, and irrigation. A daily soil water balance is maintained that recognizes tile drains when present, so direct runoff that includes both surface and subsurface flow, can be determined when a precipitation event occurs. Sheet and rill erosion from each field is predicted based on the RUSLE (Renard *et al.*, 1997); and ephemeral gully erosion is based upon the Ephemeral Gulley Erosion Model (EGEM) (Merkel et al, 1988). The model can be used to examine the effects of implementing various conservation alternatives within a watershed such as alternative cropping and tillage systems including the effects of fertilizer, pesticide, irrigation application rate as well as point source yields and feedlot management (Bosch *et al*., 1998).

1. Inputs

As part of the input data preparation process there are a number of component modules that support the user in developing the needed AnnAGNPS databases. These include: (1) TOPAZ (Garbrecht and Martz, 1995), to generate cell and stream network information from a watershed DEM and provide all of the topographic related information for AnnAGNPS. A subset of TOPAZ, TOPAGNPS, is the set of TOPAZ modules used within AGNPS. The use of the TOPAGNPS generated stream network is also incorporated by CONCEPTS to provide the link to where upland sources are entering the channel and then routed downstream; (2) The AGricultural watershed FLOWnet generation program (AGFLOW) (Bingner et al., 1997; Bingner and Theurer, 2001c) is used to determine the topographic-related input parameters for AnnAGNPS and to format the TOPAGNPS output for importation into the form needed by AnnAGNPS; (3) The Generation of Weather Elements for Multiple applications (GEM) program (Johnson et al., 2000) is used to generate the climate information for AnnAGNPS; (4) The program "Complete Climate" takes the information from GEM and formats the data for use by AnnAGNPS, along with determining a few additional parameters; (5) A graphical input editor that assists the user in developing the AnnAGNPS database (Bingner et al., 1998); (6) A visual interface program to view the TOPAGNPS related geographical information system (GIS) data (Bingner et al., 1996); (7) A conversion program that transforms a single event AGNPS 5.0 dataset into what is needed to perform a single event simulation with AnnAGNPS and, (8) An ArcView program to facilitate the use of Items 1-7. There is an output processor that can be used to help analyze the results from AnnAGNPS by generating a summary of the results in tabular or GIS format. Additional information on AGNPS can be obtained at the WEB site: http://www.sedlab.olemiss.edu/AGNPS.html

2. Outputs and Products

Simulation results can be produced in several formats as needed. These formats can be used to summarize the results from a single event or on an average annual basis. Results can be targeted for reports at the outlet or any other location in the watershed, including the channel reaches or AnnAGNPS cells. Information describing the event as well as average annual runoff, peak discharge, erosion, or sediment by particle size and chemical loadings can be produced. Average annual results can also be displayed as part of an ArcView shape file to view the spatial distribution of the results by AnnAGNPS cell.

B. WHY AGNPS WAS SELECTED

The selection of AGNPS for the project was based on the capability of the watershed approach to assess the impact of conservation planning, including BMPs, to reduce sediment loadings to Toledo Harbor. It incorporates the most current methodologies used by NRCS such as the Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1997) and Soil Conservation Service (SCS, now NRCS) hydrologic procedures (SCS, 1986). In addition, AnnAGNPS provides the ability to aid in the identification and evaluation of sources of water and sediment production within the watershed. The capability of AnnAGNPS to assess the impact of tile drains on subsurface drainage and any resulting reduction of surface runoff that could erode and transport sediment was a critical selection criterion . The impact of management practices on the production of sediment from ephemeral gullies is also a key element of information which can be generated from AnnAGNPS. The main effects of all the critical processes within the watershed are included as part of AnnAGNPS, some of which are unique. For example, three of the several unique processes recognized are: (1) gully erosion in agricultural fields; (2) tile drains in agricultural fields; and (3) the precise amount of the source of pollutant calculated by AnnAGNPS is known, made available in the output, and used for GIS display.

In 1993, NRCS completed a study of thirty-eight available water quality models then available (Theurer & Comer, 1992a). Four were chosen for further analyses—two were field-scale models and two were watershed-scale. All four were developed for agricultural non-point pollution applications. Detailed reviews were made of the two watershed-scale models: AGNPS (precursor to AnnAGNPS) and SWRRWQ (precursor to SWAT), and reports were prepared documenting the reviews (Theurer & Comer, 1992b; Theurer & Comer, 1993). AGNPS was selected for further SCS/NRCS support and development because it contained NRCS-approved science for the watershed-scale applications (up to 1,000 sq. mi.). It was, and still is, the only watershed model that starts with USLE/RUSLE erosion in the field and accumulates water, sediment, and chemicals as yield and loading. SWRRBWQ was not selected because it contains technology that is not suitable for alternative analyses at the watershed scale. The most serious deficiency with SWRRBWQ (and with SWAT) is that the sediment predictions do not make a distinction between sediment originating over the landscape (sheet & rill and ephemeral gully erosion - frequently referred to as "wash load") and sediment originating within the stream system (bed & bank material load). This may result in attributing all of the sediment production to the USLE parameters which are only related to sheet & rill erosion.

IV. PROJECT DESCRIPTION

A. TRAINING & WORK PLAN

A planning meeting was held in Columbus, Ohio on May 13, 2002 with several cooperators to develop the plan of work (POW) for the project (**Table IV-1**). This plan of work encompassed the entire effort associated with collecting information on the various conservation measures currently applied within the watershed and the associated databases needed to evaluate the impact of these and alternative measures using AnnAGNPS. The plan included a time frame for completion of certain tasks and listed the tasks that would need to be finished before others could start.

The final task was the delivery of this report to USACE. The first task was to hold a workshop July 8-12, 2002 for training on the application of AnnAGNPS for the Upper Auglaize Watershed. The week-long training provided detailed information on the data needs and implementation of AnnAGNPS to the watershed. The workshop also served to further fine-tune the plan of work since additional tasks were identified along with the people who would complete them. A more detailed plan of work is described in Section F of the Technical Appendix.

ID		Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		Start Project	0 days	Mon 6/3/02	Mon 6/3/02		USACE
2		Workshop	5 days	Mon 7/8/02	Fri 7/12/02	1	ARS,NRCS
3		**Soils**	**150 days**	**Mon 6/3/02**	**Fri 12/27/02**	**1**	**NRCS**
11		**DEM**	**30 days**	**Mon 6/3/02**	**Fri 7/12/02**	**1**	**U. of Toledo**
16		Landuse	**120 days**	**Mon 6/3/02**	**Fri 11/15/02**	**1**	**U. of Toledo**
35		**Gully**	**20 days**	**Mon 6/3/02**	**Fri 6/28/02**	**1**	**NRCS**
40		**Hydraulic Geometry**	**100 days**	**Mon 6/3/02**	**Fri 10/18/02**	**1**	**USGS**
45		Hydraulic Geometry - Bench (Second Phase)	180 days	Mon 6/3/02	Fri 2/7/03	1	ODNR/OSU
46		**Climate**	**125 days**	**Mon 6/3/02**	**Fri 11/22/02**	**1**	**USGS**
51		**Point Sources**	**90 days**	**Mon 7/15/02**	**Fri 11/15/02**	**1**	**OEPA**
55		**Feedlots**	**60 days**	**Mon 6/3/02**	**Fri 8/23/02**	**1**	**OEPA**
58		**Input Calibration**	**100 days**	**Mon 6/3/02**	**Fri 10/18/02**	**1**	**USGS**
70		**AnnAGNPS/Arcview**	**165 days**	**Mon 12/30/02**	**Fri 8/15/03**	**1**	**NRCS**
79		**Riparian**	**300 days**	**Mon 6/3/02**	**Fri 7/25/03**	**1**	**ARS**
85		**Reports**	**190 days**	**Mon 1/27/03**	**Fri 10/17/03**	**1**	**NRCS,USACE,USGS**
89		End Project	0 days	Fri 10/17/03	Fri 10/17/03	85	USACE

Table IV-1: Summary of the plan of work (POW) for the Upper Auglaize Watershed project.

B. SOILS—DIGITAL SOILS MAPS AND SOIL DATA BASES

Soils data development consisted of two main tasks. First the spatial layer was developed from digital data that was available through the NRCS Soil Survey Geographic Database (SSURGO) program. Three of the four counties in the project watershed had SSURGO data available for use in this project (Allen, Auglaize and Van Wert.) For the fourth county (Putnam), we used an older digital soils layer. The four counties were spatially merged together and their soil names correlated (in conjunction with their attribute data as described in the next paragraph) so that the same soils occurring in different counties were given the same name.

Secondly, soil attributes were incorporated and reformatted to fit the requirements of AnnAGNPS. Soil data from the National Soil Information System (NASIS) were downloaded for the counties encompassed by the watershed. Data were edited to include only the soil map units located in the watershed in order to reduce data volume. Where similar map units were used in multiple counties, one map unit was selected as representative for the watershed. This eliminated differences in data attributes between counties and reduced the amount of data to be edited. Where necessary, new map unit symbols were developed. Attributes for these selected representative map units were then edited for completeness for use with AnnAGNPS. Some data attributes were not populated in NASIS and needed to be developed for use with the model. These included soil structure and sum of bases. A protocol was developed to populate this data. Some data including albedo, silt, sand, very fine sand, and wilting point were incomplete and needed to be populated using calculations and other methods.

Initially there were 270 soils in the four county data set. However, after correlation to common names and reduction from the four-county area to just the watershed area, only 144 soils required attribute data development. These 144 soils are plotted on the watershed map below, Figure IV-1. AnnAGNPS uses this input soils layer to determine a dominant soil for each cell of the watershed. A plot of the dominant soils is included in Figure IV-2.

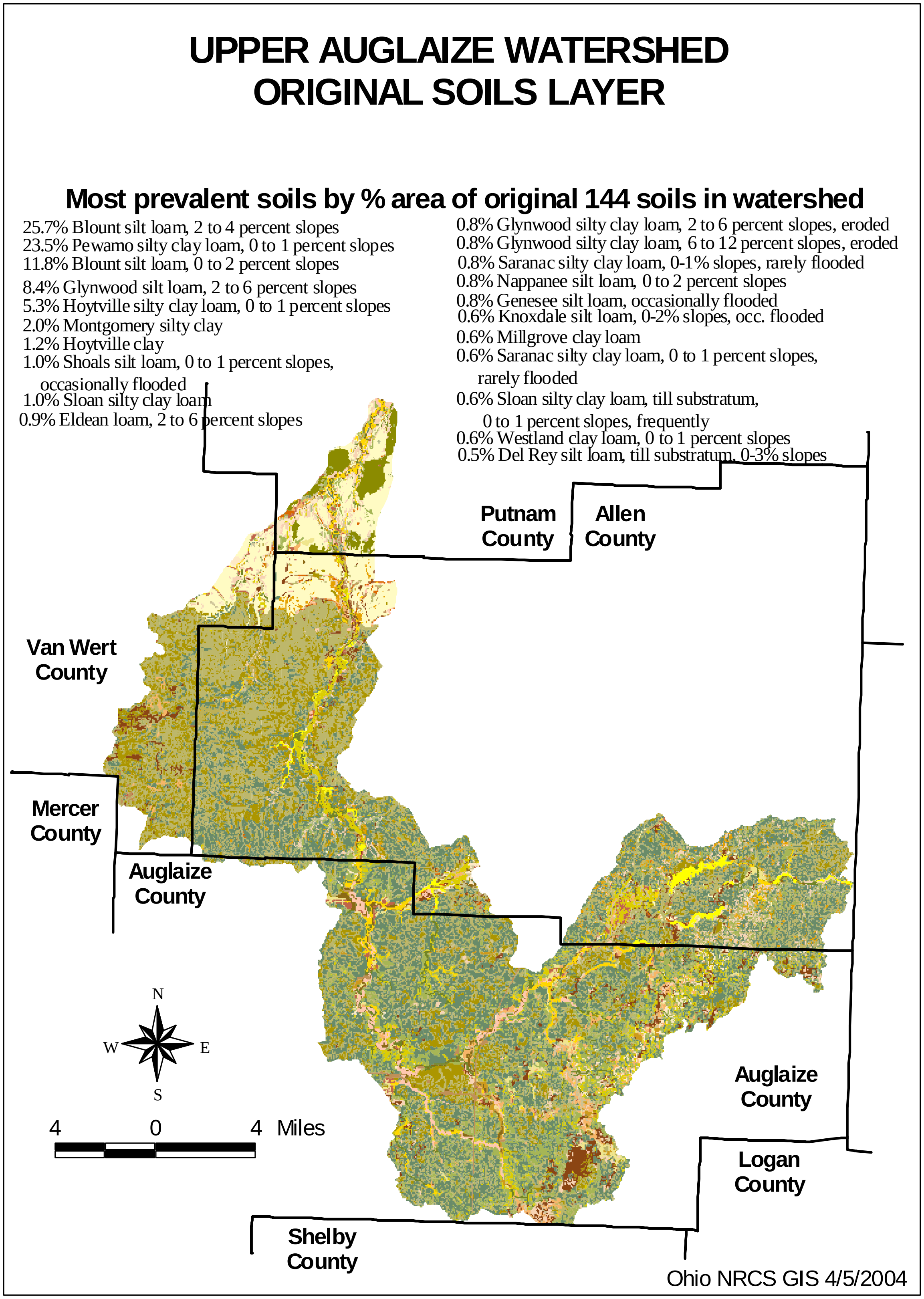

Figure IV-1: Original soil layers in the Upper Auglaize watershed.

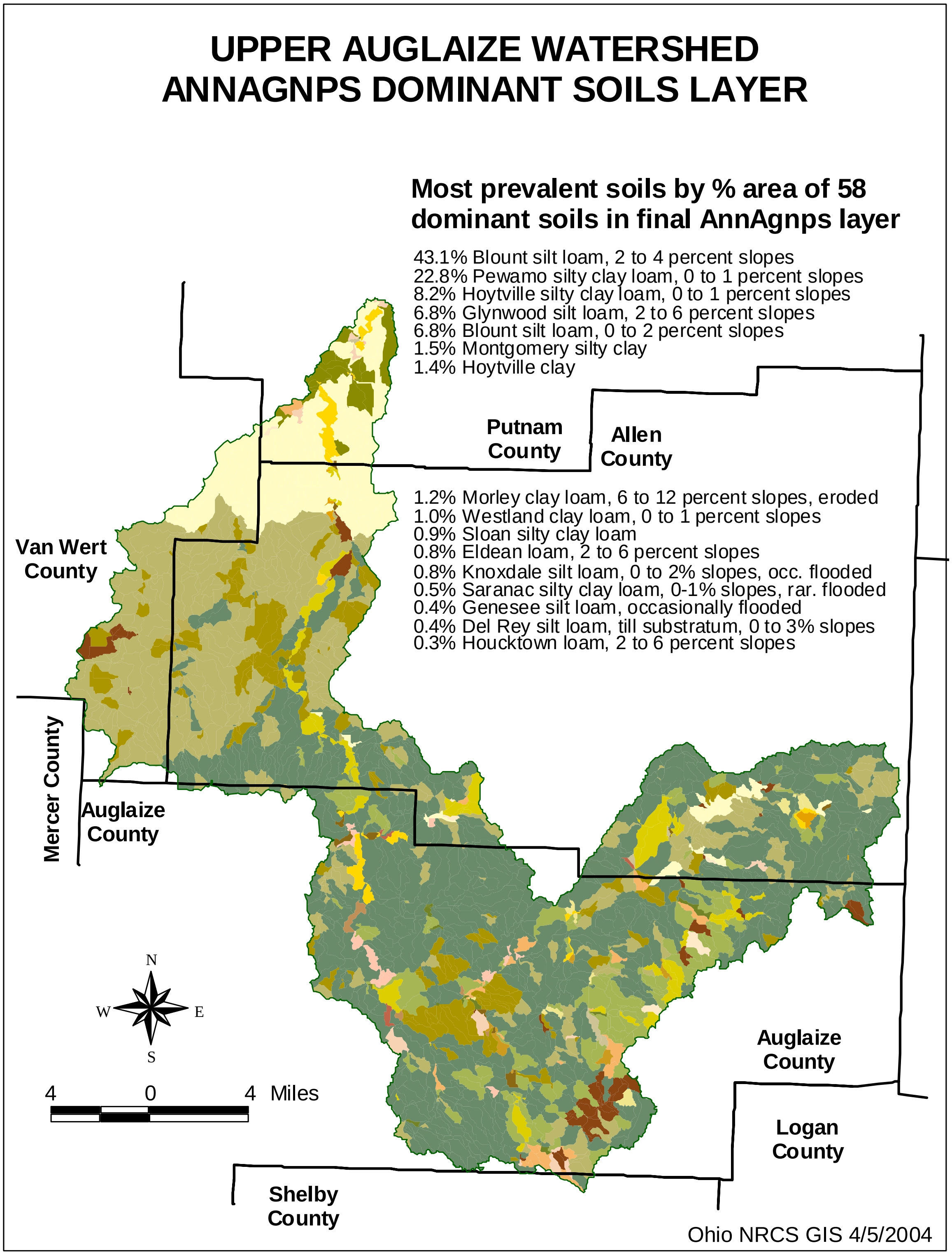

Figure IV-2: Dominant soil layers in the Upper Auglaize watershed.

C. DEM GENERATION

An accurate DEM is critical for successful execution of the AnnAGNPS model. The Upper Auglaize Watershed is relatively featureless, making it difficult to get an accurate DEM for the area. The 30-meter DEM available through the USGS, which is truncated to one meter horizontally and vertically, is too coarse a resolution to work well in flat areas like the Upper Auglaize. Some areas erroneously have holes that need to be filled while other areas produce no slope whatsoever making determination of water flow direction impossible in AnnAGNPS.

To address these problems a new technique was tried using stereoscopic Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite imagery to make the DEM. However, the ASTER DEM did not improve upon the accuracy of the USGS 30-meter DEM. A 20-meter DEM was ultimately developed from the USGS 1:24,000 Digital Line Graphs (DLG) for the Upper Auglaize River Watershed. The resulting DEM had many fewer holes than the USGS 30-meter DEM. However there were locations where water flow did not match the hydrological layer from the USGS 1:24,000 DLG. In the cases where the stream channels generated from the 20-meter DEM did not match the USGS hydrological layer stream channels, the USGS stream channels were assumed to be correct, and were "burned" into the DEM. This was done by lowering the DEM in the area of the USGS stream thus altering the DEM slope so that water would not erroneously flow into or out of the watershed. More detail on the process of DEM generation can be found in the Technical Appendix to this report.

D. LAND USE/LAND COVER REMOTE SENSING AND DIGITAL MAP DEVELOPMENT

In the case of land use/land cover (LULC), data extraction was completed in two phases. The first phase involved the construction of a LULC map created from a supervised multi-spectral image classification. The LANDSAT derived LULC layer was developed first for one year (1999) (phase one) and then for a four-year period (1999-2002) (phase two). The one year layer was developed as a polygon layer, each with its own LULC. Figure IV-3 shows the static land-use/land cover map.

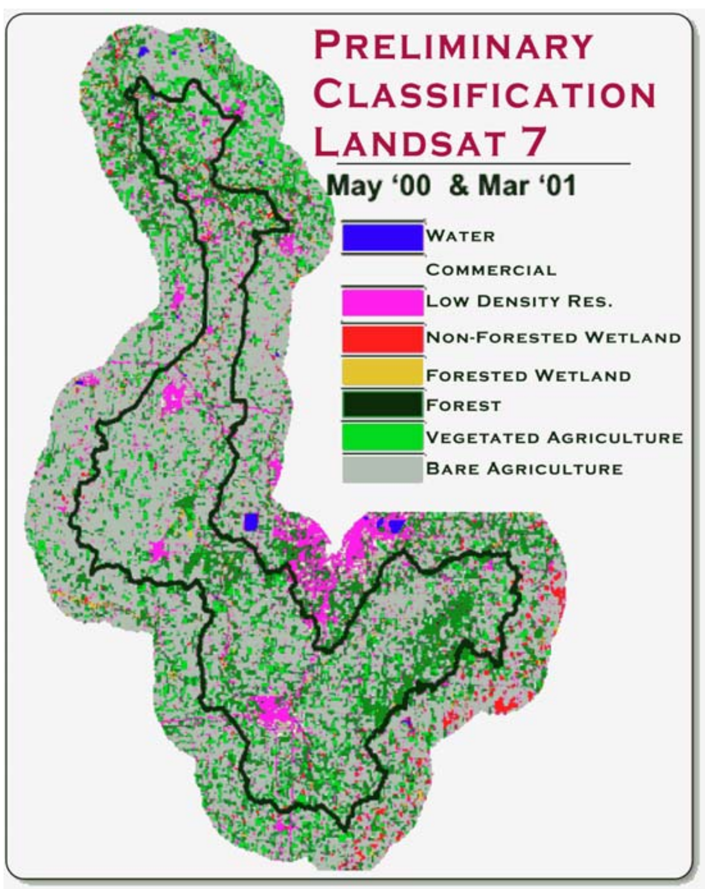

Figure IV-3: Static land use/land cover map.

In phase two, the process was developed and refined using two LANDSAT 7 images. Each image used in the classification contributed uniquely to the final classification map. This phase utilized a more complex multi-temporal multi-spectral approach in locating and determining a four-year crop rotation record for the entire watershed between 1999 and 2002. Because of changes that occur from year to year and the need in AnnAGNPS to define crop rotation, a polygon layer reflecting a four-year crop rotation was derived. The crop types (corn, soybeans, wheat and grass) were classified using multi-temporal LANDSAT imagery (refer to Section B of the Technical Appendix). The method converted these points to a polygon layer by grouping all points falling in each polygon of the one-year (1999) layer. The four-year rotation that was the most numerous in each polygon became the rotation for that LULC polygon. This became the final LULC layer that was automatically sampled by the GIS-AnnAGNPS interface to determine the dominant LULC for each cell. (See the LULC breakdown in Technical Appendix Figures I-4 and I-5.) Preparing the data for inclusion in the AnnAGNPS model also presented challenges. As detailed in the Technical Appendix, a novel solution was developed for imparting information derived from imagery into the base cells of the AnnAGNPS model, and an accuracy assessment generated by the image processing software indicated a better than 90% overall accuracy.

E. ATTRIBUTE DATA BASES—RUSLE

The RUSLE module of AnnAGNPS was used to assess and evaluate sheet and rill erosion in the Upper Auglaize River Watershed. RUSLE is an erosion prediction model that enables conservation planners to predict the long-term average annual rate of inter-rill (sheet) and rill erosion on a landscape based on the factor values assigned by the planner. The factors represent the effect of climate, soil, topography, and land use on inter-rill (sheet) and rill erosion. Erosion rates predicted by RUSLE can be used to guide conservation planning by evaluating the impact of present and/or planned land use and management on the scale of individual fields.

Soil loss computed by RUSLE is the rate of soil erosion from the landscape profile (defined by the slope length), not the amount of sediment leaving a field or watershed. The factors used in RUSLE are based on long-term averages.

The DOS computer version of RUSLE (version 1.06) was used for this project. To compute the average annual erosion rate on a field slope, appropriate data are entered by the planner. The planner selects the appropriate climate data, soils data, crops, field operations and timing of field operations, length and steepness of the slope profile, and support practices used or planned. These inputs result in specific values of R, K, LS, C, and P which are multiplied together to produce the "Average Annual Soil Loss" expressed in tons/acre/year.

The equation is expressed as follows: A = R*K*LS*C*P, where:

A = the predicted average annual soil loss from inter-rill (sheet) and rill erosion from rainfall and associated overland flow. Units for factor values are selected so that "A" is expressed in tons per acre per year.

R = Rainfall-Runoff Erosivity Factor. "R" is an indication of the two most important characteristics of storm erosivity: (1) amount of rainfall and (2) peak intensity sustained over an extended period of time. Erosivity for a single storm is the product of the storm's energy, E, and its maximum 30 minute intensity, I_{30}, for qualifying storms. A value of "R" for a location is the average of EI_{30} values summed for each year of a 22-year record. "R" values in Ohio range from 95 in the northwest to 155 in southwest Ohio. An "R" value of 120 was used for modeling, corresponding to the values listed on the NRCS Field Office Technical Guide for the counties in the project area.

K = Soil Erodibility Factor. "K" values represent the susceptibility of soil to erosion and the amount and rate of runoff, as measured under the standard unit plot condition. The unit plot is an erosion plot 72.6 feet long on a nine percent slope, maintained in continuous fallow, tilled up and down hill periodically to control weeds and break crusts that form on the surface of the soil.

L = Slope Length Factor. "L" represents the effect of slope length on erosion. "L" is the ratio of soil loss from the field slope length to that from a plot slope 72.6 feet long under otherwise identical conditions. Slope length is the distance from the origin of overland flow along its flow path to the location of either concentrated flow or deposition. Computed soil loss values are not as sensitive to slope length as to slope steepness, thus differences in slope length of + or – 10 percent are not important on most slopes. This is especially true in flatter landscapes.

S = Slope Steepness Factor. "S" represents the effect of slope steepness on erosion. "S" is the ratio of soil erosion from the field slope gradient to that from a nine percent slope under otherwise identical conditions. Computed soil erosion rates are more sensitive to slope steepness than to slope length.

LS = Slope Length and Steepness Factor. The slope length "L" and steepness "S" factors are combined into the "LS" factor in the RUSLE equation. A "LS" value represents the relationship of the actual field slope condition to the unit plot. An "LS" value of 1.0 represents the unit plot condition of 72.6 feet in length and nine percent slope steepness.

C = Cover-Management Factor. "C" represents the effect of plants, soil cover, soil biomass, and soil disturbing activities on soil erosion. RUSLE uses a sub-factor method to compute soil loss ratios, which are the ratios of soil loss at any given time in a cover-management sequence to soil loss from the unit plot. Soil loss ratios vary with time as canopy, ground cover, soil biomass and consolidation change. A "C" factor value is an average soil loss ratio weighted according to the distribution of "R" during the year. The sub-factors used to compute a soil loss ratio value are canopy, surface cover, surface roughness, and prior land use.

P = Support Practices Factor. "P" represents the impact of support practices on erosion rates. "P" is the ratio of soil loss from an area with supporting practices in place to that from an identical area without any supporting practices. Most support practices affect erosion by redirecting runoff or reducing its transport capacity. Support practices include contour farming, cross-slope farming, buffer strips, strip cropping, and terraces.

T = soil loss tolerance. "T" is not part of RUSLE, but is used with RUSLE to establish a benchmark for evaluating the predicted erosion rate from an existing or planned conservation system. "T" is the average annual erosion rate that can occur with little or no long-term degradation of the soil resource on the field. Soil loss tolerance values ("T") are assigned to each soil map unit by NRCS.

The specific application of the RUSLE methodology for use with the AnnAGNPS modeling of the Upper Auglaize Watershed involved the following:

1. Assignment of local watershed climate data to represent the “R” factor (120).
2. Using the appropriate soil erodibility properties to represent the “K” factor.
3. The assignment of representative length and slope factors for each soil mapping unit to represent the “LS” factor.
4. The development of crop management files that represent the crops and field operations performed in the watershed to represent the “C” factor.
5. No supporting practices (contouring, terraces, etc.) were used in the RUSLE/AnnAGNPS modeling as these practices are not applicable in the watershed.

The crop management factor “C” is the most important factor in the revised universal soil loss equation reflecting land management practices. The “C” factor is developed by combining (1) crop growth data, (2) field operation types, (3) timing of field operations, and (4) residue decomposition above and below the soil surface.

To address crop management in the Upper Auglaize Watershed, and potential alternatives to reduce soil loss and sedimentation, an extensive list of crop management files was developed for use in the RUSLE/AnnAGNPS model. The crop management files describe the various rotations used in the watershed as well as the different methods of crop establishment and management. For example, a three-year rotation of corn-soybeans-wheat where the corn is established by fall plowing, and two spring diskings followed by planting; the soybeans established by fall chisel plowing and two spring diskings followed by drilling; and the wheat established by one disking of the soybean stubble followed by drilling. A second alternative example of this same corn-soybean-wheat rotation would involve establishing the crops using no-till methods. There are multiple combinations of crop rotations and field operations (approximately 38) making up the crop management files used in the RUSLE/AnnAGNPS modeling of the watershed.

The actual crop management applied to any particular area in the watershed to model past and present soil loss was based on a combination of historical rotations and tillage systems determined through aerial photo interpretation, and roadside surveys conducted over the last ten-plus years.

To model crop management systems for the proposed treatment to reduce erosion and sedimentation, a combination of crop rotation and conservation-tillage systems was used to simulate land treatment. The proposed crop management systems assume more soil surface cover (crop residue) than used in current practices. Figure IV-4 shows sheet and rill erosion in the Upper Auglaize Watershed.

RUSLE is an effective tool to assist in the planning of conservation management systems that address soil erosion resource concerns and pollutants that may be associated with movement of soil.

Figure IV-4: Sheet and rill erosion in the Upper Auglaize Watershed

F. TILLAGE TRANSECTS AND LAND COVER DATA

Developing the land cover data presented a major challenge for the project. Once the project team settled on 1833 cells as the appropriate number of cells for the full watershed run, each cell had to be assigned a crop rotation and tillage scenario for both the existing condition runs and then the alternative BMP runs. Further complicating things was the situation where each cell could potentially be composed of several different crop fields that were individually owned and managed separately with different crop and tillage scenarios. Manipulating the data involved more than 30,000 potential pieces of crop/tillage designations (1833 cells x 4 fields per cell x 4-year time period). Assigning this data and inputting it manually would have been time prohibitive.

The information available to do this work included remotely sensed land use and crop cover data from the UT, and conservation-tillage transect data from NRCS and the SWCD’s. The UT data was available for a four-year project period of 1999–2002 and represented land cover as determined from satellite images of the watershed. Tillage transect data was available for the years of 1999, 2000, and 2002, but not for 2001.

The crop data was assembled into cropland cover data by UT. UT developed a satellite data analysis process to differentiate between corn, soybeans, wheat, and grass. The watershed was subdivided into a 40 meter by 40 meter grid. Each individual unit in the grid (not to be confused with AnnAGNPS cells) was assigned a four-year crop rotation based on what the satellite remotely sensed data showed for that particular grid unit for each of the four years. This grid data was manipulated into polygons in which the crop rotation occurring most frequently was assigned to the land use polygon. This polygon layer was automatically sampled by the GIS-AnnAGNPS interface to determine the dominate crop rotation for each cropland cell, and this was the crop rotation assigned to that cell. The accuracy of this process was measured by checking the total "digitally sensed" crop rotation acres against acres of various crop rotations developed from the NRCS county transect data. These numbers were determined to be in a reasonable range in comparison to data from other sources. In addition, 87 percent of field checks of crop cover agreed with the results of the remote sensing process.

One situation that had to be dealt with was the occurrence of grass cover as a land use or in the crop rotation. Grass cover could be a long-term designated land use, such as pasture or Conservation Reserve Program (CRP) set-aside acres, or a short-term rotational crop, such as hay. The satellite-sensed data could not differentiate between these uses. It was determined that, in most instances, the use wouldn't matter since grass covers have low erosion rates. Thus it was decided to put all such covers in the crop category "grass."

Assigning a tillage system to each crop in the rotation in each cell proved to be more challenging than determining a rotation. NRCS had a conservation-tillage database for three of the four years of crop rotations developed. This data base had been developed by driving a set route in each of the counties and collecting crop type and tillage data for approximately 420 points (more than 100 miles with point data collected left and right of road each half mile). This process is now performed every other year, and the results are extrapolated on a countywide basis. A data set existed for each county, but terminology was not consistent. NRCS converted the data to a consistent terminology and joined the databases. Since the Allen and Auglaize data bases were most complete and covered a large percentage of the watershed, these two were used to determine the predominate tillage type (no-till, mulch or conventional till, or plow) for each crop (corn, soybeans, wheat) over the entire watershed. Figure IV-5 shows typical no-till crop production.

Figure IV-5: No-till crop production

An attempt was made to manipulate the transect data to determine more specific crop and tillage sequences by area and percentage for each of the crop sequences in the transect data base—for instance one crop tillage sequence might be corn-no-till, beans-plow, corn-no-till, beans-no-till, and wheat-mulch till. Although this manipulation was possible, the process proved unwieldy. Additionally, gaps were found in the data, and assigning the data correctly to individual AnnAGNPS cells would have been difficult. For these reasons, this effort was abandoned.

Since field checks confirmed the accuracy of the UT four-year crop rotation classifications, these data were assigned to the AnnAGNPS cells. It was further decided that the tillage transect database represented the best data available for the different tillage practices employed in the watershed. For the existing condition run, since this data could not be spatially applied accurately to each cell, a decision was made to have the model randomly apply the tillage types to the AnnAGNPS cells in the percentages existing in the data base as a whole. For subsequent BMP runs, the model was given the percent of each tillage to apply to the four-year crop rotations.

G. Hydraulic Geometry Considerations

The AnnAGNPS model requires information on stream-channel hydraulic geometry and roughness to route water and contaminants through the stream-channel system. Hydraulic geometry data required includes bankfull depth, bankfull width, and valley width. AnnAGNPS computes each of these characteristics as a function of drainage area by means of power equations that must be developed and supplied by the user.

Field surveys were conducted at 18 locations in the Upper Auglaize River at sites ranging in drainage area from 1.8 to 332 square miles. At each of the 18 locations, a representative cross-section profile was measured by means of an electronic theodolite, channel roughness (Manning's n) was estimated, and bed-material samples were obtained. The cross-section profile data were then analyzed to determine bankfull depth (hydraulic depth at bankfull) and bankfull width (width at top of bank). The bed-material samples were sent to the USGS Kentucky District Sediment laboratory for particle size analyses. Technical Appendix Tables I-7 and I-8 present the results of these analyses.

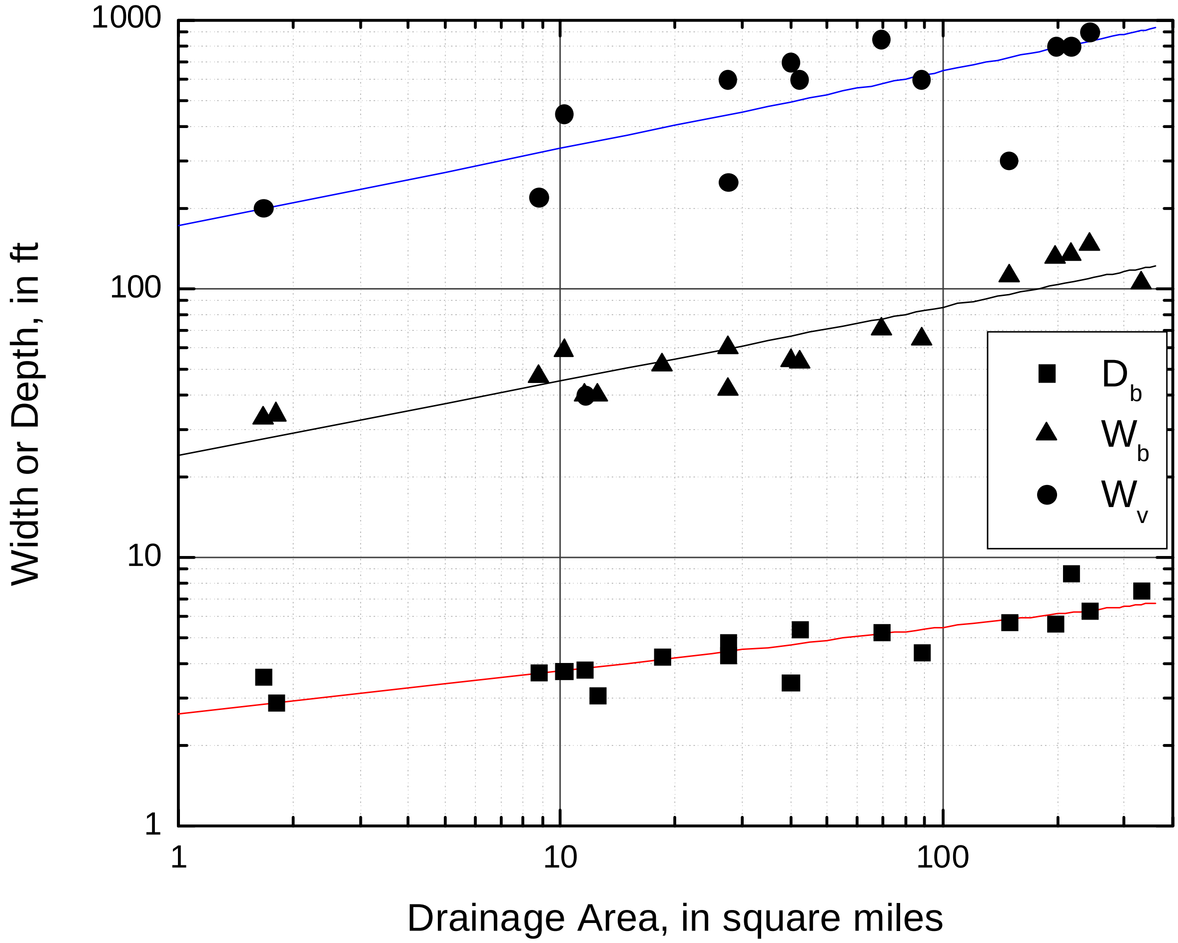

Figure IV-6: Scatter plot of hydraulic geometry characteristics versus drainage area with line plots of power equation functions

Power equations for bankfull depth and width were determined by analyzing channel geometry data gathered from the field surveys. Log-transformed drainage areas were regressed on log-transformed bankfull depths and widths to determine the parameters of the bankfull depth and width equations. Power equations for valley width were determined by analysis of data from Federal Emergency Management Agency (FEMA) flood insurance studies

(FIS) published for the basin. At 16 of the 18 locations where channel geometry measurements were made, the width of the 100-year recurrence interval flood plain shown in the FIS was measured and used as the estimated valley width. Log-transformed drainage areas were regressed on log-transformed valley widths to determine the parameters of the valley width equation. The following equations relating drainage area to width at bankfull, depth at bankfull, and valley width were developed and used in the AnnAGNPS model:

$$W_b = 24.03A^{0.2755}$$

$$D_b = 2.60A^{0.1623}$$

$$W_v = 171.12A^{0.2883}$$

where:

A = drainage area, in square miles;
W_b = width at bankfull, in feet;
D_b = depth at bankfull, in feet; and
W_v = valley width, in feet.

The R^2 values associated with the above equations for W_b, D_b, and W_v are 0.82, 0.73, and 0.58, respectively. **Figure IV-6** shows a log-log scatter plot of the measured hydraulic geometry data versus drainage area, with lines representing the power equation functions superimposed. The hydraulic geometry curves developed for this project for bankfull width and depth are similar to regional curves being developed by the USGS for use in Ohio. However, the curves presented here were developed solely for hydrologic routing computations with AnnAGNPS and are not intended or verified for other purposes. It is noted that stream reaches that have been extensively channelized may have substantially different hydraulic geometries than predicted by the equations presented above.

H. CLIMATE DATA CONSIDERATIONS

Daily precipitation, maximum and minimum temperature, dew point temperature, sky cover, and wind speed data are required by the AnnAGNPS model to perform continuous simulations. Climate data used with AnnAGNPS can be historical, synthetically generated, or a combination of the two. Climate data were generated synthetically for this study due to the desire to compute sediment loads for time periods longer than the period of available historical climate record.

The USDA's Generation of weather Elements for Multiple applications (GEM) model (Johnson et al, 2000) was used to generate the synthetic climate data. According to the documentation for the GEM model, "daily precipitation is described by a first-order Markov chain with precipitation amounts distributed as a mixed exponential distribution. In addition, data on daily maximum and minimum air temperatures, dew-point temperature, solar radiation and wind speed are simulated using a weekly stationary generating process that was first described by Matalas (1967) and adapted to daily weather by Richardson (1981)." Fourier series are used to describe the seasonal variations of parameters. GEM uses climate statistics derived from data collected at climate observation stations to determine selected statistical characteristics required to synthesize the climate data.

The GEM model has an integrated database of predetermined climate statistics for a number of climate observation stations located around the country. The authors concluded that the climate stations in the GEM database were not sufficiently close to the Upper Auglaize River Watershed to provide optimal synthetic climate data. Consequently, data from climate observation stations located closer to the watershed were sought out and used to compute the climate statistics to generate the synthetic climate time series. Temperature and precipitation data from 1961-90 were obtained for the Findlay Airport climate observation station in Hancock County, Ohio. The Findlay Airport climate observation station did not have solar radiation and wind speed data available and so those data were obtained from the Dayton International Airport climate observation station in Montgomery County, Ohio. USDA utility computer programs called Agua_GEM and Genpar6 were used to create the custom climate statistics file used by GEM.

One hundred years of synthetic daily climate data were generated using the GEM model. The climate time series generated by GEM was post-processed with a custom computer program written by the project team to convert solar radiation to approximate percent sky cover. The output was formatted to make it compatible in structure and units required for AnnAGNPS.

I. Ephemeral Gully Issues

The need to include gully erosion in the model was identified early in the project when it was found that model predictions of sheet and rill erosion (even before reductions to account for upland deposition) were significantly lower than the volumes of sediment recorded at the Fort Jennings gage. Streambank erosion is not major problem in the Upper Auglaize River, and work performed by USACE in the 1980's indicated that streambank erosion on the Cuyahoga River (a river with fairly significant bank erosion problems) represented only about 5% of the annual dredging volume at that time (USACE, 1986). Furthermore, much of the river has a rock bottom, and analysis of suspended samples indicates that roughly 90% of the suspended sediment load consists of clay-sized particles. Therefore, channel erosion sources were deemed unlikely to contribute significantly to sediment measurements at the gage. This left gully erosion as the sole remaining mechanism capable of generating sufficient sediment to account for the deficit. Field observations indicated that ephemeral gullies form in many agricultural fields in the watershed, but that classical non-ephemeral gullies were not present. For these reasons a decision was made to utilize the Ephemeral Gully Erosion Model (EGEM) together with AnnAGNPS to estimate ephemeral gully erosion, yield and loading in the Upper Auglaize Watershed.

In keeping with the overall watershed modeling project goal of locating sources of erosion, gully erosion for each cell was calculated in an effort to place and prioritize source areas. The capabilities of the GIS-AnnAGNPS interface made possible the development of the required inputs for each of the 1833 cells. Estimated existing gully erosion was 1.772 tons per acre per year averaged over the entire 211,950 acre watershed, or 375,575 tons per year. A delivery ratio of 0.4 was used to calculate the amount of gully erosion entering the stream system (yield) from its upland source. Table IV-2 gives a summary of the output from the AnnAGNPS model.

Table IV-2: Summary of ephemeral gully erosion for existing conditions.

Items	Amount	Units
Average gully erosion	1.772	t/ac/yr
Total gully erosion	375,600	t/yr
Cell maximum gully erosion	70.350	t/ac/yr
Cell minimum gully erosion	0.000	t/ac/yr
Average gully yield	0.709	t/ac/yr
Total gully yield	150,300	t/yr
Average gully load	0.225	t/ac/yr
Total gully load	476,700	t/yr

The AnnAGNPS model uses a power curve function of runoff volume to model gully erosion. The inputs are the volume of runoff and a coefficient and exponent to apply to the volume. In contrast to this, the EGEM is a more physically-based model of ephemeral gully erosion that requires approximately 15 different parameters for input. EGEM was a more complete and therefore more desirable model for the undertaken analysis. However, it is not incorporated into AnnAGNPS and therefore has to be run outside the model. Thus, to model gully erosion in the Upper Auglaize Watershed, there were three possibilities. 1) Model erosion by the AnnAGNPS power curve using values for the coefficient and exponent from other studies. 2) Use EGEM in a stand-alone fashion and be satisfied that we could not model the delivery of gully erosion through the watershed stream network to the outlet. 3) Use the AnnAGNPS power curve, but develop the power curve for each cell based on the results of running EGEM on the parameters of each cell. The third alternative was chosen. Figure IV-7 is a picture of an ephemeral gully being formed in a recently tilled field.

Figure IV-7: Ephemeral gully forming in the Upper Auglaize Watershed

The GIS interface to AnnAGNPS creates the cell data needed for the watershed model. Some of the parameters developed by the interface for sheet and rill erosion are the same ones needed for EGEM. Thus, area, slope and length parameters were available for each cell from a preprocessing run of the GIS interface. The GIS also determined a dominant soil for each cell. This soil was then cross-referenced in the NASIS soils database to get a soil texture that determined several needed soil properties. Once the parameters were developed, EGEM was run for each cell for a series of rainfall amounts from one to seven inches. A power curve was then fitted through the single storm output points, and the coefficients and exponents were used as input for the AnnAGNPS gully erosion routine.

Calibration of the AnnAGNPS model erosion was accomplished through a comparison with the stream gage data at Fort Jennings (located at the outlet of our Upper Auglaize Watershed.) This calibration corrects for some inadequacies in the modeling process. For instance, some gully erosion could have been missed due to the 20-meter DEM not picking up shorter, smaller slopes. Similarly, only the main drainage of each cell was considered for gully erosion. In other words, if a cell contained a branched gully, the branches were not picked up by the method used since only the length of the main drainage in each cell was determined and used as input to EGEM.

Three types of tillage (conventional, no-till, and "other", all as provided for by EGEM) were used for each cell to calculate the gully erosion expected under different management scenarios. Tillage for each cell was assigned randomly on a statistical basis to match the proportions determined from the tillage transect data. This same assignment was used for both existing-condition gully erosion and sheet and rill erosion. For alternatives considered, again gullies were given the same tillage as assigned to each cell for the sheet and rill input data. Table IV-3 shows the number of cells having ephemeral gully erosion out of the total 1833 cells in the watershed model. Only cropland cells were considered for gully erosion.

Table IV-3: Number of cells with ephemeral gully erosion

Condition	# of cells per soils and topography	# of Cropland Cells
All cropland cells conventionally tilled	1129	983
All cropland cells "other" (mulch) tilled	990	843
All cropland cells no-tilled	562	472

Average watershed erosion and sediment yield attributable to ephemeral gullies for various cropland alternatives are given in Table IV-4. Note that the Existing Conditions Scenario B served as the base model to which modifications were made for the development of Scenarios C through K.

Table IV-4: Average ephemeral gully erosion for the watershed under various scenarios

Scenarios	Gully [t/ac/yr]		Reduction[1] from Existing Conditions Scenario B [%]	
	Erosion	Yield	Erosion	Yield
A. All conventional tillage (alt.17)	3.242	1.297	-83.0	-82.9
B. Existing Conditions (alt.9)	1.772	0.709	0	0
C. 12.1% of highest rate cells converted to no-till (alt.10)	1.166	0.466	34.2	34.3
D. 17.4% cropland, chosen randomly, converted to no-till, additionally 7.6% converted to grass (alt.16)	1.404	0.562	20.8	20.7
E. 7.9% of highest slope cells converted to grass (alt.13)	1.213	0.485	31.5	31.6
F. 25.7% of highest rate cells converted to no-till (alt.11)	0.816	0.326	53.9	54.0
G. 39.5% of highest rate cells converted to no-till (alt.12)	0.739	0.296	58.3	58.2
H. 17.4% of highest slope cells converted to grass (alt.14)	0.773	0.309	56.4	56.4
I. All cropland converted to no-till (alt.18)	0.562	0.225	68.3	68.3
J. 27.1% of highest slope cells converted to grass (alt.15)	0.495	0.198	72.1	72.1
K. All cropland converted to trees (alt.19)	0.000	0.000	100	100

[1] a minus sign indicates an increase.

J. PILOT WATERSHED RUNS

Choosing a smaller pilot watershed allowed for becoming familiar with the model before all input data layers were completed. Two Mile Creek Watershed was chosen because it is about 20,000 acres, or less than one-tenth the size of the full project watershed. Model runs, which could be done much faster than those on the full watershed, were made with varied overall watershed average cell sizes and length of simulation periods. Within each model run the size of each cell varied from less than a fraction of an acre to the maximum cell size as shown in Table IV-5. The table also shows summary output for the pilot runs in ascending order of overall watershed average cell size. The computed absolute values of runoff and erosion are unimportant since the pilot runs were made before any calibration of the model. The relative values, however, indicate that computed sheet and rill erosion tend to increase with increasing overall watershed average cell size, and to decrease with increasing simulation period length. The decrease with length of simulation period is explained by the fact that the first 10-year period in the synthetically generated weather data was wetter than the average for the 100-year period. No gully modeling was done during the pilot watershed analysis. Overall watershed average cell size ranged from 23 to 145 acres in these pilot runs, and a value within this range was chose for the full watershed model. As a trade off between increased detail and longer run times, TOPAGNPS parameters were selected for the full watershed model that resulted in an overall watershed average cell size of 115 acres. The pilot watershed runs demonstrated that for the same tillage type the runoff volume did not vary as greatly as the erosion, which ranged by 40% for the runs. The variation of the simulation results by cell size could also be caused from the characterization of the variability of the watershed attributes such as soils and management. A study of the effect on variation of overall watershed cell size by Bingner et al. (1997) demonstrated for a watershed in Mississippi that cell size has more of an effect on erosion than runoff. Bingner et al. (1997) reported that an upper limit was also observed to cell size in order to adequately simulate fine sediment yield produced from upland sources. Decreasing the size of cells beyond this threshold did not substantially affect the computed fine sediment yield for the watershed in Mississippi.

Table IV-5: Two Mile Creek pilot watershed runs

Avg. Cell Size [ac]	Max. Cell Size [ac]	No. of Cells	No. of Reach	Simulation Period [yr]	Runoff Vol. [in.]	Gross S and R Erosion [t/ac/yr]	Sediment Yield [t/ac/yr]	Sediment Loading [t/ac/yr]	Highest Cell Erosion [t/ac/yr]	Tillage*
23	130	875	356	10	11.43	1.37	0.32	0.16	5.33	Type 1
"	"	"	"	100	10.14	1.07	0.25	0.12	4.17	Type 1
66	318	303	122	10	11.70	1.48	0.30	0.18	5.33	Type 1
"	"	"	"	10	7.68	0.19	0.04	0.02	0.70	Type 2
"	"	"	"	100	10.41	1.16	0.24	0.13	4.17	Type 1
96	589	208	84	10	11.78	1.51	0.32	0.18	4.54	Type 1
145	1070	138	56	10	11.81	1.51	0.35	0.23	4.54	Type 1
"	"	"	"	100	10.52	1.18	0.27	0.17	3.55	Type 1

* Type 1-Corn and Soybeans were fall plowed in a two-year corn-soybeans rotation, wheat was mulch tilled in a 5-year corn-soybeans-corn-soybeans-wheat rotation where corn and soybeans were fall plowed. Type 2-Corn, soybeans and wheat were all no-tilled in a 5-year corn-soybeans-corn-soybeans-wheat rotation.

K. FULL WATERSHED MODEL RUNS

Using the digital data layers of soils, DEM, and land use described above, a majority of the large data input requirements of AnnAGNPS were developed by a customized interface developed in ArcView GIS. Additional steps to further provide the model with the necessary inputs included developing the soil layer attributes to supplement the soil spatial layer, the different crop operation and management data, ephemeral gully inputs, channel hydraulic characteristics, and climate data.

After all inputs were developed and debugged, a run was made to model the existing conditions of the watershed. This existing condition modeled the four crop years of 1999 to 2002 on a repeating basis for a 100-year simulation period in order to average out the statistical variation of the climatic factors.

Following the successful completion of an existing condition run, various alternative runs were modeled for their effects on the erosion and sediment delivery in the watershed. Descriptions and results of these alternative runs are given below in Section V.

The run time for any given model alternative is not so much a function of the watershed size but of the number of cells that partition the watershed, and the number of reaches required to hydrologically link these cells to the watershed outlet. Each cell's soil moisture is updated daily while the reaches are activated only when there is direct water runoff. An equally important factor is the number of simulation years used to determine the desired output; and the average number of precipitation events per year. A 100-year simulation period with two years on initialization was used for all simulations.

Performance time is also affected by the requested output. Default output has no noticeable affect on performance time, and the same is true for the ordinary output tables. However, requesting verification and "CSV" files, especially the "CSV" files, will greatly increase the run time.

A major factor is, of course, the power of the computer used to run the simulation(s). The processor speed and type and available memory can be the most significant factor when deciding upon the maximum number of cells and reaches one is willing to run on a given PC. Although arrays are only allocated as needed and deallocated when no longer needed, memory can become a significant factor in overall performance. If memory is not sufficient for a particular application, "virtual" memory is used which greatly increases performance time. However, all of the PCs used had sufficient RAM to perform all calculations within each PC's RAM. In fact, the maximum RAM allocated by the system for any run was less than 300 MB.

Four different Microsoft compatible personal computers (PC's) with various motherboard (MB) speeds were used to complete the analyses: (1) a Dell Precision 420 (797 MHz, Pentium III processor, and 1 GB RAM); (2) a Dell Latitude C840 (laptop, 1.18 GHz, Pentium IV processor, and 1 GB RAM); (3) a Dell Dimension 8200 (1.99 GHz, Pentium IV processor, and 2 GB RAM); and (4) a hybrid (2.60 GHz, Pentium IV with hyper-threading, and 1 GB RAM).

The watershed input dataset included 1833 cells and 736 reaches, and the simulation period was 100-years. The run times for this input dataset when requesting only default output are shown in Table IV-6.

Table IV-6: Baseline run times for four different PCs.

PC No.	PC Model	Processor Model	CPU Speed [GHz]	MB Speed [GHz]	RAM [GB]	Run Time [hr]
1	Dell Precision 420	Pentium III	0.80	0.80	1.00	35
2	Dell Latitude C840 (laptop)	Pentium IV	2.20	1.18	1.00	30
3	Dell Dimension 8200	Pentium IV	2.00	1.99	2.00	18
4	Hybrid	Pentium IV w/ hyper-threading	2.60	2.60	1.00	12

Although the choice of hardware had a significant effect on the run times, additional RAM beyond 528 MB had no effect on the run time if AnnAGNPS was running alone without any other use of the PC. It is recommended that a PC with maximum performance (state-of-the-art processor and motherboard, highest performing hard drive with maximum capacity, and at least 1 GB RAM–2 GB is preferable) be utilized.

L. VALIDATION AND CALIBRATION ISSUES

The water and sediment output for the "Existing Conditions" (Scenario B) were calibrated using data from the Fort Jennings USGS gage at the outlet. Landuse and field management for the "Existing Conditions" was established close to what existed during the time period when data was collected at the Fort Jennings gage. The average annual water load from surface runoff plus quick return flow (surface and subsurface flow from the tile drains) at the gage was estimated to be nearly 10 inches—8 inches from direct surface runoff and 2 inches from the tile drain subsurface quick return flow. The average annual sediment load was calculated from the gage data to be approximately 0.30 tons per acre per year.

By default, AnnAGNPS assumes that interception evaporation is zero. The user can input a value between 0 and ¼ inch (6.35mm). A literature review suggests that interception evaporation varies between 0.047 inches (1.2mm) and 0.098 inches (2.5mm). A value of 0.059 inches (1.5mm) yielded 9.999 inches of water at the Fort Jennings gage. This value for the interception evaporation was used for all scenarios.

Examination of gage data throughout the Maumee River Basin has shown that the suspended load is almost entirely fine-sediment wash load originating from the landscape. Very little suspended sediment originates from the bed or banks of the stream system. Careful analysis of the landscape erosion indicates that less than half is due to sheet and rill. The remainder must come from gully erosion—primarily ephemeral gullies. A field investigation during a recent spring storm and supported with pictorial evidence indicated widespread ephemeral gullies form during surface runoff events. As described above, ephemeral gully analyses were made using information from EGEM to develop AnnAGNPS gully relationships for each cell.

The sediment loading at the Fort Jennings gage was calibrated by: (1) fitting a power curve to gully erosion results for each field computed as a function of rainfall depth from EGEM to determine the curve parameters to be used within AnnAGNPS; (2) assuming a value for the delivery ratio of gully erosion to gully yield to each field's receiving stream; and (3) transporting the sediment yielded from both sheet and rill and gully erosion to the Fort Jennings gage. The gully delivery ratio assumed in Step 2 was adjusted until the average annual total suspended sediment load at Fort Jennings gage was nearly 0.30 tons per acre per year, and a value of 0.40 was found to give the best results.

M. RIPARIAN BUFFER (REMM MODULE) PROGRESS AND NEEDS

The Riparian Ecosystem Management Model (REMM) (Lowrance et al., 2000; Altier et al., 2002) has been developed by USDA-ARS to simulate the water quality impacts of riparian buffer systems (RBS) and other edge of field buffer systems. REMM is a tool to assess the function of RBS to filter pollutants from a field. Inamdar et al. (1999a, 1999b) evaluated REMM capabilities for hydrologic performance as well as water quality and nutrient cycling at Gibbs Farm, near Tifton Georgia. Uncalibrated REMM hydrology simulation gave close agreement between average water table depths, water table pattern, surface runoff volumes, and patterns of surface runoff (Inamdar et al., 1999a). Inamdar et al. (1999b) concluded that REMM simulations generally represented these riparian buffer systems functions well.

The need to assess a riparian buffer system can be an important part of assessing the impact of conservation measures within the Upper Auglaize Watershed project. The current version of AnnAGNPS does not include REMM technology to assess riparian buffer systems. This need was identified in the project plan and the AnnAGNPS developers proceeded to address the development of riparian buffer system capabilities into the model. Since REMM is a single field scale model, there is a need to develop a watershed version that captures the main effects of REMM for potentially each AnnAGNPS cell. As part of this development, a lateral subsurface flow component was included within AnnAGNPS to allow for the subsurface flow of water and nutrients to the buffer. As part of the subsurface flow component, a tile drain feature was also developed that was needed for the project. Figure IV-8 pictures a riparian forest buffer and grass filter strip system.

Figure IV-8: Riparian forest buffer and grass filter strip system

Bringing the development of REMM technology within AnnAGNPS at the watershed scale to completion will require a further integration of edge of field buffer processes as they filter sediment and chemicals. The REMM technology of water flowing through the buffer and vegetation filtering and extracting sediment and chemicals needs to be incorporated within AnnAGNPS. It will require more time and resources to completely incorporate REMM technology into the watershed system approach used within AnnAGNPS.

V. RESULTS OF FULL WATERSHED MODEL RUNS

A. Existing Condition Simulation Outputs and Sediment Contribution

The existing condition was simulated by using current remote sensing imagery but randomly distributing the agricultural tillage parameters within the crop landuse. The existing condition simulation resulted in an average erosion over the entire 211,950 acre watershed of 2.473 tons per acre per year. Table V-1 summarizes the results for this benchmark condition. Of the 524,200 t/yr of gross erosion in the watershed, the model indicates that only 65,070 t/yr, or 12.4%, is delivered to the watershed outlet. This watershed delivery ratio is determined by the fact that the vast majority of the eroded sediment is redeposited on a field scale and never makes it to a stream, and a small amount is also lost to deposition within the stream transport system.

Table V-1: Summary of existing condition simulation output

Item	Amount	Units
Watershed Average Sheet and rill Rate of Erosion	0.701	t/ac/yr
Watershed Average Ephemeral Gully Rate of Erosion	1.772	t/ac/yr
Watershed Average Total Rate of Erosion	2.473	t/ac/yr
Watershed Total Tons of Erosion	524,200	t/yr
Watershed Sediment Yield to Streams	0.965	t/ac/yr
Sediment Loading Rate to Watershed Outlet	0.307	t/ac/yr
Sediment Loading Amount to Watershed Outlet	65,070	t/yr
Highest Erosion from Individual Cell	77.045	t/ac/yr

The existing condition simulation erosion is shown in Figure V-1. This simulation was calibrated for both water and sediment as explained above and therefore gives valid total amounts. However, the spatial distribution is a best available simulation rather than a fully location based result. The reason for this is that data was not available for the type of tillage practiced for each crop field. From representative tillage transect data the overall percentages of tillage types were known, but the exact field by field values were not. Thus, tillage type was applied on a random basis to each field to come up with the total amount of conventional, mulch and no-till percentages. Having said this, the existing condition simulation map still gives a general idea of the location of higher and lower erosion and sediment producing areas. In other words, the random distribution of tillage types maintains the overall distribution of erosion rates. This is borne out by the accompanying maps where tillage has been factored out as a determining variable. Tillage is factored out by applying the same tillage type to all fields. These maps reflect modeling all cropland under conventional tillage and another set with all cropland under no-till. With these maps the soils and topography are determinative. The following 12 maps, Figures V-1 to V-12, show four sets of three maps each. The first set of three (Fig. V-1 to V-3) show erosion under three tillage types, namely, “existing”, all conventional, and all no-till. The second set (Figs. V-4 to V-6) and the third set (Figs. V-7 to V-9) show the same three tillages for sediment yield to streams and sediment loading to the watershed outlet. The fourth set of three (Figs. V-10 to V-12) maps show percent reduction in erosion, yield, and load when tillage is changed from all conventional tillage to all no-tillage. Each set has a uniform legend scale to allow for straight forward comparisons.

Table V-2 shows management alternatives involving different tillage operations and/or landuse. These were used to compare with the baseline existing condition. These alternatives were modeled with the AnnAGNPS program.

Table V-2: Management Alternatives

Scenario	Management Alternatives
A	All cropland fall plowed.
B	Existing condition simulation
C	12.1% of highest eroding cropland cells (23,288 Ac.) converted to no-till.
D	17.4% of random cropland cells (33,356 Ac.) converted to no-till and 7.6% (14,486 Ac.) converted to grassland.
E	7.9% of cropland cells with the highest slope (15,124 Ac.) converted to grassland.
F	25.7% of highest eroding cropland cells (49,284 Ac.) converted to no-till.
G	39.5% of highest eroding cropland cells (49,284 Ac.) converted to no-till.
H	17.4% of cropland cells with the highest slope (33,410 Ac.) converted to grassland.
I	All cropland no-tilled.
J	27.1% of cropland cells with the highest slope (52,056 Ac.) converted to grassland.
K	All cropland converted to forestland.

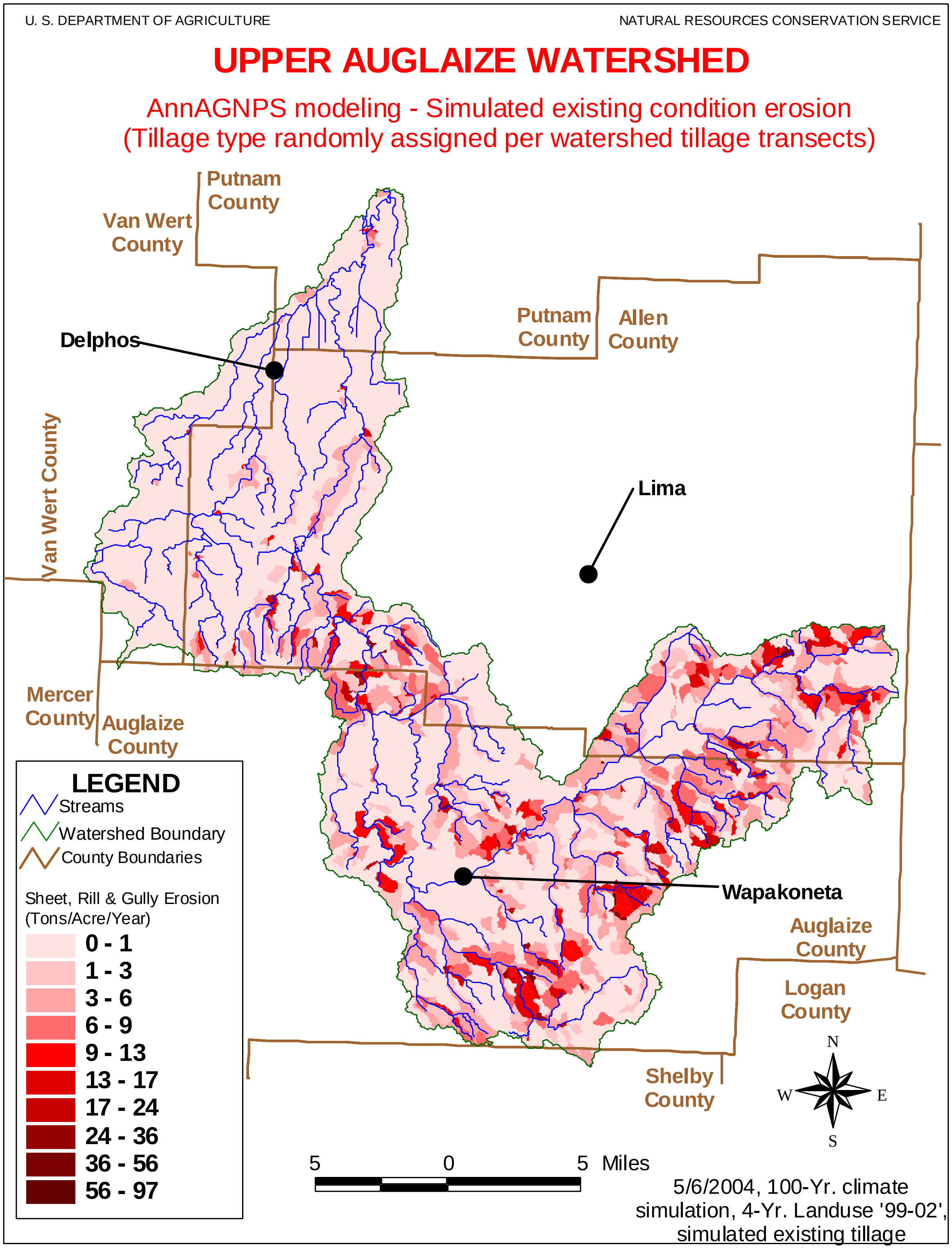

Figure V-1: Map showing spatial distribution of erosion for Scenario B—existing condition simulation

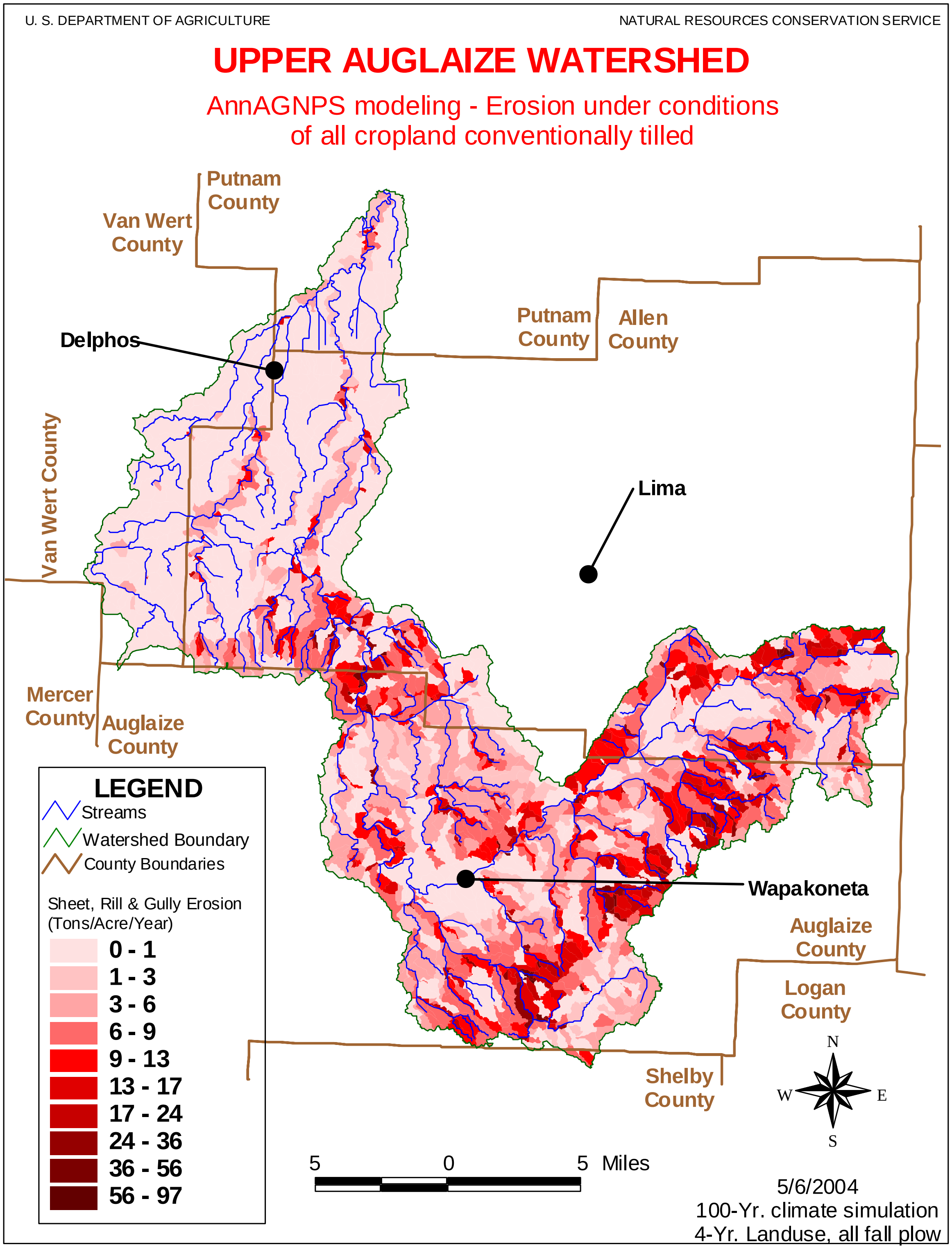

Figure V-2: Map showing spatial distribution of erosion for Scenario A—All Conventional Tillage

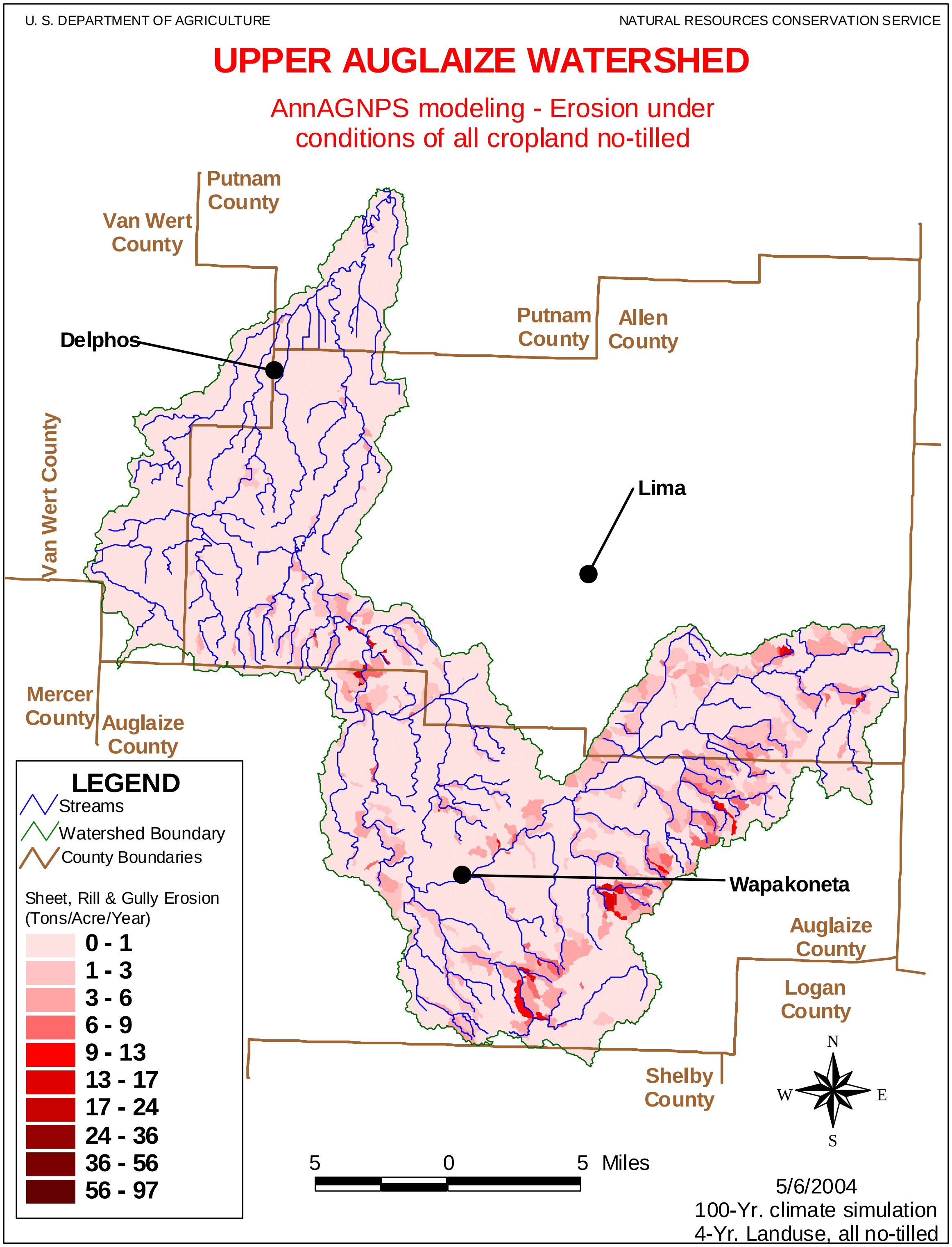

Figure V-3: Map showing spatial distribution of erosion for Scenario I—All No-till

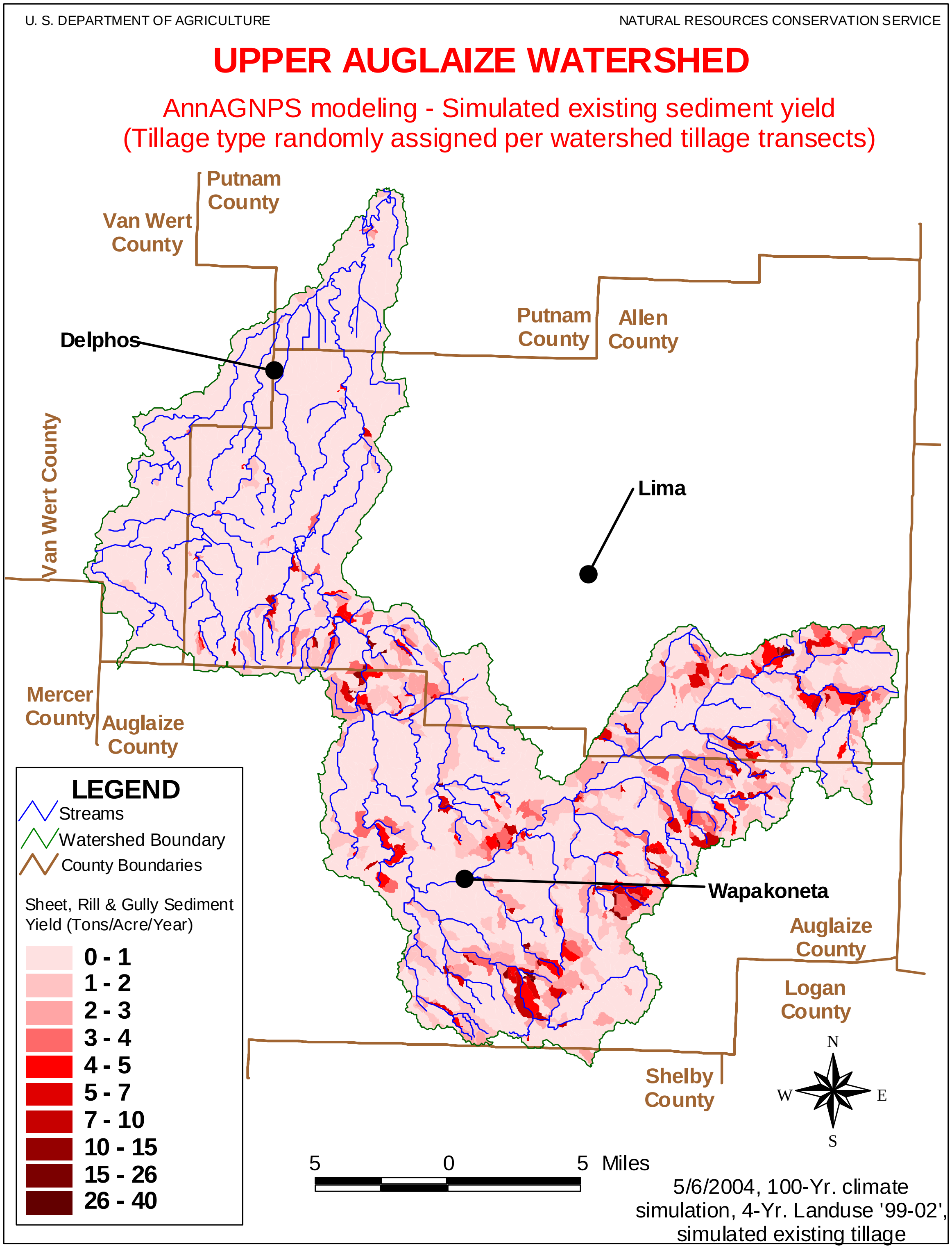

Figure V-4: Map showing spatial distribution of sediment yield to streams for Scenario B—existing condition simulation

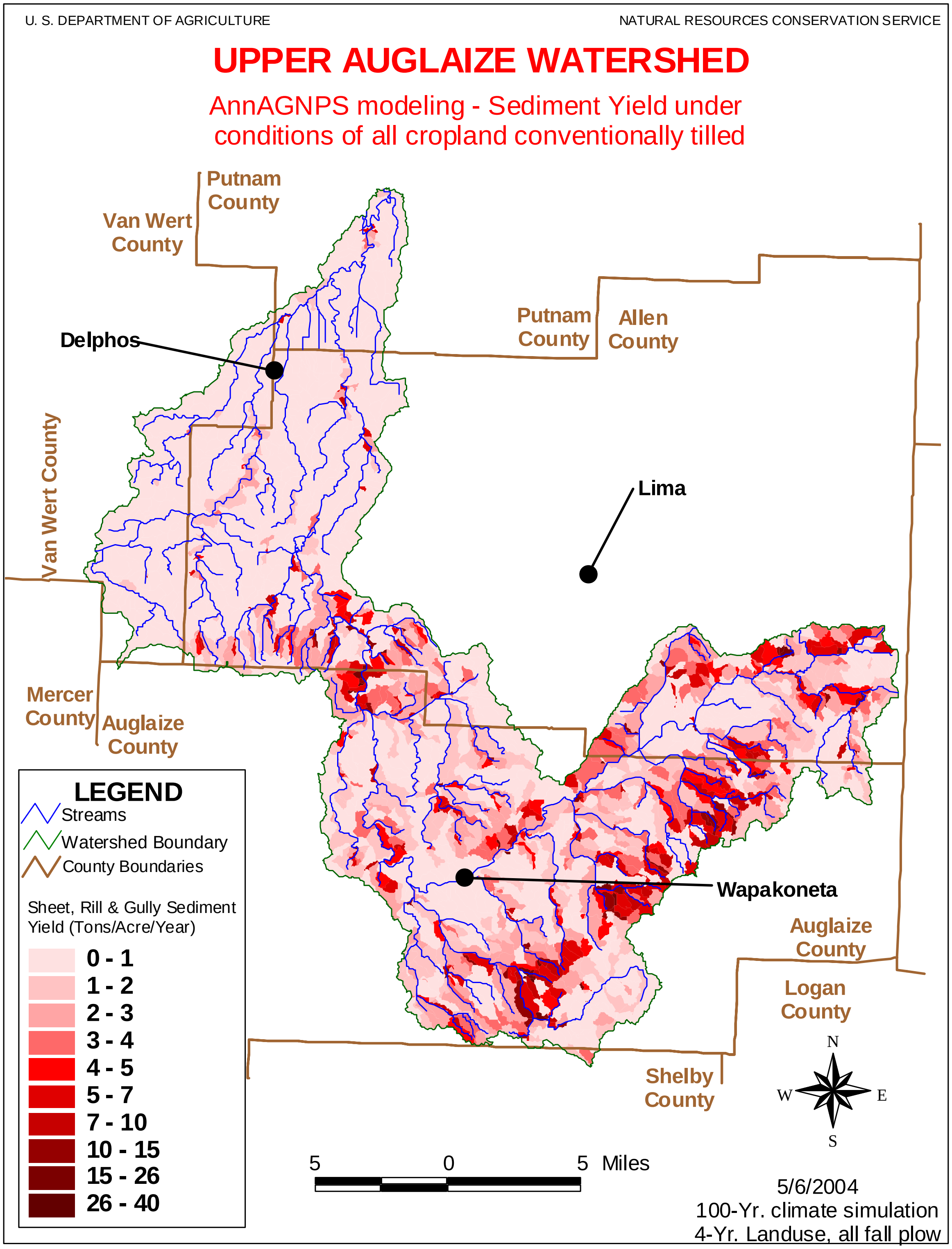

Figure V-5: Map showing spatial distribution of sediment yield to streams for Scenario A—All Conventional Tillage

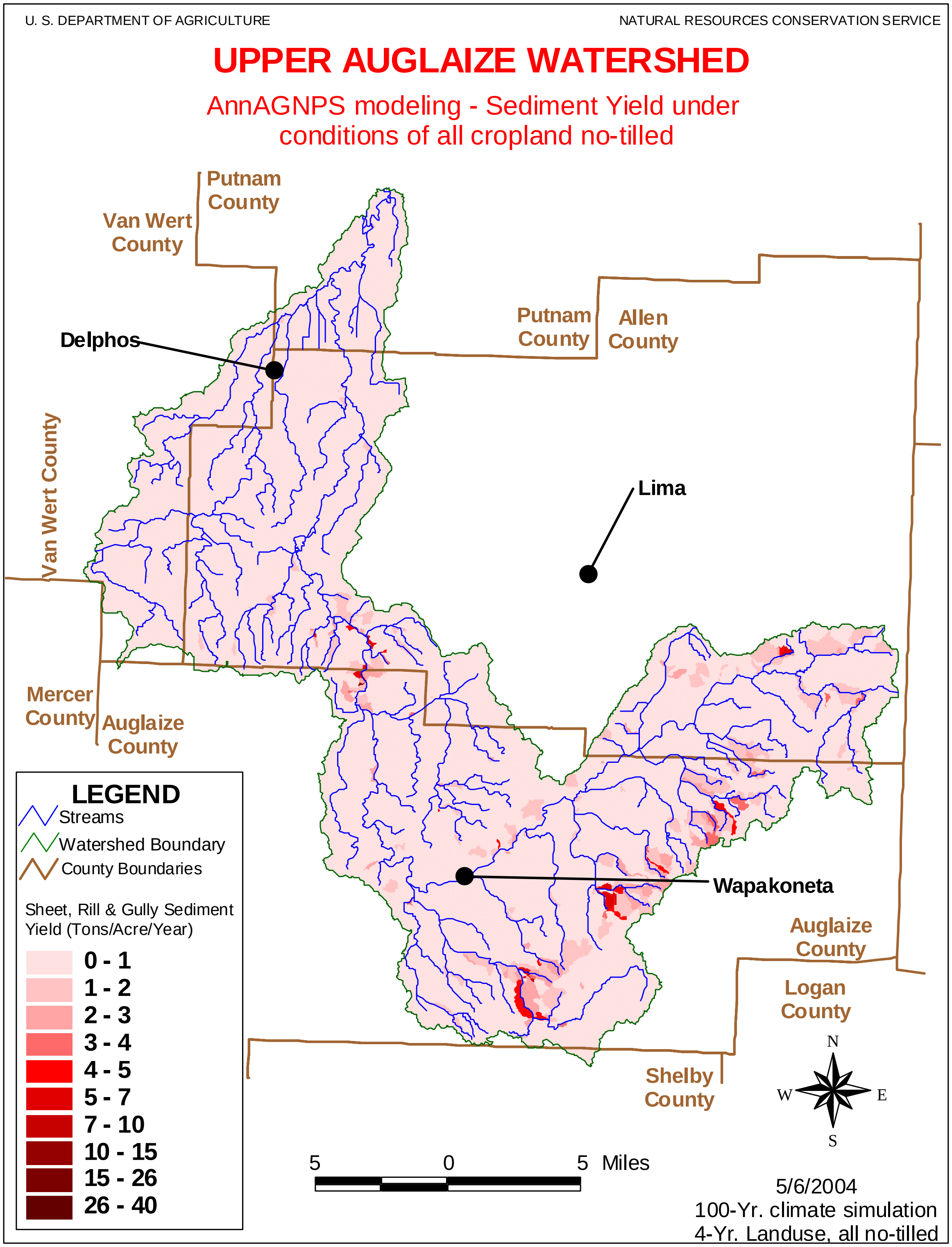

Figure V-6: Map showing spatial distribution of sediment yield to streams for Scenario I—All No-till

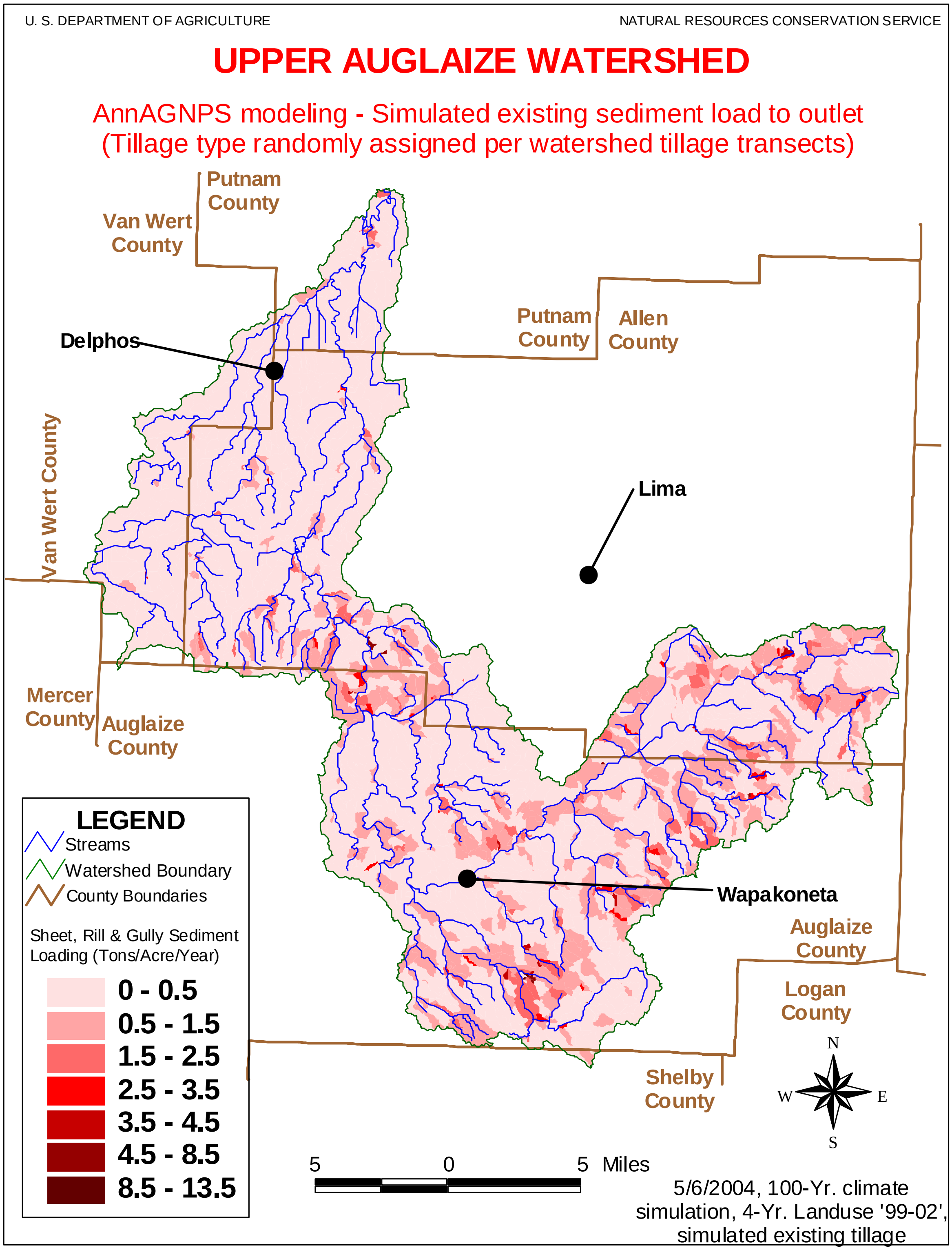

Figure V-7: Map showing spatial distribution of sediment load to watershed outlet for Scenario B—existing condition simulation

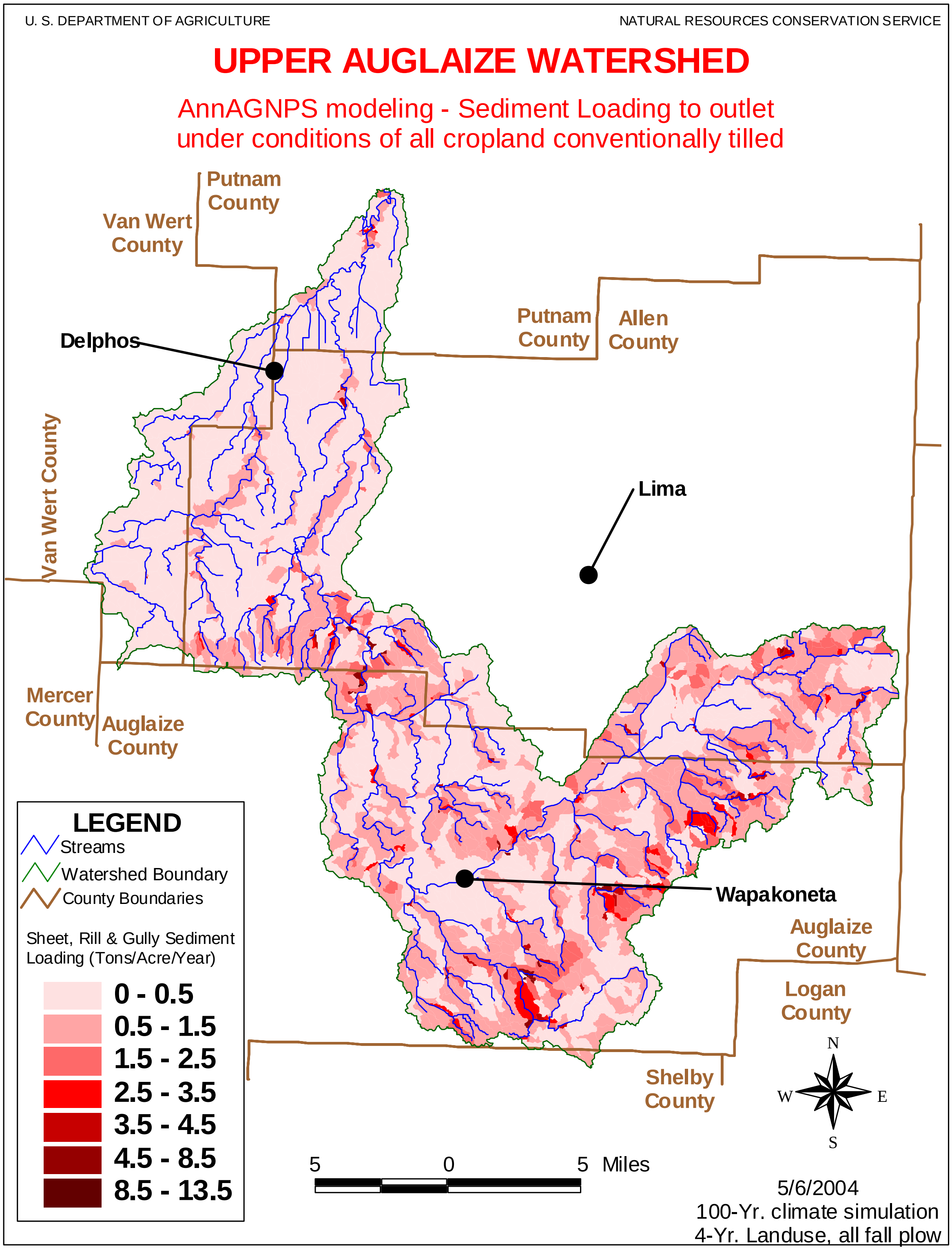

Figure V-8: Map showing spatial distribution of sediment loading to watershed outlet for Scenario A—All Conventional Tillage

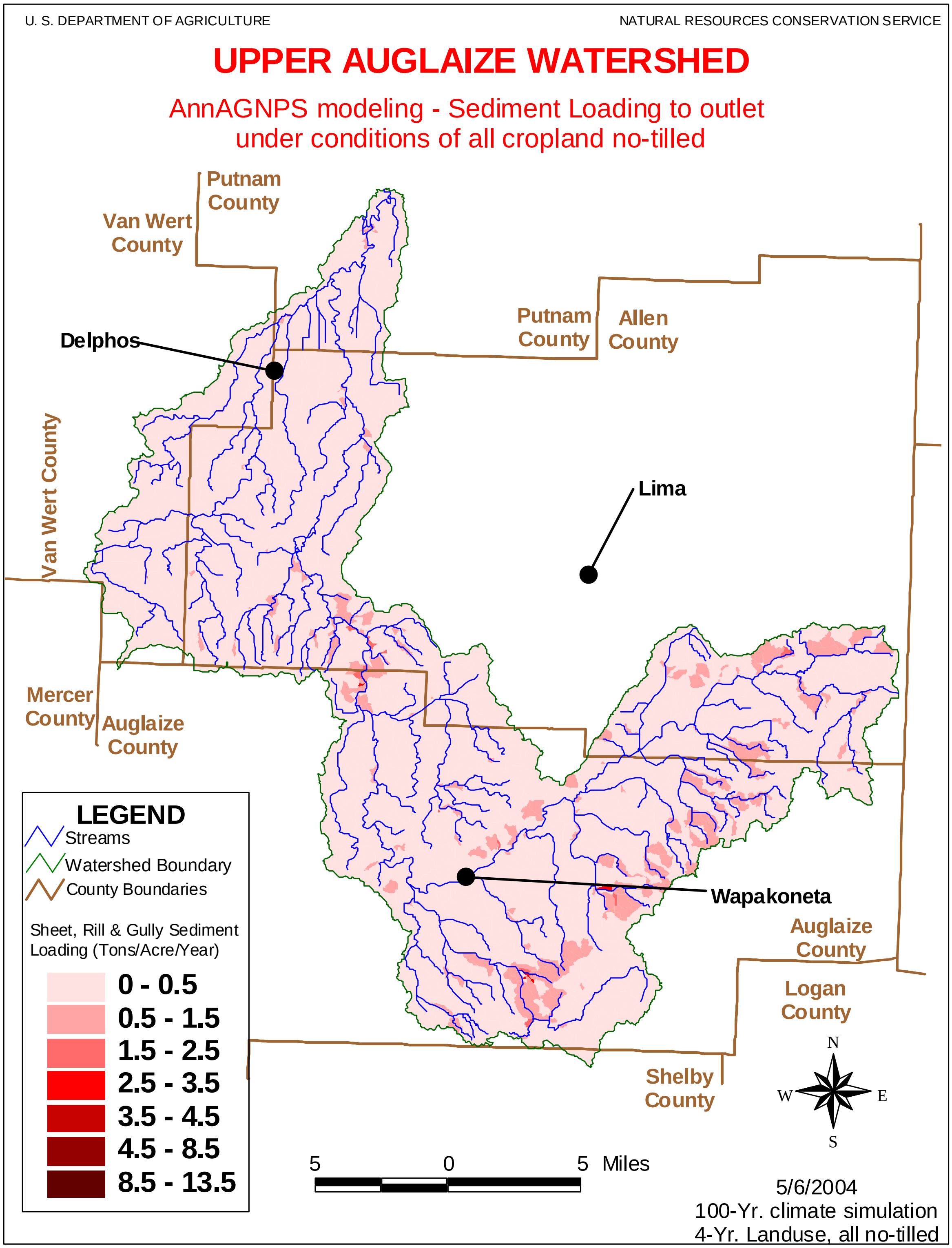

Figure V-9: Map showing spatial distribution of sediment loading to watershed outlet for Scenario I—All No-till

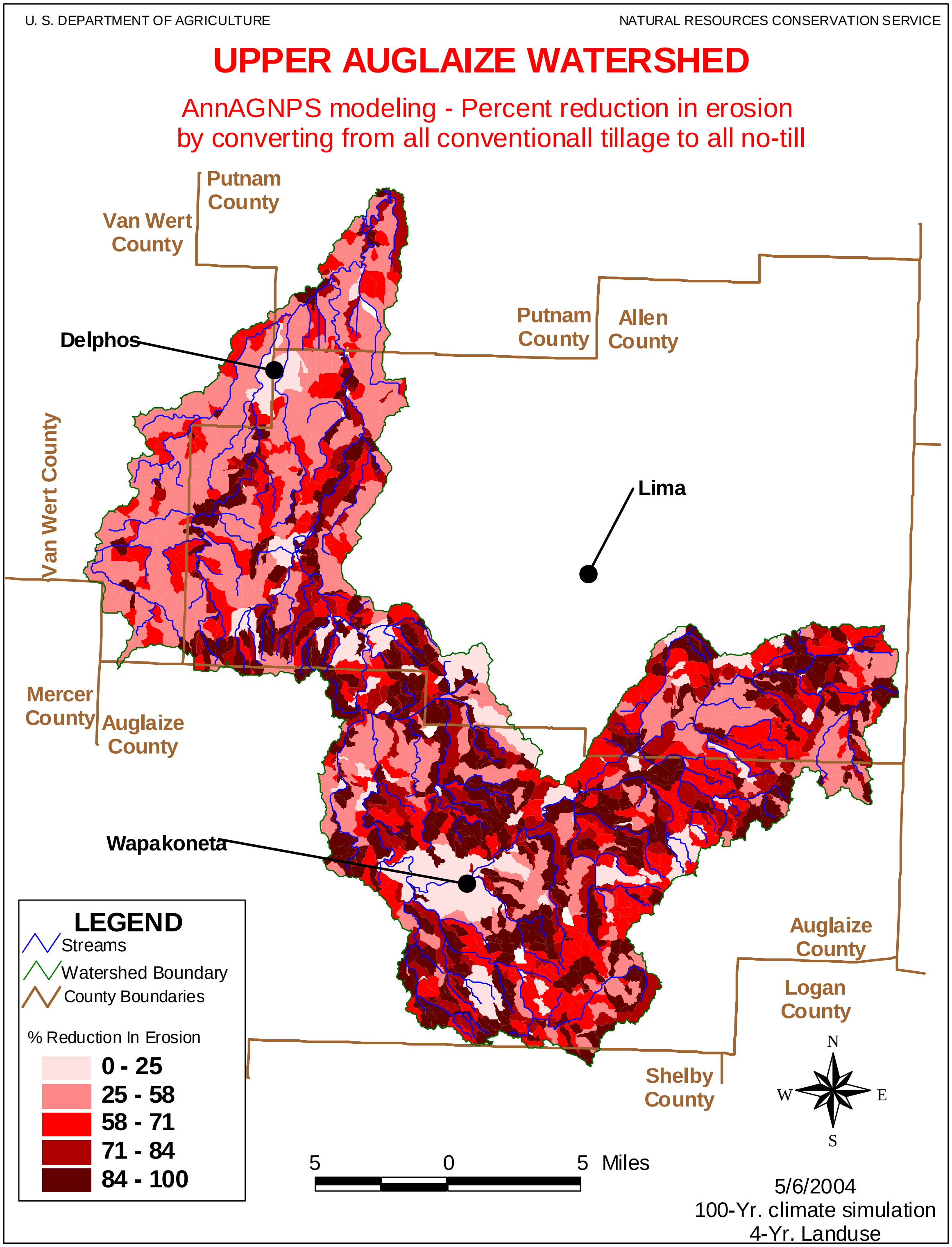

Figure V-10: Map showing percent reduction in erosion by converting from all conventional tillage to all no-till

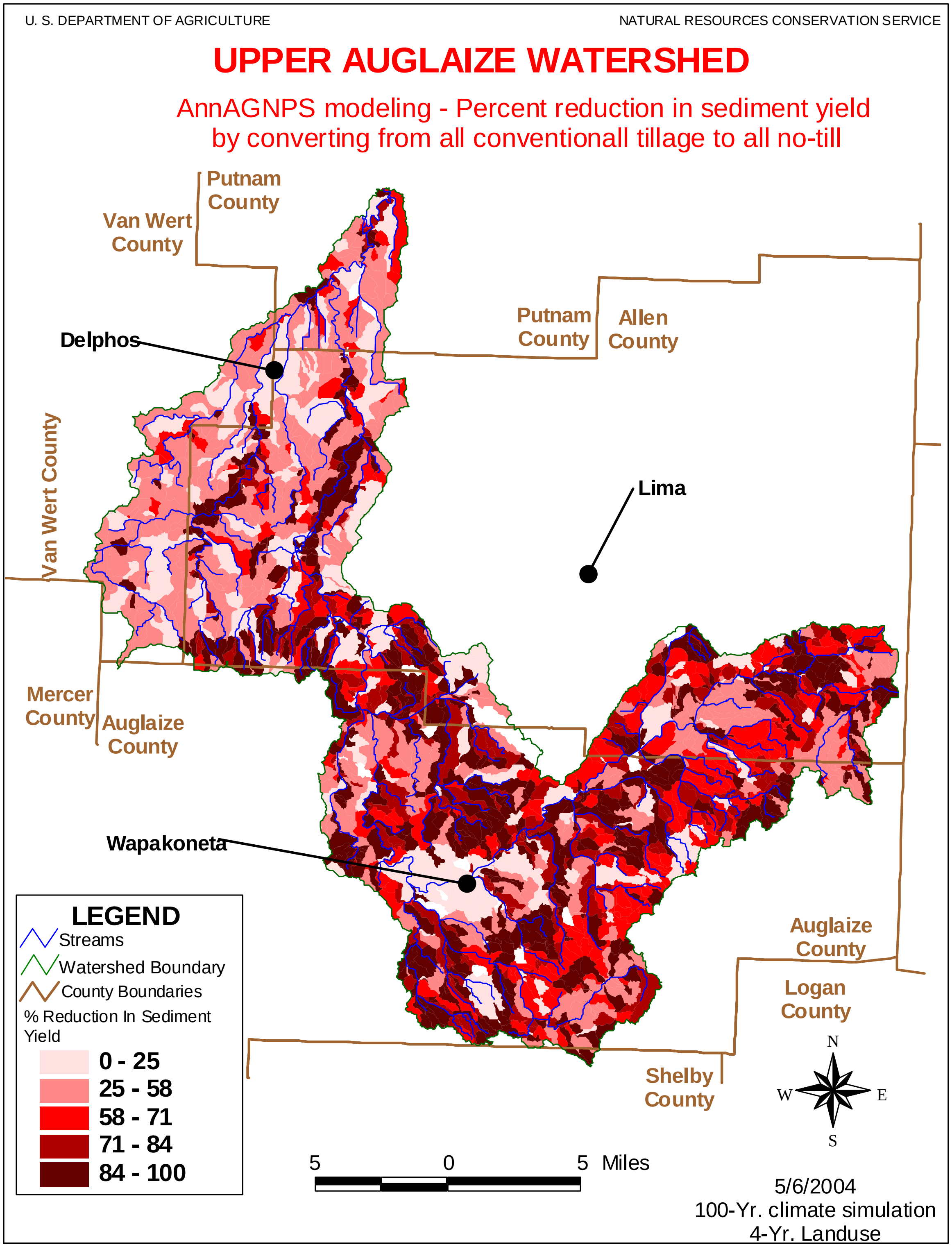

Figure V-11: Map showing percent reduction in sediment yield by converting from all conventional tillage to all no-till

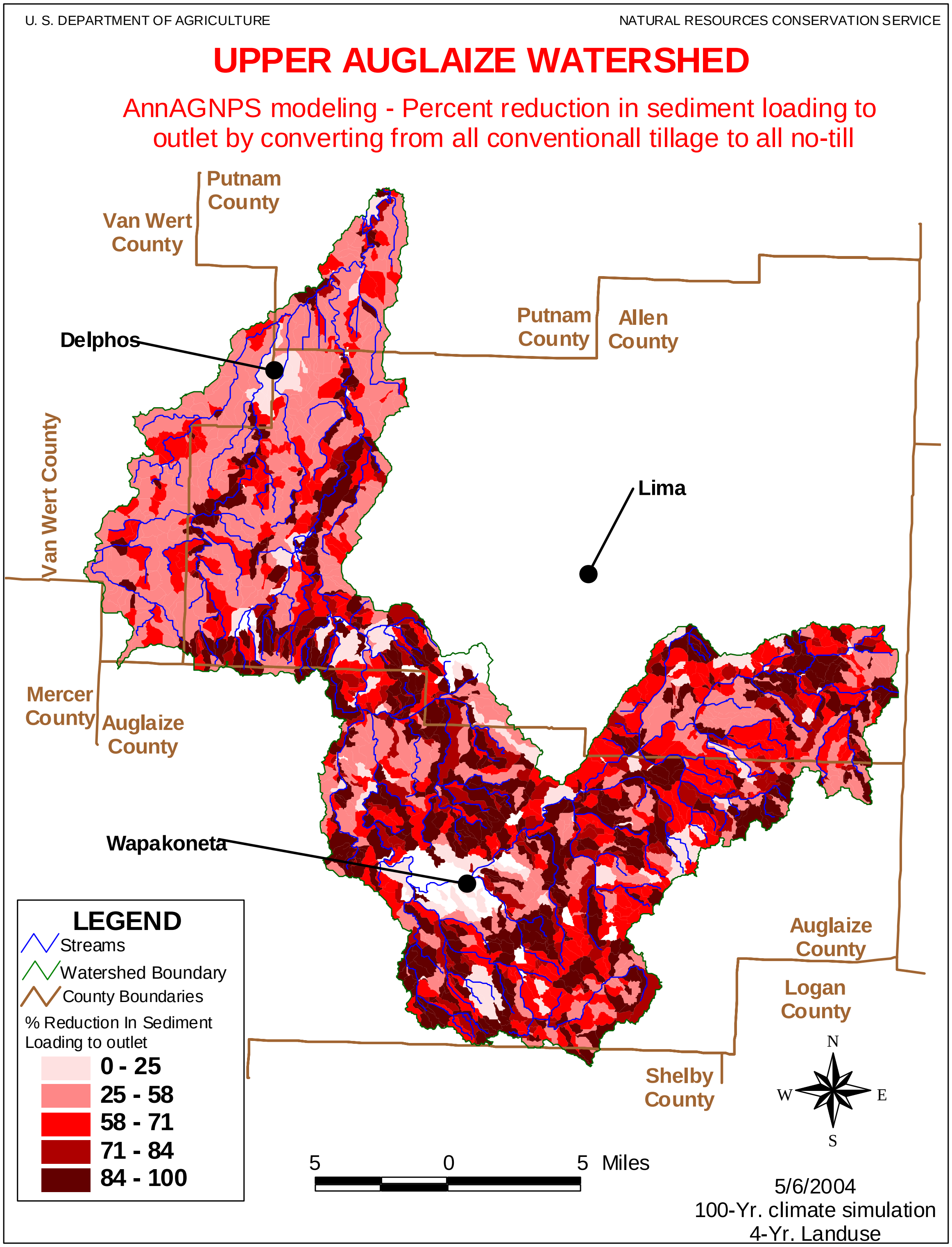

Figure V-12: Map showing percent reduction in sediment loading to outlet by converting from all conventional tillage to all no-till

Tile drainage was modeled as a part of the project. Figure V-13 shows a tile drain discharging into a ditch.

Figure V-13: Tile drain discharging into a ditch.

Table V-3 summarizes the "with tile drain" model runs, showing watershed averages for each scenario. Common parameters shared by all the model runs are 35.3 inches of average annual rainfall, average cell size of 116 acres, maximum cell size of 855 acres, 100-year simulation period, 1833 total cells, and 736 reaches.

Table V-3: Summary of Alternative Management Models

Scenario ID	Scenario Description	Runoff Volume [in]	Gross S and R Erosion [t/ac/yr]	Gross Gully Erosion [t/ac/yr]	Sediment Yield [t/ac/yr]	Sediment Loading at Outlet [t/ac/yr]	Highest Erosion in any cell [t/ac/yr]
A	all cropland, fall plow, freshly cultivated	10.86	1.055	3.242	1.665	0.523	96.75
B	existing condition simulation	10.00	0.701	1.772	0.965	0.307	77.04
C	12.1% greatest erosion converted to no-till	9.92	0.612	1.166	0.687	0.230	72.69
D	17.4% random cropland converted to no-till and 7.6% to grass	9.84	0.609	1.404	0.788	0.251	77.05
E	7.9%greatest slope cropland converted to grass	9.94	0.602	1.213	0.698	0.229	45.92
F	25.7% greatest erosion converted to no-till	9.83	0.553	0.816	0.529	0.179	72.69
G	39.5% greatest erosion converted to no-till	9.75	0.502	0.739	0.483	0.161	72.69
H	17.4%greatest slope cropland converted to grass	9.87	0.498	0.773	0.481	0.164	37.77
I	all cropland in no-till	9.58	0.466	0.562	0.404	0.132	25.14
J	27.1%greatest slope cropland converted to grass	9.80	0.427	0.495	0.346	0.121	26.36
K	all land converted to forest	4.68	0.003	0.000	0.001	0.001	0.46

* All results in this table represent runs with tile drainage turned on.

Table V-4 shows the amount of clay, silt, and sand simulated by AnnAGNPS for each scenario.

Table V-4: Simulated amount of clay, silt, and sand.

Scenario	Erosion [t/ac/yr]					Yield [t/ac/yr]			Load [t/ac/yr]		
	Clay	Silt	Sand	Aggregates Small	Aggregates Large	Clay	Silt	Sand	Clay	Silt	Sand
A	0.277	0.452	0.264	1.724	1.581	0.601	1.056	0.008	0.514	0.009	0.001
B	0.160	0.260	0.151	0.991	0.911	0.347	0.607	0.011	0.302	0.005	0.000
C	0.116	0.185	0.108	0.712	0.658	0.248	0.429	0.011	0.225	0.000	0.000
D	0.130	0.212	0.123	0.808	0.740	0.282	0.495	0.011	0.247	0.004	0.000
E	0.118	0.187	0.109	0.734	0.668	0.252	0.436	0.010	0.225	0.004	0.000
F	0.089	0.143	0.083	0.546	0.507	0.191	0.328	0.011	0.175	0.000	0.000
G	0.081	0.130	0.075	0.495	0.460	0.173	0.299	0.011	0.158	0.004	0.000
H	0.084	0.129	0.075	0.513	0.470	0.176	0.296	0.009	0.160	0.004	0.000
I	0.067	0.109	0.063	0.411	0.378	0.143	0.250	0.011	0.129	0.003	0.000
J	0.061	0.092	0.053	0.372	0.343	0.128	0.210	0.008	0.117	0.003	0.000
K	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000

The summary results of the above alternatives are compared graphically in Figure V-14 through Figure V-19 in which the alternatives are sorted by decreasing total tons of sediment loading.

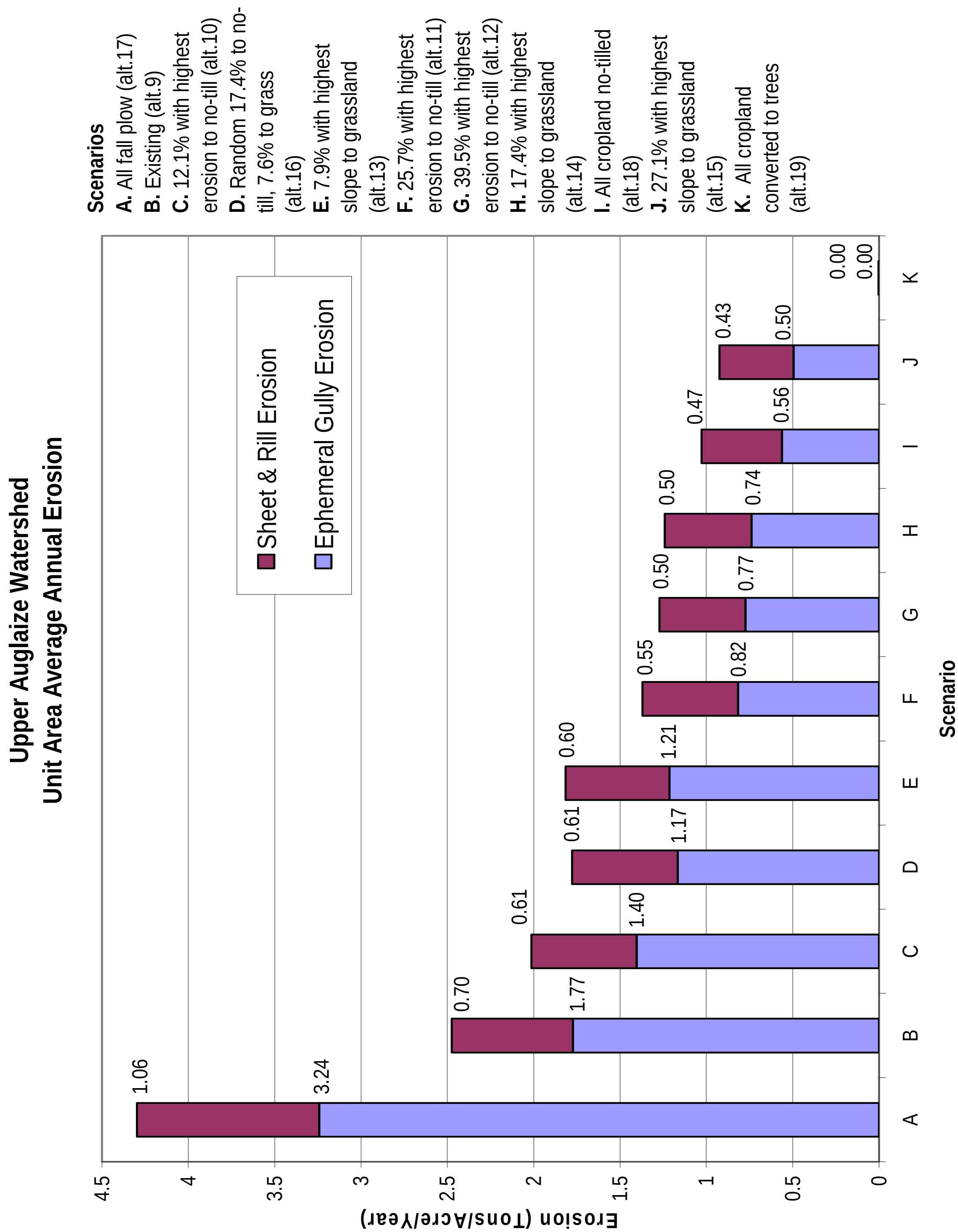

Figure V-14: Upper Auglaize Watershed—average annual erosion [t/ac/yr]

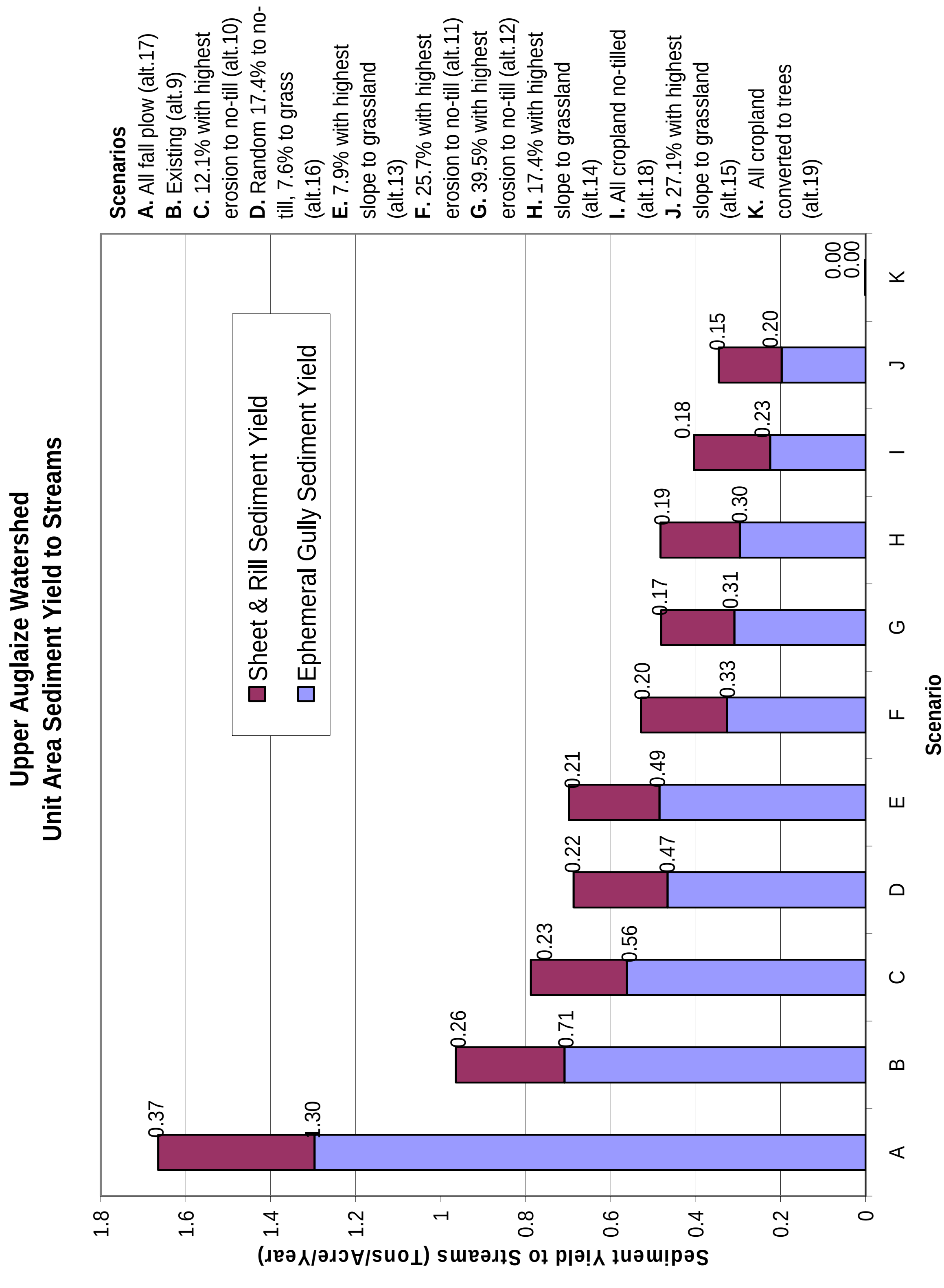

Figure V-15: Upper Auglaize Watershed—average annual sediment yield [t/ac/yr]

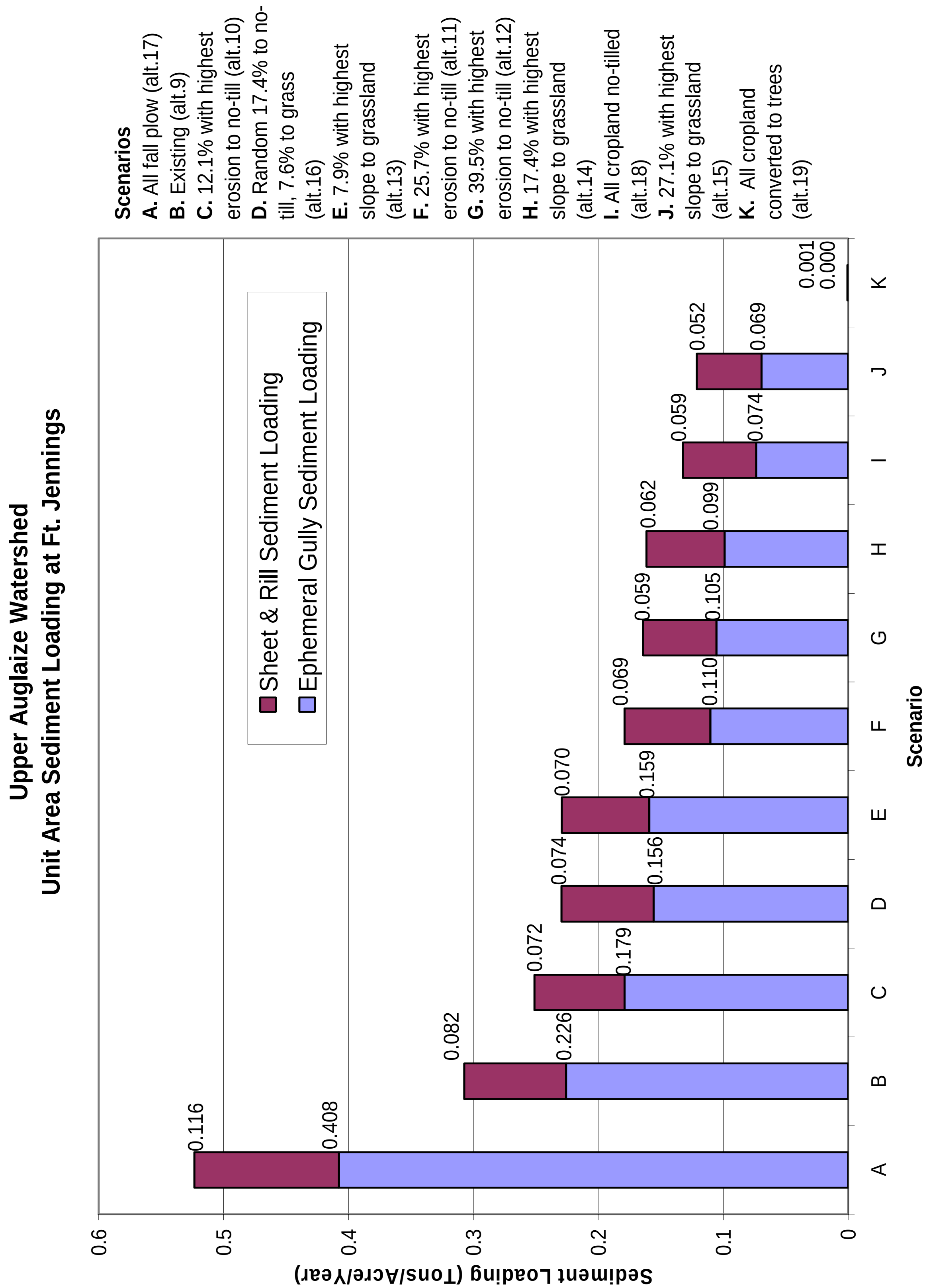

Figure V-16: Upper Auglaize Watershed—average annual sediment loading [t/ac/yr]

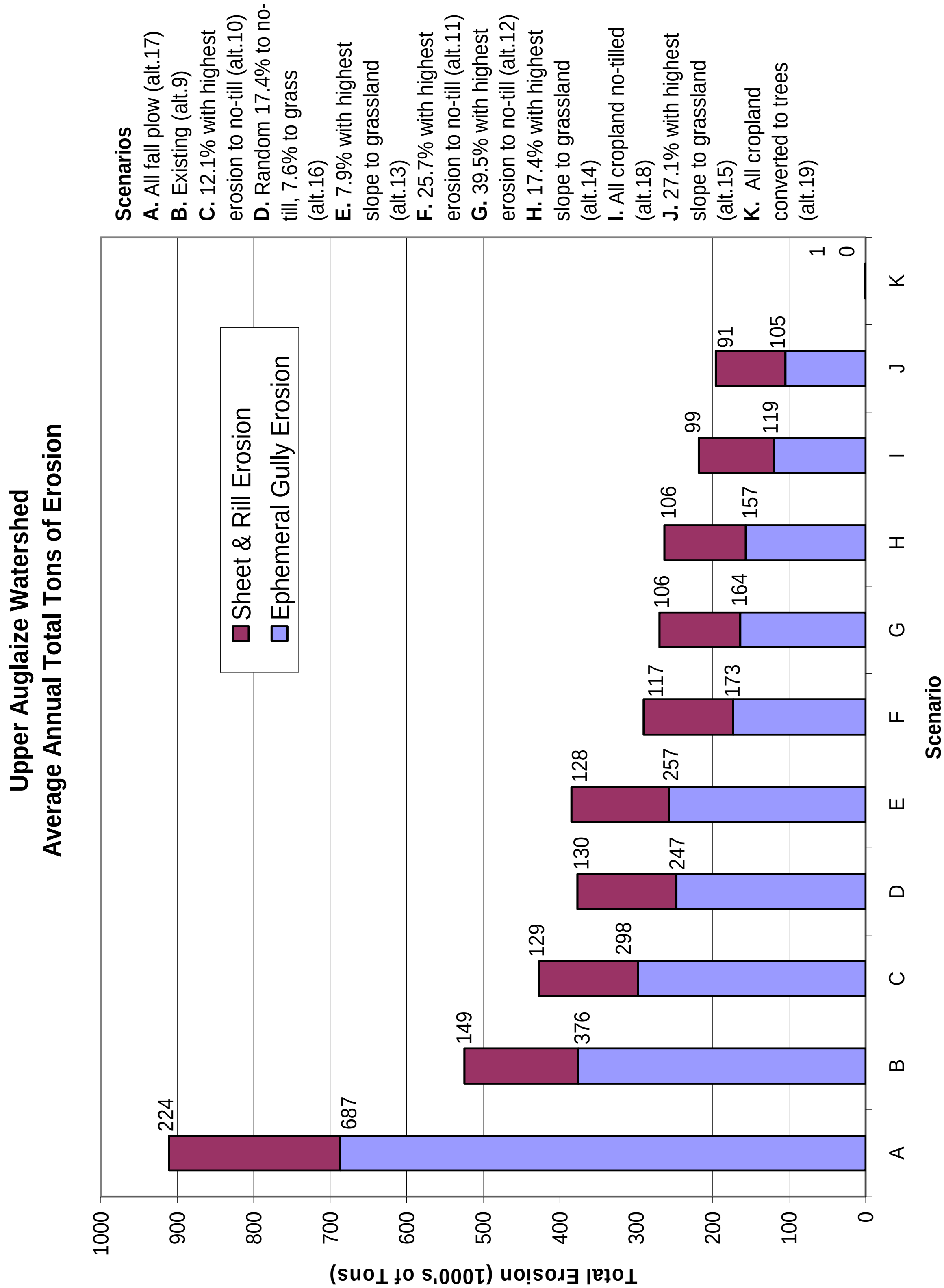

Figure V-17: Upper Auglaize Watershed—erosion [tons/yr]

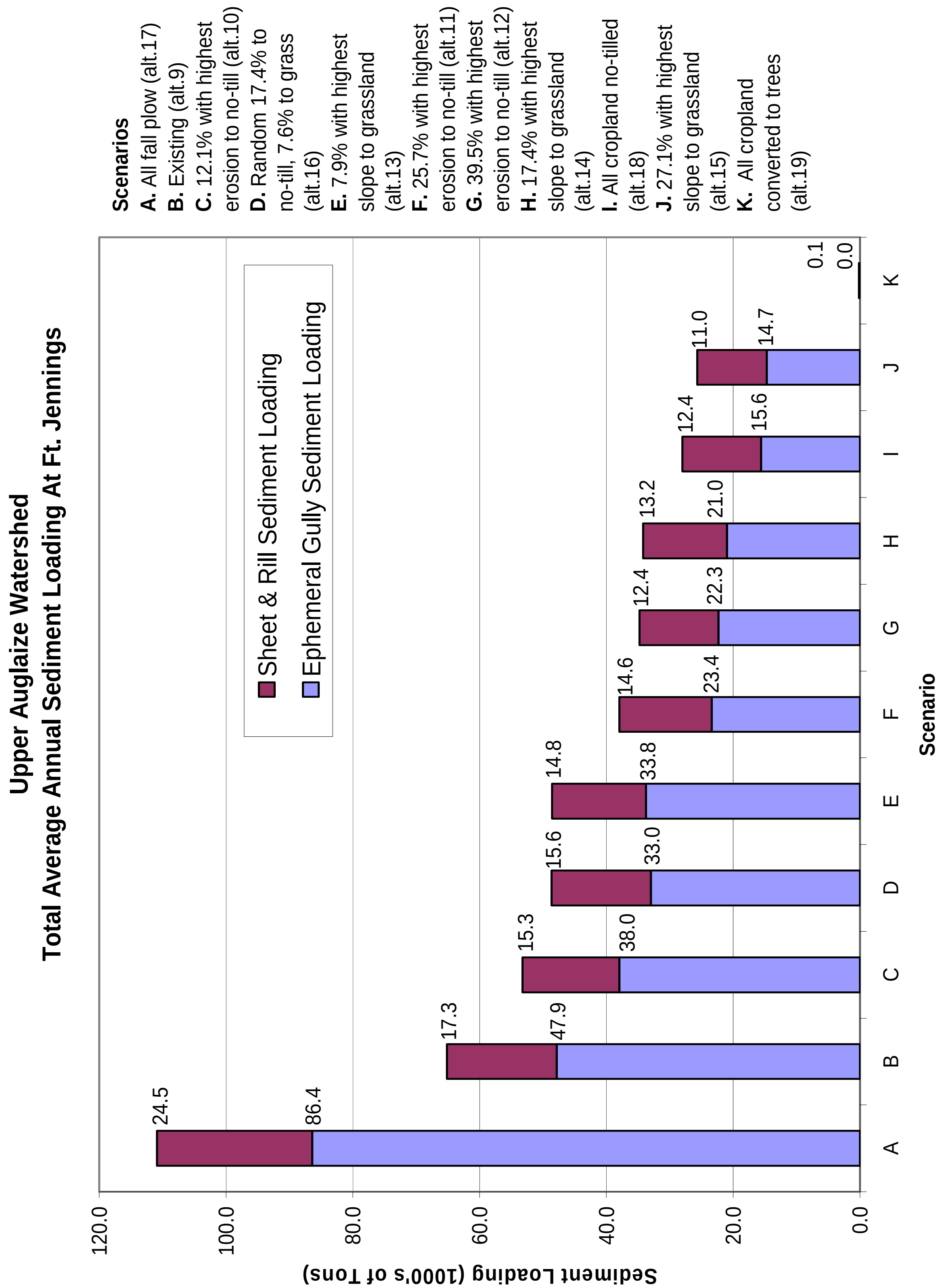

Figure V-18: Upper Auglaize Watershed—loading at Ft. Jennings [tons/yr]

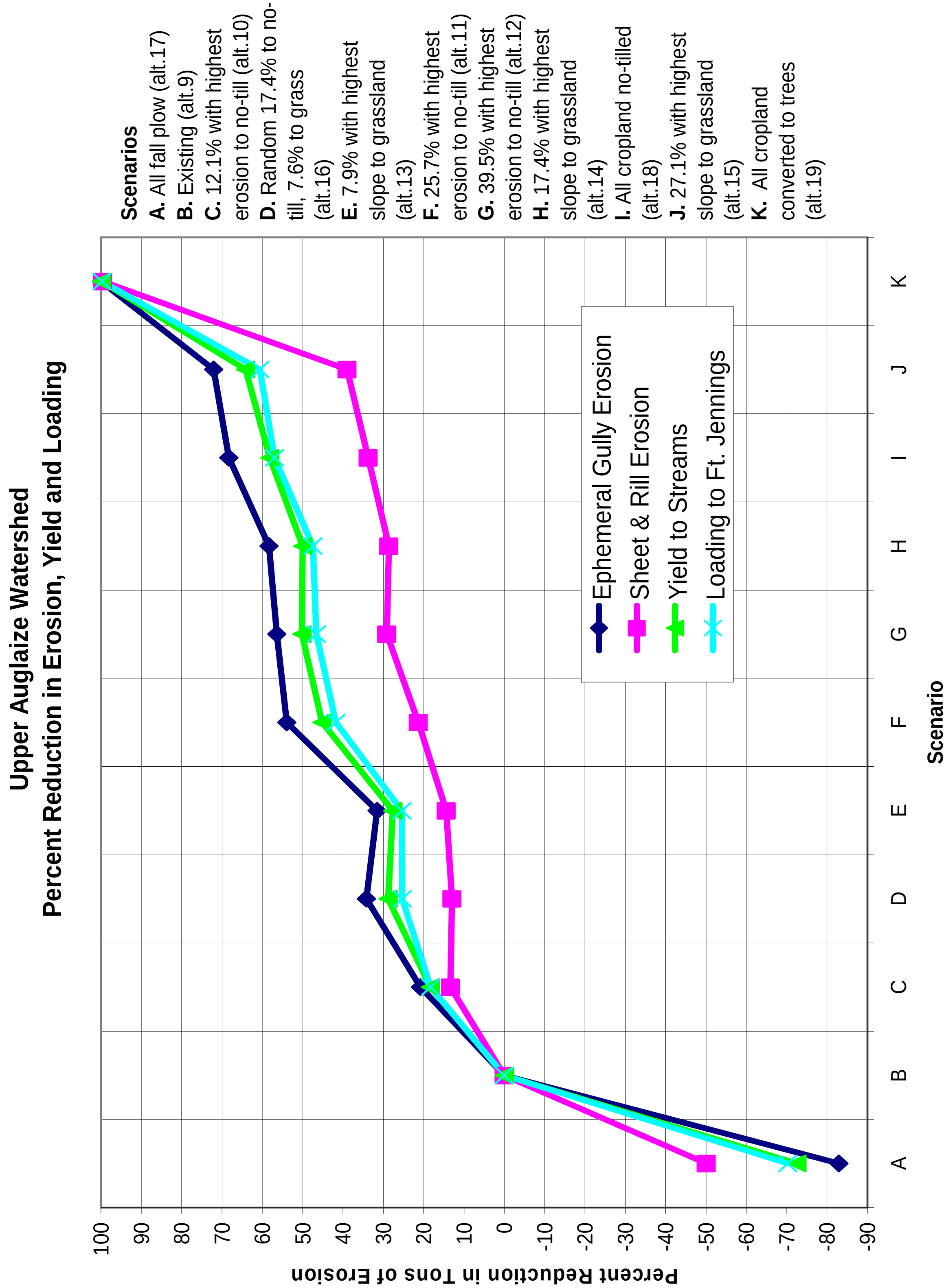

Figure V-19: Upper Auglaize Watershed—Percent Reduction in Tons of Erosion

B. TREATMENT ALTERNATIVES CONSIDERED

Several BMP alternatives were evaluated as means to reduce erosion within the watershed and sediment load transported from the watershed. These BMPs centered on the concept of reducing erosion within the watershed (compared to the existing condition simulation) by increasing the type, amount, effectiveness, or duration of the land cover within the watershed compared to a reference condition of all row crops with a clean till (plow) system. In general, only systems that had a reasonable chance of being implemented and/or for which financial incentive programs existed or could be developed were considered. There were some systems evaluated which could not be realistically implemented, such as converting the watershed to 100 percent no-till (Scenario I) or 100 percent trees (Scenario K). However, evaluating these scenarios provided results that served as reference information or helped in understanding and calibrating the model.

AnnAGNPS allows for tile drainage systems to be turned on or off for any given cell during the model runs. Thus each BMP was evaluated with the watershed in both the fully drained condition and the fully undrained condition. This provided data which predicts the effect of tile drainage on erosion and sediment transport rates. Local experience substantiated that due to the nature of the soils, most fields in the watershed are tiled drained to a very large extent. Since it was impossible to differentiate at this watershed scale which cells were drained or not, the a decision was made to calibrate the model and make all model runs with tile drainage turned on in all cells. Once this was done, the model was re-run for the same alternatives with the tile drainage module turned off. This provided significant data quantifying the effect of tile drainage on erosion and sediment transport within the watershed. Table V-5 shows the average annual water and sediment erosion, yield, and loading with and without tile drains runs for each scenario. Table V-6 shows the differences in sediment loading attributable to the use of tile drains in the Upper Auglaize Watershed. Although the extent of tiling in the watershed is less than the 100% assumed in the model, the differences shown in the table provide an estimate of the extent of erosion and sedimentation avoided under each scenario as a consequence of current tiling practices in the watershed.

Table V-5: Comparison of scenarios with and without tile drains.

Scenario		Runoff Volume [in]			Total S and R Erosion [t/ac/yr]	Total Gully Erosion [t/ac/yr]	Total Landscape Erosion [t/ac/yr]	Total Sediment Yield [t/ac/yr]	Sediment Loading at Outlet [t/ac/yr]
	Tile Status	Surface	Subsurface	Total					
A	without	9.709	0.007	9.716	1.061	3.527	4.588	1.780	0.548
	with	8.953	1.910	10.863	1.055	3.242	4.297	1.665	0.523
B	without	7.680	0.010	7.690	0.716	2.065	2.781	1.081	0.337
	with	6.440	3.559	9.999	0.701	1.772	2.473	0.965	0.307
C	without	7.469	0.012	7.481	0.629	1.405	2.034	0.782	0.258
	with	6.183	3.740	9.923	0.612	1.166	1.778	0.687	0.230
D	without	7.210	0.011	7.221	0.625	1.647	2.272	0.884	0.277
	with	5.893	3.951	9.844	0.609	1.404	2.013	0.788	0.251
E	without	7.453	0.013	7.466	0.617	1.404	2.021	0.773	0.250
	with	6.197	3.746	9.943	0.602	1.213	1.815	0.698	0.229
F	without	7.213	0.012	7.225	0.571	1.015	1.586	0.608	0.206
	with	5.882	3.950	9.832	0.553	0.816	1.369	0.529	0.179
G	without	6.968	0.012	6.980	0.520	0.928	1.448	0.557	0.187
	with	5.596	4.151	9.747	0.502	0.739	1.241	0.483	0.161
H	without	7.153	0.014	7.167	0.512	0.895	1.407	0.528	0.178
	with	5.882	3.985	9.867	0.498	0.773	1.271	0.481	0.164
I	without	6.563	0.012	6.575	0.485	0.723	1.208	0.467	0.156
	with	5.086	4.491	9.577	0.466	0.562	1.028	0.404	0.132
J	without	6.877	0.014	6.891	0.440	0.570	1.010	0.374	0.130
	with	5.593	4.206	9.799	0.427	0.495	0.922	0.346	0.121

It should be noted, that some of the fields in the watershed might not be in use as cropland if they were not tiled. Farmers generally perform tiling both to allow them to bring unusable land into cultivation, and to improve crop production levels on already usable land. Over 100 years ago much of the land in the watershed was cleared and farmed in an untiled state, drained only by surface drainage ditches. As production methods improved, tiling was first initiated and then intensified. Initially tile was installed at wide spacings. Then drainage systems were upgraded and intensified with increasingly narrow tile spacings and complete new installations over the more recent years. Today nearly all the land in the watershed is tile drained, albeit at varying levels of intensity. While it is true that tiling may allow some land to be cultivated that would be normally uneconomical to farm, it is conversely true that tiling enables much of the land, once converted to crop production, to be farmed with increasingly higher levels of conservation tillage systems. No-tillage farming, the most effective erosion control crop production scenario modeled, would not be technically or economically feasible on most of the soils in the watershed if they were not tile drained. In fact the most erosive practice in the watershed, fall plowing, began as a practice to increase production levels on undrained land. While tiling does have the effect of increasing the land that is in production, once that land is in production it has the beneficial effect of reducing erosion compared to non-tiled farming methods. Any assessment of the total effects of agricultural tiling in the watershed would be complex and difficult, and may be moot considering that the conversion and drainage is history.

Certainly returning large areas of the watershed to undrained uncultivated land would significantly reduce erosion in the watershed. However, given the economic value of the productive soils in the watershed it is not reasonable to expect this to occur on a large scale. Experience with conservation incentive programs, however, including the Conservation Reserve Program, the Wetland Reserve Program, and the Conservation Security Program, has shown that with sufficient incentives, landowners in the watershed can be induced to convert meaningful amounts of cropland in strategic areas to permanent cover, thereby reducing erosion and runoff.

Table V-6: Comparison of sediment loading with and without tile drainage.

COMPARISON OF UNIT AREA LOADINGS WITH AND WITHOUT TILE DRAINAGE – [t/ac/yr]			
Scenario	**Unit Loadings With Tile Drainage [t/ac/yr]**	**Unit Loadings Without Tile Drainage [t/ac/yr]**	**Drained Loadings As Percent Of Undrained Loadings**
A	0.523	0.548	95.4%
B	0.321	0.359	89.4%
C	0.230	0.258	89.1%
D	0.251	0.277	90.6%
E	0.229	0.250	91.6%
F	0.179	0.206	86.8%
G	0.161	0.187	86.0%
H	0.164	0.178	92.1%
I	0.132	0.156	84.5%
J	0.121	0.130	93.1%
		AVERAGE	**89.2%**

The modeled effects of tile drains on surface & subsurface runoff agree with the field experience of ARS scientists and NRCS engineers. Since tile drains reduce the soil moisture above the tile drain inverts, it is clear that the antecedent soil moisture will be less than without tile drains whenever a rainfall event occurs. Furthermore, subsurface flow increases with the presence of tile drains, with the resulting tile drain outflow adding to the recession leg of the surface runoff hydrograph. Therefore, the presence of tile drains: (1) reduces water and sediment surface runoff, resulting in a reduction of sediment yield from landscape erosion, and; (2) increases subsurface flow resulting in an increase in the total water yield and prolonging the duration of event runoff. It is noted, however, that the quantitative predictions of the effect of tiling on erosion and sediment transport provided by the AnnAGNPS model have not been independently verified. Although it is believed that the magnitude of the effect is in the range of the model predictions, additional research would be needed to validate the numerical results.

Figure V-20, Figure V-21, Figure V-22, and Figure V-23 show comparisons of average annual water and sediment erosion, yield, and loading with and without the use of tile drainage.

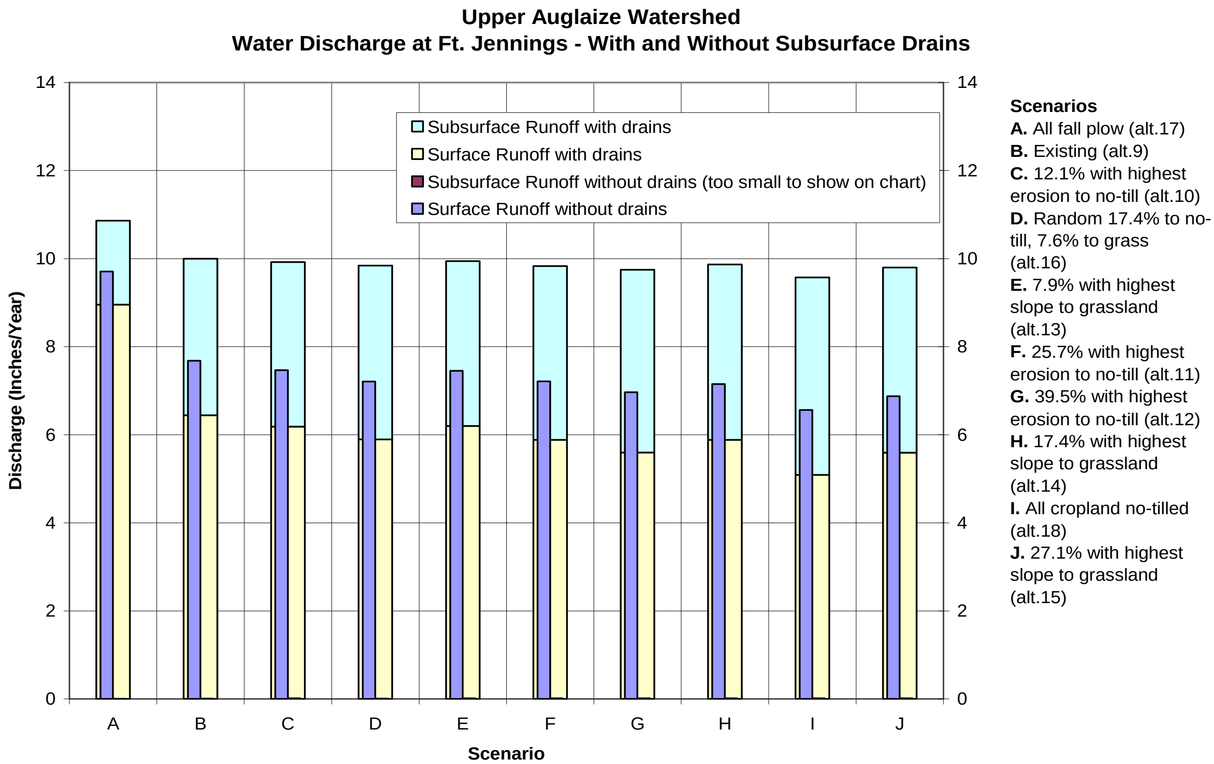

Figure V-20: Tile drain comparison of average annual water load at watershed outlet.

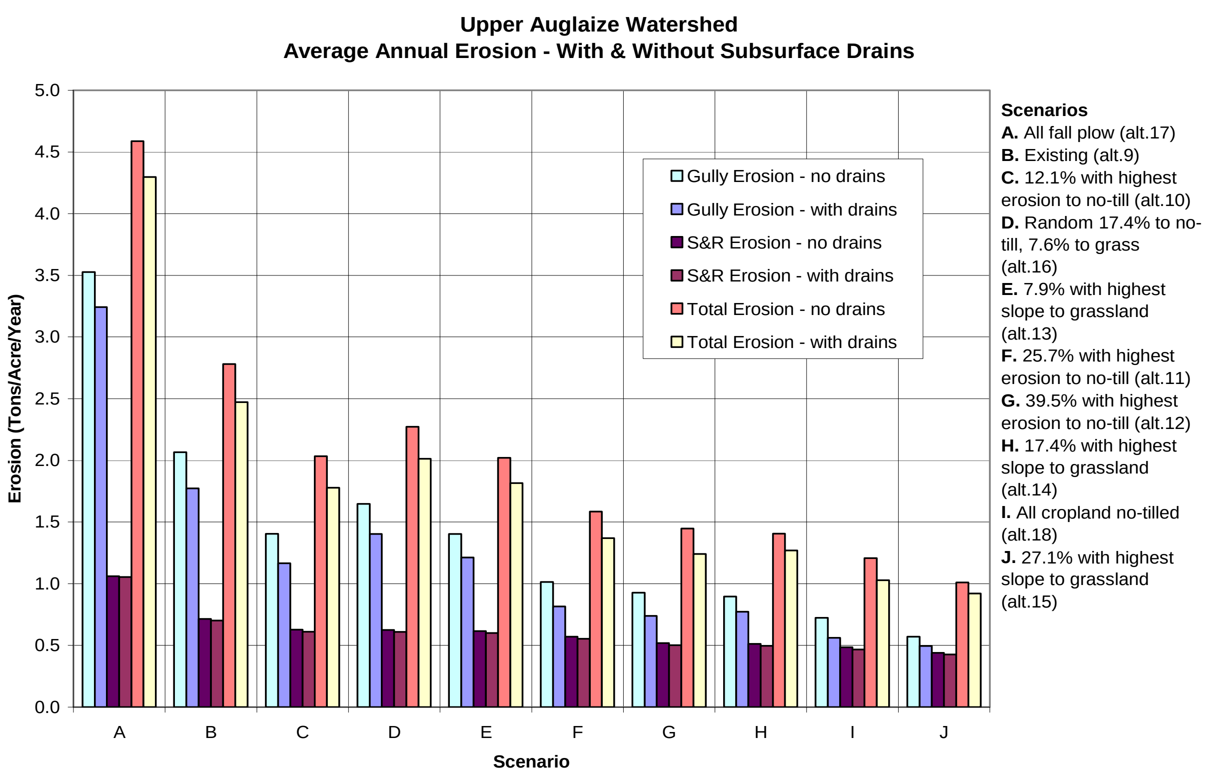

Figure V-21: Tile drain comparison of average annual landscape erosion for entire watershed.

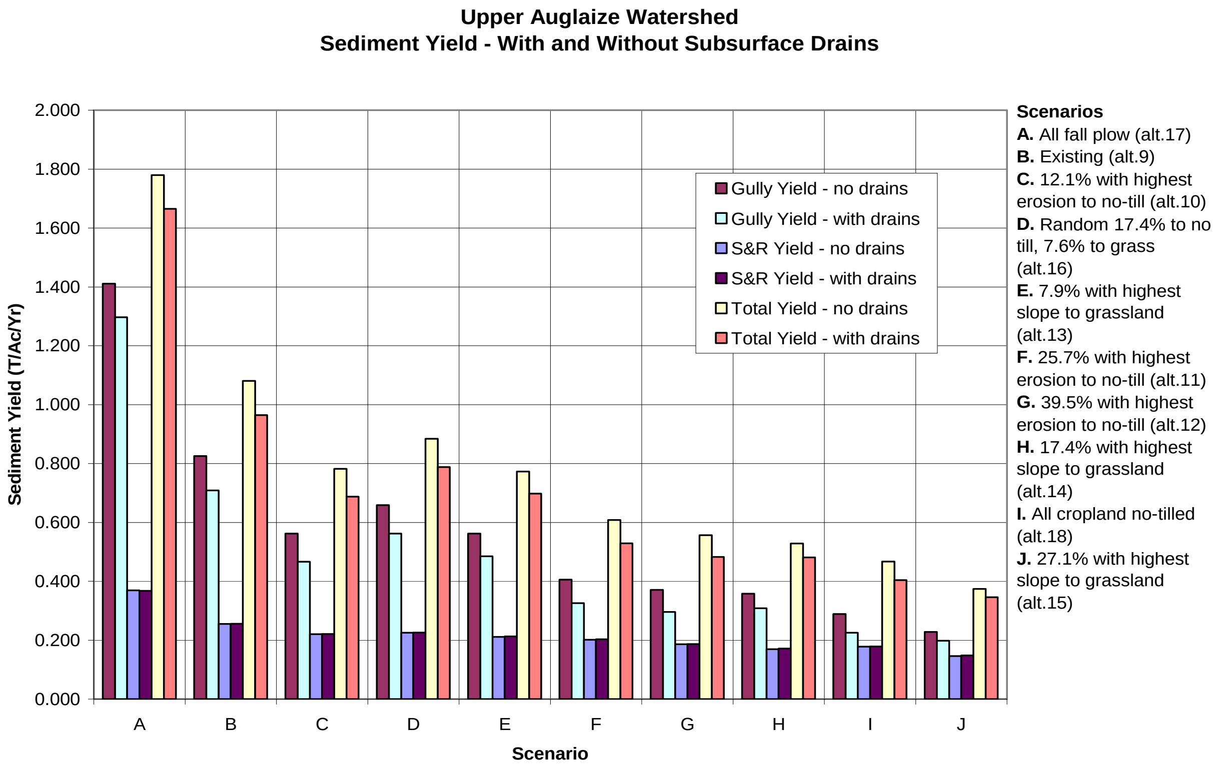

Figure V-22: Tile drain comparison of average annual sediment yield for entire watershed.

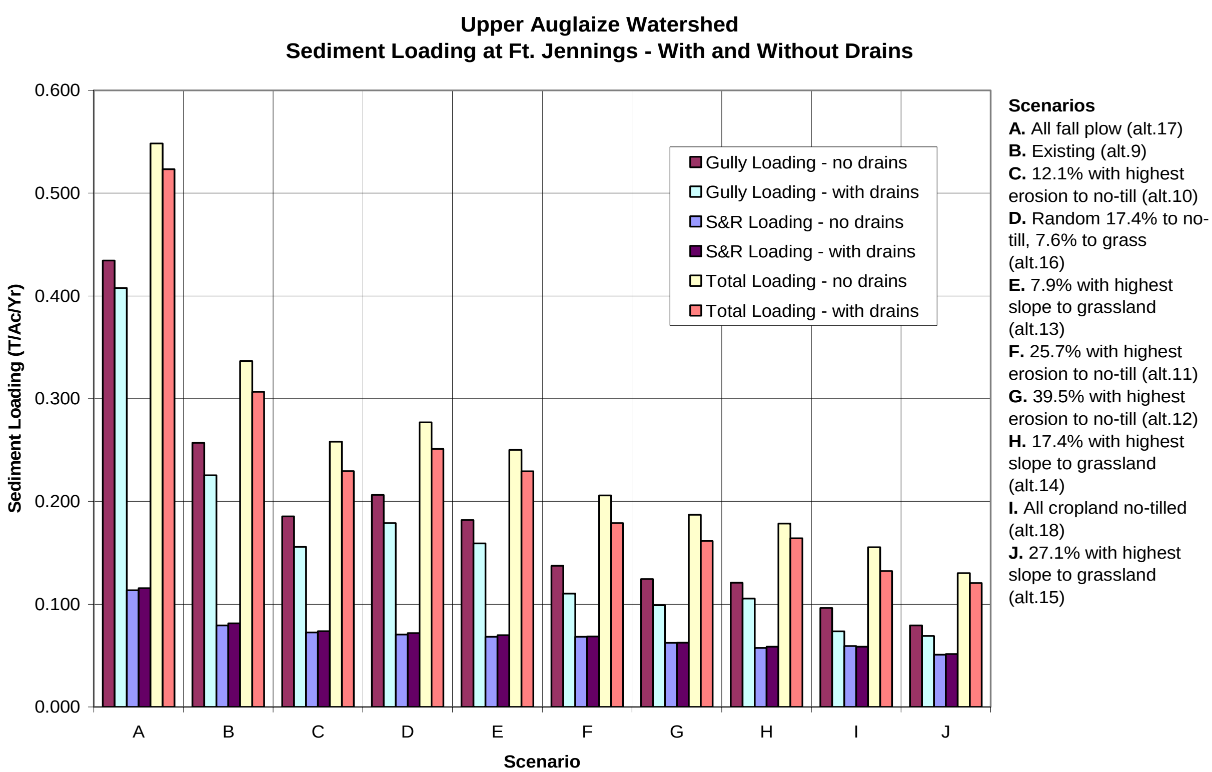

Figure V-23: Tile drain comparison of average annual sediment load at watershed outlet.

The treatments evaluated are shown in Table V-2 and included:

1. Crop Rotations

Crop rotation changes were considered, but it was determined to hold these constant for the BMP simulation runs. Given the productivity of the soils in the watershed, it is unlikely any program can affect a major shift away from the high percentage of cash grain (corn and soybeans) grown in the watershed. Likewise, market conditions will dictate the relative percentage of the cash grain crops since it is relatively easy to switch from corn to soybeans or visa versa.

2. Changes in Tillage Systems to Increase No-till Acres

The effect of conservation-tillage was evaluated by converting various areas to different levels of no-till crop production (management alternatives Scenarios C, D, F, G, and I). No-till was applied in two different ways: 1) by converting the highest eroding cells to no-till, and 2) by randomly converting a percentage of cells to no-till. When a change in no-till acres was applied the change was applied to the existing crop rotation system. Increases in no-till acres not only reduced the rates for sheet and rill erosion, but also reduced the rate of ephemeral gully formation. No-till crop production would reduce landscape erosion, which in turn reduces sediment yield and load. Figure V-24 shows a no-till conservation practice. Notice the large amount of residue between rows.

Figure V-24: No-till BMP

3. Increase in Filter Strips

The model as run for this project does not have a riparian buffer or filter strip component. Work is under way to develop that capability. For this project an effort was made to capture some part of the filter strip benefits. It is expected that savings from filter strips will be the result of two processes: 1) the trapping of soil particles as runoff flows over the filter strips, and 2) reducing erosion on the filter strip area itself due to conversion from crop production to grass or tree cover. Figure V-25 depicts a grass filter strip. Optimization of combinations of BMPs lead to the most reduction in erosion, sediment yield, and sediment loading. Figure V-26 is a picture of a combination of no-till with filter strips.

While the model cannot yet account for this trapping process, it can account for the changes in erosion when an acre of cropland is converted to grass. Thus a rudimentary attempt was made to account for filter strip effect by converting to grass the equivalent number of acres planned for filter strip treatment (see Scenario D, Table V-2.

Figure V-25: Grass filter strip

Figure V-26: Combination of no-till and filter strips

4. Increase in Whole Field CRP Acres

Acre for acre, grass is the most effective cover for reducing erosion. To simulate the effect of the whole field Conservation Reserve Set-aside Program, which pays farmers rental incentives to convert cropland to long term grass cover, additional acres were converted to grass in the same manner as the filter strip acres were applied to the model (see Scenario D, Table V-2).

5. Slight Increase in Pastureland

Due to the productive soils and high land values, it is not expected that a large number of acres will ever be converted to pastureland in the watershed. Nevertheless, recent experiences with the Environmental Quality Incentive Program (EQIP) have shown that there is modest interest from some smaller farmers in expanding pasture and grazing operations. Hence, a small value was inserted for conversion of a limited number of acres from cropland to grassland (management alternatives Scenarios D, E, H, and J).

6. Grassed Waterways and Drop Structures

Grassed waterways and erosion control drop structures are effective practices that help to control gully erosion and ephemeral gully formation. These practices will be an important part of any land treatment program to reduce erosion within the watershed. At this point there is no way to capture the full effect of these practices in the model, (short of making cell by cell manual entries which is impractical at the scale of this watershed). While the model runs did not capture the full effect, which would be to decrease scouring of drainage-ways and increase sediment trapping in the drainage-ways, the model did account for cropland to grassland conversion and the erosion reduction for the land taken out of crop production by these practices. Figure V-27 shows grassed waterways.

Figure V-27: Grass waterways prevent gully erosion

7. Reference Condition Alternatives

There was an interest in looking at what the erosion potential was for the watershed under pre-settlement conditions. To achieve this, a model run was made in which all cropland was restored to forestland (Scenario K). Not surprisingly, this treatment resulted in the lowest erosion and sediment loading rates.

Reference condition runs were also made in which all cropland was converted to all fall plow (Scenario A) and all no-till (Scenario I). The fall plow run was thought to represent the worst case scenario for the existing crop rotation and land use within the watershed, whereas the all no-till run represented the upper end or the best case scenario that could be obtained applying state of the art technology to each acre of the existing crop rotation and land use with in the watershed.

C. ALTERNATIVES CONSIDERED BUT NOT MODELED

Several new or innovative BMP treatments are considered viable treatment options. These include several practices that we were not able to model, but which may have significant potential for sediment reduction in the watershed. These practices include:

- *Wetland restorations that filter significant areas of surface run-off from cropland*—Wetland restoration practices have been popular within the CRP, Conservation Reserve Enhancement Program (CREP), and the Wetland Reserve incentive program. In the last seven years, 9,012 acres of these practices have been installed in the Lake Erie Watershed. When these practices are installed in landscape situations where they collect significant amounts of surface runoff, they can serve to trap sediment and reduce sediment loads delivered to downstream receiving waters. Although the trapping efficiency of these areas is not known, it may be much greater than traditional ponds since these areas have fluctuating water levels, go dry which providing some storage for storm events, and promote emergent vegetation, both of which serve to provide sediment trapping capabilities. Additional work is needed to quantify the trapping efficiency of these areas. Figure V-28 shows a wetland.

Figure V-28: Restored wetlands can trap sediment and reduce pollutant loadings from the watershed.

- *Sediment traps that might be constructed at the outlets of man made drainage ditches.*—The area has an extensive network of manmade drainage channels. Many of these are under a formal maintenance program. If functional sediment traps could be designed and installed in these drainage ditches it would provide for additional trapping of sediment within the watershed rather than transporting it to downstream receiving waters. This idea merits further investigation but is not without challenges. The depth of most of these ditches would require the sediment traps to be installed to that same depth so as not to restrict flow. Also if they proved effective it would necessitate regular cleanout. Finally, the idea would probably require land rental payments to the landowner who would have to give up crop acres to install the traps. Nevertheless this item merits further investigation and perhaps development of a pilot project. Figure V-29 details a concept sketch of the idea.

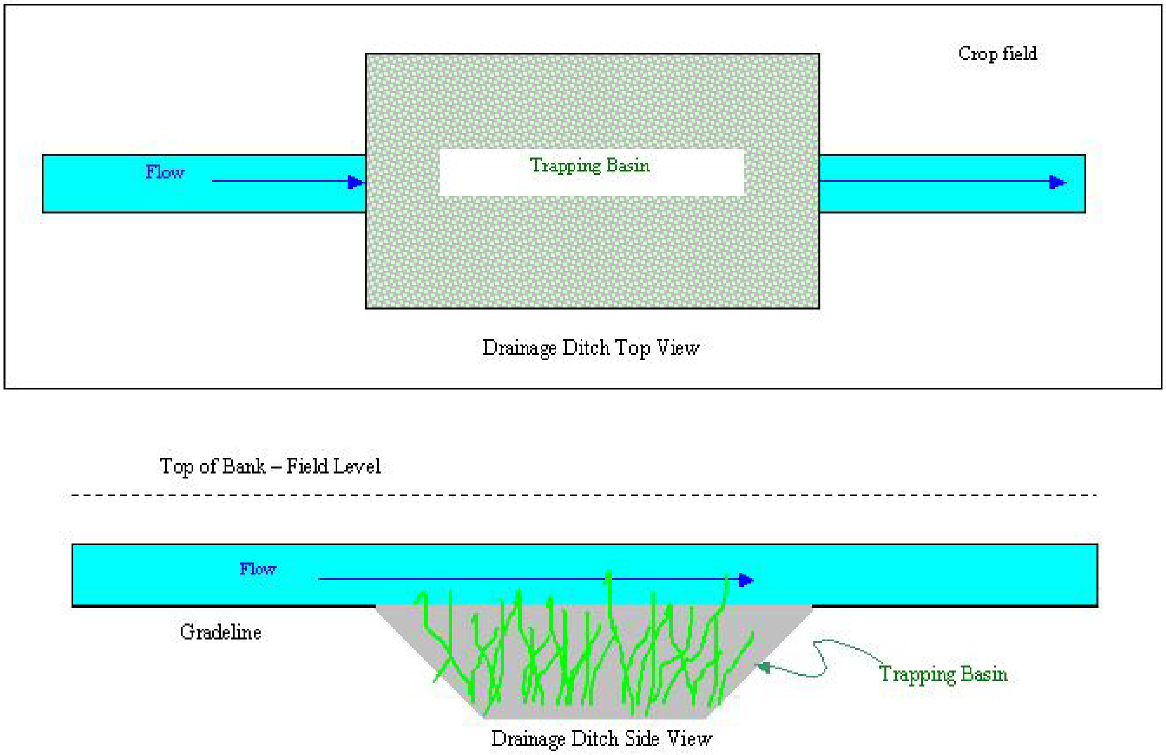

Figure V-29: Schematic of trapping basin.

- *Impact of riparian forest tree buffers along major streams*—The concept of reforesting corridors along the major natural streams and tributaries has gained increasing popularity with the development of the Lake Erie CREP program and provides promise as an additional tool for sediment reduction. These practices are being applied to the landscape in increasing amounts. At this time however the model does not have a means to account for sediment reductions from the application of these practices. Work is underway to add this component.

  Riparian forest buffers function in three different ways. Like grass buffers they can trap sediment in sheet flow off adjoining cropland. However riparian forests can also serve to remove sediment from floodwaters in out-of-bank flow that occurs during major storm events. Velocities outside of the channel are reduced by the trees during flood events, causing increased fallout of soil particles in the wooded flood plain. In addition, soil particles attach themselves to the riparian vegetation and are trapped on the flood plain when the waters recede. Thus, for the riparian component of the model to be effective, we need to recognize and account for all three of these modes of sediment trapping.

D. Obstacles and Challenges

Soil texture for the gully input data was obtained from the dominant soil for each cell rather than from the soil type in the drainage way. These may have been different and it would be more accurate to use the drainage way soil.

We need to come up with a way to allow for the possibilities of branched gullies in each cell. Our method of calculating gully input resulted in only one gully in each cell through the main drainage way, whereas in the field we saw significant branching of gullies.

Assignment of the cropland cover to each cell was challenging due to the number of crop and tillage combinations in the watershed. The main crops grown in the watershed, corn, soybeans, and wheat, can be and are grown in any combination of sequences. Likewise, the farmers do not follow any set tillage scheme by crop sequence. Any of the crops may be conventionally tilled, mulch (conservation) tilled, or no-tilled in any given year. Many farmers use a varying combination of crops and tillage in a multi-year sequence. The variations are influenced by weather, crop markets, etc. Early or late springs, early or late fall harvests, or ruts from harvest equipment during a previous wet fall often influence tillage as much as conscious decisions planned by farmers. Thus the land cover database became complex and the random assignment of known tillage proportions across all cells was used to overcome this.

The random assignment of known types across all cells is sufficient to develop watershed estimates of the existing condition simulation for discharge and sediment loads and to compare the results of "what if" simulations of applying various forms of BMPs to the watershed. The resulting AnnAGNPS watershed maps can be useful in identifying regions of the watershed with higher or lower erosion potential. However, since tillage practices are randomly applied to each cell, the values shown for each individual cell may or may not be accurate. That is to say, the values in any single cell may be based on an assigned value of fall plowing when actual field practice for that cell may be no-till (or visa versa). Thus, there is danger of inappropriately using the cell maps or individual cell data to target individual fields or farms, since the maps presented here may incorrectly show high erosion rates for individual cells or properties, even though the model is accurate as a whole for the watershed. The model results and maps are more valuable and reliable at the watershed or sub-watershed scale for watershed or river basin planning purposes. They can be used to target watersheds, regions of a watershed, land forms or land use situations, but should not be used to identify and target individual landowners or individual fields.

When modeling a watershed of this size, it is impractical to manually collect the tillage data that would be needed to insure the model was accurate for each specific individual cell or field. Thus remote sensing techniques that pick up year-by-year tillage practices for individual fields would be a very beneficial addition to the model input database to increase accuracy of the results.

The model had limitations when assigning specific treatment scenarios to the various model runs. For instance, due to varying cell sizes, when the model was programmed to randomly assign treatment, to say 10 percent of the watershed, the actual results might come back as 8.6 percent or 11.3 percent treated. This did not affect the accuracy of the final results, but meant that although the treatment scenarios were initially designed as integer percentages, they ended up varying slightly from the targets, typically by tenths of a percent. The final results were reported using the actual values for the each run.

One needs to be careful not to expect real world land treatment applications of the model to precisely match the model output results. In particular, this applies to the model runs that treat the highest eroding cells, or the steepest cells. It is simple to specify these criteria within the model, but nearly impossible to apply them in practice in the field. One reason is that nearly all the available land treatment programs are voluntary, incentive driven, and predicated on working with willing farmers. Just because a cell or area of the watershed is identified, it does not follow that it is owned by a landowner who will participate or make a change in the use or management of that cell. Also, any given identified cell may fall on several fields or even multiple landowners. In these cases, since land treatment must be done on a field basis the actual treated acres may vary considerably from the identified cell acres. For example, a target area of highly erodible soil might comprise a portion of several fields. Since treatment must be applied on field basis, the entire area of each field containing the erosive soil would need to be treated in order to cover the target area. Therefore, in general the number of acres requiring treatment in a given model run is likely to be smaller than the number of acres for which land treatment practices would actually need to be modified to fully implement the model scenario in the field. As previously stated, a major limitation of a model of this scale is the ability to deal with large numbers of conservation practices which are applied in narrow bands in strategic positions on the landscape, i.e. along streams, in identified drainage-ways or on field boundaries. These practices include grass filter strips, grassed waterways, and field windbreaks. Individual cells could have been subdivided to specify exactly where such practices would go, but with 1833 cells in the watershed this approach was impractical. Therefore, we chose to apply these practices in a manner which accounted for the effect they would have on land cover in the watershed, but which did not account for the effects due to landscape position. This is to say, a filter strip located next to a stream would be expected to give greater benefits than the same filter strip acreage far away from the stream, but these benefits were not captured in the model. Likewise, an acre of grass properly placed as a grassed waterway in an ephemeral gully would afford more benefits than the same acre of grass randomly applied as in the model. Thus it is likely that the model underestimates the benefits of the grassland acres that were applied to represent filter strips and grassed waterways in Scenario D. Additional model capabilities to be able to specify the locations of these practices; (or easily tie them via GIS methods to streams, watercourses or drainage-ways) would improve the reliability of the model predictions.

Due to the need to randomly apply tillage practices, it was difficult to design data sets using mixed tillage systems (for instance, a rotation using no-till one year, mulch till the next year, and plow the third year). For this reason most of the alternatives evaluated involved increases in total no-till acres.

VI. IMPLICATIONS OF THE RESULTS FOR TOLEDO HARBOR AND LAKE ERIE

The model results show that application of conservation practices, BMPs, could result in a significant reduction in quantities of sediment delivered from the Upper Auglaize Watershed. If the Upper Auglaize is representative of other areas of the Maumee Basin, the model would indicate it is a feasible long-term goal to achieve a 15 percent reduction in the loadings from the Maumee River into Toledo Harbor. This 15 percent reduction would be based on the loadings that existed in the 1992 land use reference condition of the watershed, and would represent the goal established in the LTMS Phase IV Report that was published by the Toledo Harbor Planning Group in April of 2001. Specific results of the model and impacts on designing a land treatment program for the watershed include:

1. The model identified an average annual load of 0.307 t/ac/yr from the mouth of the Upper Auglaize Watershed due to sheet and rill and ephemeral gully erosion. This equates to 65,200 tons per year. The model also identified average annual gross erosion in the watershed to be 524,200 tons. The unit loading of 65,200 tons divided by the 524,200 total tons gives a delivery ratio of 0.124. Figure VI-1shows ephemeral gully erosion in a recently cultivated field.

   This study identified ephemeral gully erosion as a significant source of sediment in addition to the already understood sheet and rill erosion. As discussed above, new techniques were developed to quantify ephemeral gully erosion within the model. When ephemeral gully erosion was calibrated to account for the full sediment load observed at the Fort Jennings gage, the model suggested that more sediment originates from ephemeral gully erosion than from sheet and rill erosion (see Figure V-16). This finding, while different from traditional thinking, is plausible in the sense that available data for the Maumee River Basin from the Waterville gage shows that the bulk of the sediment is transported in a few major events per year. These major events would be more likely to form ephemeral gullies than would the high intensity short duration localized rainstorms.

   The ephemeral gully contributions to loading might explain the findings of Meyers et al. (2000) whose report suggests "highest delivery ratio's and yields are associated with sub basins in the Maumee watersheds with the lowest erosion rates. . . . [that] are areas of fine textured poorly drained soils with high runoff potential."

Figure VI-1: Ephemeral gully erosion was identified as a major source of sediment.

2. The model documented effects of various management scenarios as shown in Table VI-1 below.

Table VI-1: Comparison of various management practices.

Item	Scenario					
	A	B	C	D	J	K
Condition/Treatment	All Fall Plow	Existing Condition Simulation	12% Additional No-till Applied to Highest Erosion Areas	17% Additional No-Till plus 7.6 % Additional grass practices Randomly Applied	27% Additional Grass Acres Applied to Highest Slope Areas	Reforestation of all cropland
Sediment Unit Loads [t/ac/yr]	0.523	0.307	0.230	0.251	0.121	0.0007
Percent of Existing Condition Simulation Load [%]	170	100	75	82	39	0.2

3. A targeted application of 12 percent new no-till (Scenario C) on the highest eroding acres would achieve a 25 percent reduction in loading at the mouth. However, this is probably not politically or programmatically feasible to implement as a land treatment program which relies on voluntary incentives. A more realistic treatment is Scenario D, which is 17 percent random new no-till and 7.6 percent random new buffer areas, pasture conversions and new CRP, that would achieve an 18 percent reduction. **Figure VI-2** pictures no-till that was utilized to reduce erosion and sediment load.

Figure VI-2: An increase in no-till acres reduced erosion in and sediment load from the watershed

4. Even though the model identifies areas where higher erosion rates are occurring, treatment will be required to either be added or maintained on a significant percentage of the watershed. To achieve the Toledo Harbor project goals of a 15 percent reduction in loadings, additional new conservation treatment will be needed on at least 25 percent of the watershed (Scenario D is 17 percent new no-till and 8 percent new buffer areas).

   Considering that between 50 and 68 percent (depending on the crop and year) of the watershed is already using no-till and/or conservation-tillage in the current condition, full implementation will require conservation treatment that is newly added or kept in place on approximately 75 to 93 percent of the watershed. While the model can be used to identify areas of higher unit loadings, or BMPs which will provide higher benefits, it cannot be used to say the goal can be achieved by treating only a small portion of the watershed.

5. Reforestation of the entire watershed would reduce unit loads to less than one percent of the existing condition simulation. This alternative is not feasible on a large scale, but the scenario does point out the high sediment reduction value of each acre of grass or trees that can be restored in the watershed under the buffer incentive programs.

6. On average, the relative value of each acre of trees provided 1.8 times the reduction of an acre of no-till when these treatments were applied to the entire watershed.
7. The effectiveness of grass or tree buffers captured in the model represents only the effect of land cover change on erosion and not the benefits that will accrue from any trapping efficiency when practices are positioned adjacent to a stream. Thus the model likely underestimates the effects of these practices and they may provide additional reductions beyond the benefits shown.
8. The model can identify areas within the watershed with the highest erosion rates, which could be targeted for land treatment to achieve the highest benefits (see Figure V-1). While the random application of tillage types prevents correctly identifying any individual fields or farms, the model does identify regions that have highest potential to contribute to sediment load from the watershed. These areas include sloping moraine areas, escarpment and sloping areas nearest the streams, and drainage-ways where ephemeral gullies are likely to form.
9. The model demonstrates effect of tile drainage in reducing erosion and sediment delivery. Loadings under drained conditions were less than loadings under undrained conditions in all cases. The average of all alternatives for drained loadings was 89.2 percent of the average for the undrained loadings. Figure VI-3 shows the installation of sub-surface tile drainage.

Figure VI-3: Tile drainage was shown to reduce erosion and sediment load from the watershed.

A major question asked is how scaleable the Upper Auglaize model results are to the Maumee River Basin as a whole, and will the same impacts be had at the outlet of the Maumee as are seen at the outlet of the Upper Auglaize? This can only be answered definitively by modeling the entire Maumee. There is evidence however, that the results are more likely to be similar than greatly different. The Maumee Basin is fairly homogenous in terms of soils, topography, land-use, and cropping systems. The Upper Auglaize Watershed is reasonably representative of the Maumee as a whole, containing both moraine areas in upper reaches and flatter lake plain soils at the lower end. There are no known areas of the Maumee that are vastly different or contributing disproportionably higher unit area loads. Channels in the Maumee are reasonably stable and are neither vastly aggrading or degrading, and historical Waterville gage data indicate that large amounts of sediment move during a small number of major storm events, suggesting that once material moves into the stream transport system a large amount of it is delivered to the outlet of the watershed.

VII. RECOMMENDATIONS AND NEXT STEPS

Extensive research has documented that BMP practices are effective at the field scale. The Upper Auglaize model results indicate this effectiveness also applies at the watershed scale. The results of this project indicate there is no need to wait for additional modeling before beginning to implement an accelerated land treatment program, either within the Upper Auglaize Watershed, or the Maumee as a whole. The Maumee River Basin is one of the most studied areas in the country and it is the recommendation of the project team that justification exists for accelerating land treatment efforts in the basin without any further delay for studies or additional data analysis. The study team also recommends that, in addition to accelerated land treatment programs, the AnnAGNPS modeling effort be continued and expanded to provide additional information that can be used to fine tune the accelerated land treatment program, monitor changes, and measure progress. Continuation of the modeling would allow the team to improve modeling techniques and to add to the model components which could not be included in the first phase efforts, such as the riparian module or nutrient issues. The Maumee River Basin has also been approved as a

Conservation Effects Assessment Project (CEAP) watershed. Expansion of the modeling effort would compliment and support that effort.

It is the recommendation of the study team that the modeling effort be continued, either by improving the model in the Upper Auglaize Watershed and expanding it to include components such as nutrients that were not modeled in this effort, or by expanding the sediment modeling task to another sub-watershed and linking the two models together. It is recommended that this expansion and the desired plan of action be discussed during a subsequent meeting between resource managers and the modeling team members.

The team believes that the working model for the Upper Auglaize would be substantially improved by the availability of additional stream gage data. Therefore, it is recommended that the sediment gage at Fort Jennings be funded and reactivated to provide time weighted sediment data that could be compared to future runs of the Upper Auglaize model. It is also recommended that future expansion of the modeling effort include stream gaging as part of the modeling effort wherever practical.

While AnnAGNPS provides capability to model nutrient cycles and pathways along with the sediment movement, this project did not allow time or resources for the team to utilize that capability of the model. The addition of nutrients would require a considerable amount of time to run and populate the model. Nevertheless this data may be extremely useful for TMDL plans or for other Lake Erie water quality programs. If other organizations have the need for this capability, nutrients could be added if funding for this purpose were provided.

If decision makers wish to continue additional modeling studies within the Maumee watershed, the project team recommends that the St. Joe Watershed be the next sub-watershed to be modeled. Modeling of the St. Joe would provide both additional sediment loading information and also the opportunity to further fine tune the modeling process within the watershed. A study of the St. Joe watershed would include:

- Contrasting soils and topography as compared to the Upper Auglaize watershed
- Multi-state involvement
- More varied land-use as compared to the Upper Auglaize watershed
- A more natural (less anthropogenically altered) stream network and sediment transport network

The combined results from the St. Joe and Upper Auglaize watersheds would be representative of nearly all the land-use/hydraulic conditions that are found in the Maumee Watershed.

It is recommended that if and when additional work is to be pursued, the modeling team and agency managers convene to scope out a work plan for the next phase of this effort. The scoping plan should include the technical, administrative and financial needs necessary to support additional modeling studies in the Maumee.

VIII. PROJECT CONCLUSIONS

The Upper Auglaize Watershed was effectively modeled to quantify erosion, sediment transport, and sediment load at the mouth of the watershed. The model was calibrated to available stream gage data. The model predicted average annual load (unit loading passing Fort Jennings) to be 65,200 total tons or 0.307 tons/ac/yr unit loading based on 1999-2002 land use conditions and a 100 year climate simulation.

The project successfully developed GIS techniques to automate the imputing of the land use cover data at 90 percent accuracy and to remotely sense, calculate and input predominant crop rotations for the individual cells at an 87 percent accuracy level. The project developed routines to apply the digital elevation module to flat landscapes.

The project team identified ephemeral gully erosion as a significant source of sediment in the watershed and developed modeling techniques to predict the ephemeral gully erosion. Ephemeral gully erosion accounted for 2.5 times the mass of soil loss due to sheet and rill erosion.

Tile drainage was found to have a significant beneficial effect, reducing both sheet and rill and ephemeral gully erosion, sediment yield, and sediment load by approximately 11 percent for otherwise identical land use. This is because tile drainage reduces direct surface runoff by lowering the antecedent soil moisture levels. Since direct runoff is the primary erosive mechanism that mobilizes and transports sediment, this reduction in runoff results in a reduction in erosion and sediment yield. It is noted, however, that tiling is already widespread throughout the watershed – the effect modeled represents erosion and sedimentation avoided by current practice.

The model indicates that application of various alternative land treatment scenarios could realistically reduce the unit loading transported from the watershed to a range of 75-82 percent of the existing condition. The reduction would be of a magnitude that would meet the LTMS reduction goal of reducing sediment loading by 15 percent from the Maumee River Basin if they are scalable to the entire watershed. It is noted that due to the complex nature of sediment transport and deposition processes there may not be a one to one relationship between reduction in sediment delivery and reduction in dredging needs at Toledo Harbor. Determining the magnitude of dredging reduction expected as a result of reduction in sediment delivery would require detailed sediment transport modeling of the harbor. However, it is likely that the predicted achievable reduction in sediment delivery would significantly reduce dredging requirements at Toledo Harbor.

The project identified further work that could improve the model, including adding a riparian buffer component, the ability to automate the placement of grass filter strips adjacent to drainage-ways, and placement of grassed waterways in ephemeral gullies. Reliable techniques to remotely sense crop residue levels to an accuracy sufficient to separate conventional tillage, mulch tillage, and no-tillage practices for each field for each year are also needed.

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MAUMEE RIVER BASIN: UPPER AUGLAIZE REPORT TECHNICAL APPENDIX

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X. TECHNICAL APPENDIX—DETAILS OF PROCESSES, ISSUES AND DECISIONS

A. DEM GENERATION

An accurate DEM is critical for erosion modeling. The Upper Auglaize Watershed is relatively featureless. The 30-meter DEM available through the USGS, which is truncated to one meter horizontally, is too coarse a resolution to work well in flat areas like the Upper Auglaize. Some areas have holes that need to be filled while other areas produce no slope whatsoever making water flow impossible in AnnAGNPS.

Source materials were obtained from the USGS in the form of 1:24K scale digital line graphs. Line segments were translated into polyline shape files using customized Avenue scripts within ArcView GIS. Degenerate line segments representing point elevations were translated into shape files in a similar fashion. Both sets of inputs were then geo-referenced into a Universal Transverse Mercator Zone 17 (UTM) projection using the North American Datum 1983 (NAD 83).

Polyline shape files were edited to only include contours and carrying contours. Original contour data within the digital line graphs was reported at a resolution of 10ft. Carrying contours within the study site were reported at resolutions of 5ft. All elevations were converted into meters.

Polyline and point elevation data were used to create a DEM within the PCI OrthoEngine® 8.2 software package. The output pixel resolution of the resulting DEM was set to 20m. A thin plate spline algorithm operates within this framework to estimate pixel heights at intervals between the source elevation inputs. This process operates on an internal global semivariogram where error is documented as a function of distance from the source data.

The process of DEM generation operates in an iterative fashion. The user selects the number of iterations and the maximum vertical error permitted within the resulting DEM. Maximum internal error within the DEM is reported during each of the iterations of the DEM generation process. Maximum allowable error within the resulting DEM was set to 1.0m. Ten iterations were used to create the DEM. The resulting DEM was output as a raster of floating point precision. The resulting DEM contained a maximum vertical error of 0.53m on the final iteration.

Streams were burned-in (a process of forcing the known stream topography onto the data set in areas where the DEM failed to pickup the drainage feature) using USGS 1:24K scale hydrology see Figure X-1. Original digital line graphs were translated in a similar fashion as the contours. Elevation values for pixels falling under the hydrology layer were lowered 0.76m. This corresponds to one half of the lowest elevation interval (2.5ft) within the original contour line files. Floating point precision was maintained under the pixels falling under the hydrography layer.

OBLIQUE VIEW OF THE DEM CREATED FROM THE STEREO ASTER IMAGERY.

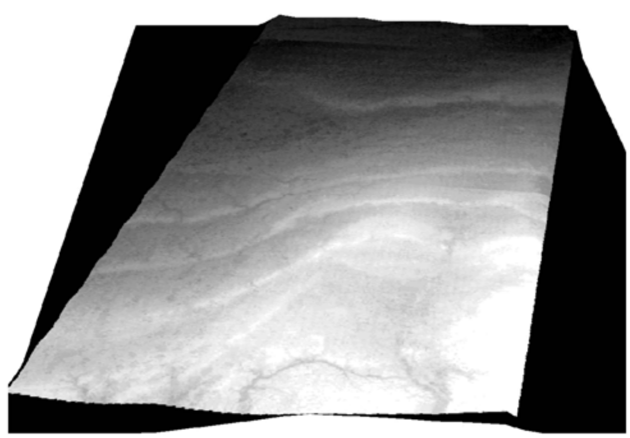

Figure X-1: Oblique View of the DEM Created from the Stereo Aster Imagery

Preliminary rivers extracted from this stage in the DEM generation process showed slight deviations from the USGS 1:24K scale hydrology layers. A maximum deviation of three pixels was used as criteria for manually editing the resulting DEM to force matching between the derived streams and accepted USGS hydrology. Individual line segments from the hydrology line file were selected in areas where deviations were observed. Pixel values were replaced under the designated line segment with the minimum value for the segment in question.

The majority of these segments occurred in very flat areas where drainage is dominated by the presence of ditches along roadways. Editing in this fashion maintains the flat nature of the ditches without interrupting the relations of height to the neighboring drainage features. Lowering elevation values to the minimum value maintains the floating-point precision of the file. Derived streams were then extracted again using the AGNPS model. This process was repeated for all areas deviating more than the three pixel criteria. Approximately 20 line segments were edited in this fashion. Derived hydrology from the DEM now matches USGS 1:24K hydrology within three pixels. Deviations outside of the watershed boundary were not edited.

The derived DEM was then output as an ASCII raster grid and zipped using WinZip. In summary, the DEM that was generated has the following characteristics

- 20m-pixel resolution
- Generated from 1:24K USGS digital line graphs
- Points and Contours as inputs
- Resulting DEM has 0.53m internal error
- Streams were lowered by 0.76m
- Line segments showing deviations from USGS hydrology were flattened to the minimum value of hydrology line segments containing the error
- Extracted river networks from the resulting DEM now match USGS hydrology within three pixels.

B. LAND USE & REMOTE SENSING

LANDSAT 7 imagery from May 14th, 2000 and March 3rd, 2001 was acquired for path 20-row 32 of the LANDSAT Worldwide Reference System representing the Upper Auglaize Watershed in west-central Ohio. The University of Toledo data archive provided the images that were originally downloaded from the online image archive Ohio View.

The software package ERDAS (ERDAS, 1991) was utilized to process the satellite imagery. Both images were processed for haze correction with ERDAS implementing a tasseled cap transformation on the image data. The transformation "yields a component that correlates with haze" (ERDAS, 2001), removes that unit, and transforms the image to the original red, green, blue (RGB) space.

A decision tree supervised classification was performed manually and subjectively using the AOI tool inside ERDAS to delineate urban and non-urban areas for both images. As each urban area was selected, it was subset individually. The remaining image underwent a polygon fill operation to recode the pixels of the urban areas defined by the AOI's to zero in each spectral band (Figure X-2). Their recoding ensures that a classification on the remaining non-urban image will not take into account the urban pixel values. Seven urban regions throughout the watershed buffer were selected for individual classification. Training sites for four classes were chosen with the AOI tool and added to the Signature Editor in ERDAS based on visual interpretation of the urban images. Pixels representing water, forest, low-density residential and commercial were selected.

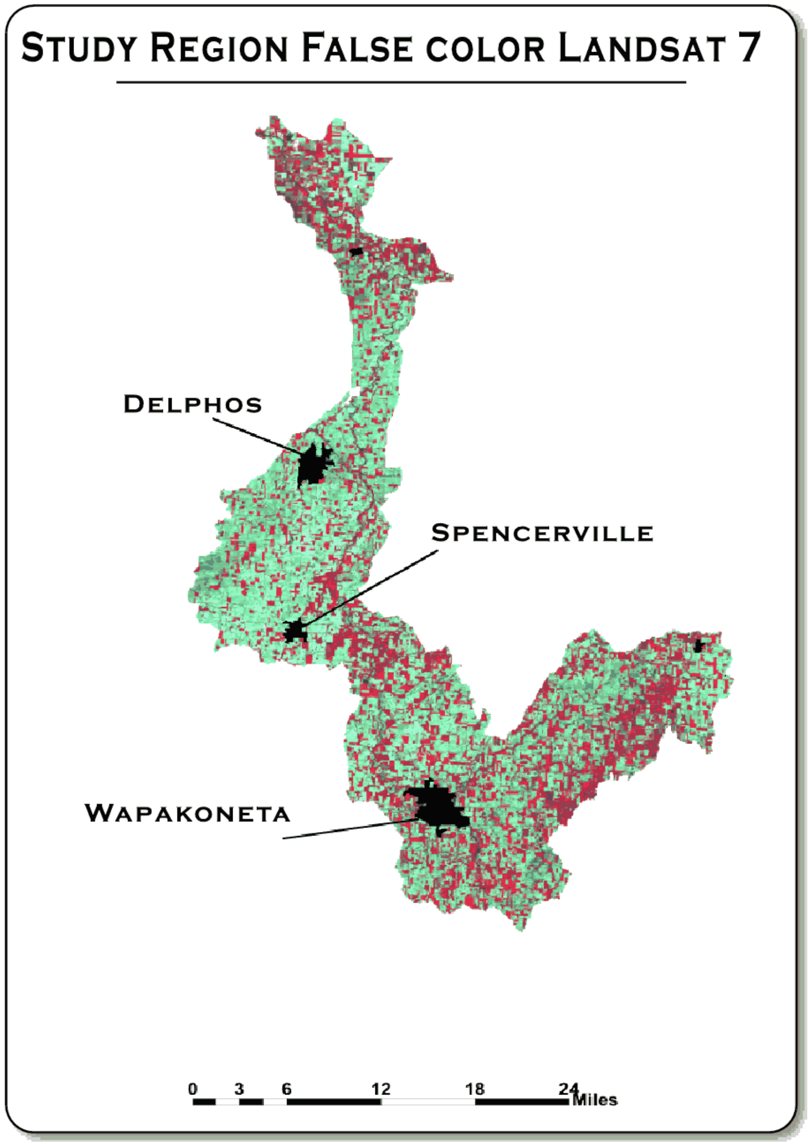

Figure X-2: False Color LANDSAT 7 Image of Watershed with Urban Areas Subset & Recoded to 0

The number of pixels contained in a training set was representative of the size of the urban area being classified. All sets within a single urban classification were +/- 20 pixels of each other. Most sets resided between 60 and 100 pixels. Supervised classifications were completed in ERDAS with a parametric rule of maximum likelihood.

The remaining image with urban areas removed was classified using a supervised classification. Training sets for five classes: water, forest, low-density residential, vegetated agriculture, and bare agriculture, were selected based on visual interpretation of the satellite image and checks of aerial photographs of the watershed. Training set pixel counts were between 1500 and 2000 pixels. Once training sites were chosen, a supervised classification was implemented with the parametric rule of maximum likelihood. The output was a file containing five classes for the non-urban area of the watershed.

The seven urban classified files were combined into a single output. The pixel values representing classes in each image were organized to correspond to all other images. For instance, water in an urban area has a pixel value of one; therefore water in all the other urban areas and the non-urban area must also have an assigned value of one. If these values are not standardized throughout all the files, the mosaic function would cause entire classes to switch values resulting in large errors. Recoding of pixel values was done with the recode function in ERDAS Imagine. Water was assigned a value of 1, commercial = 2, low density residential = 3, forest = 4, vegetated agriculture = 10, and bare agriculture = 11. The seven urban classifications were opened in the mosaic utility and combined into one ERDAS Imagine image file. The AnnAGNPS model requires either grid or shape file format for analysis.

1. Wetland Classification

Wetlands can be an important land cover in a watershed. In the Upper Auglaize, most of the wetlands have been drained for agricultural development. For definition of wet areas in the spring, a different methodology was used to increase the accuracy of their detection. Utilizing the infrared band, band 4, from the LANDSAT 7 imagery, a classification of wet areas with good accuracy was performed because the infrared band is sensitive to moisture. Band 4 of LANDSAT 7 imagery measures reflected near infrared radiation from 0.750—0.900 μm. Soil moisture is known to absorb radiation in this range and decrease the strength of the signal received by the satellite (Jensen, 2000).

The ERDAS modeler allowed band 4 to be isolated from the spring image via the stacklayers command. The result is a file that contains a single layer represented in gray-scale. The assumption is the darker an area, the wetter that area. Ohio Department of Natural Resources (ODNR) Ohio Wetlands Inventory Data (OWI) was downloaded in shape file form and overlaid on the band 4 image to help identify the existence of previously classified wet areas for use as partial training sites for the thresholding classification. Dark areas were also used in the training sites as they represented areas of potential wetlands. Nearly 150 pixels were identified as potential wetlands for the training set. A supervised classification was completed in ERDAS to approximate a threshold procedure. The non-parametric rule of parallelepiped was chosen because only a single class classification was necessary. This rule is one of the more popular due to the simplicity of its Boolean operations. Decision boundaries are formed for classes and if a pixel's value lies between the high and low threshold of a class's values, it is assigned to the class. Pixels that do not meet the criteria of thresholds for any classes are deemed unclassified (Jensen, 1996). Within ERDAS, parallelepiped allows the overlap rule and the unclassified rule to become unclassified. These choices will result in wet areas being put into a class and all other areas being left as unclassified. Figure X-3 shows the preliminary land use/land cover map created in the first phase of the project.

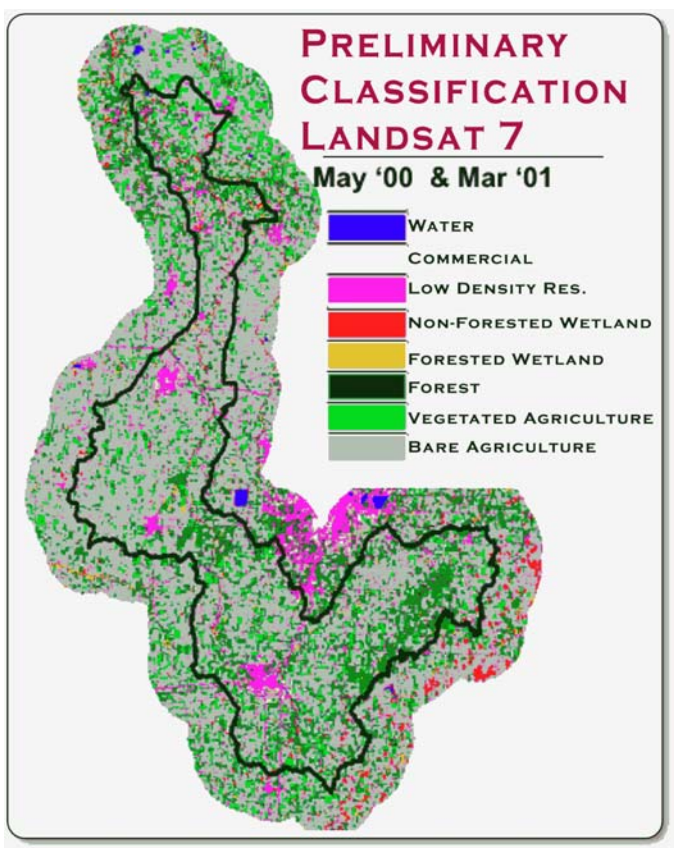

Figure X-3: The preliminary land use land cover map created in the first phase of the project.

Measuring the level of accuracy with the ERDAS Imagine assessment tool demonstrated an accuracy rate of better than 90 percent. See Figure X-4 The classification further proved out under scrutiny when LULC classes were measured in terms of rates with known existing rates of LULC. Figure X-5 demonstrates the percentages each of the LULC extracted from the classification. These rates correspond with similar studies, and empirical measures.

CLASSIFICATION ACCURACY ASSESSMENT REPORT

Image File : f:/student/mikepalmer/upaug_class6.img
User Name : mpalmer

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	0	0	---	---
Water	12	11	11	91.67%	100.00%
Industrial	9	12	9	100.00%	75.00%
Low Res	34	41	30	88.24%	73.17%
Forest	64	72	58	90.63%	80.56%
Winter Wheat	35	31	26	74.29%	83.87%
Hydric soil Ag	10	10	10	100.00%	100.00%
Fallow	186	173	172	92.47%	99.42%
Totals	350	350	316		

Overall Classification Accuracy = 90.29%

----- End of Accuracy Totals -----

Figure X-4: The accuracy assessment output table generated by ERDAS Imagine showing a better than 90% overall accuracy.

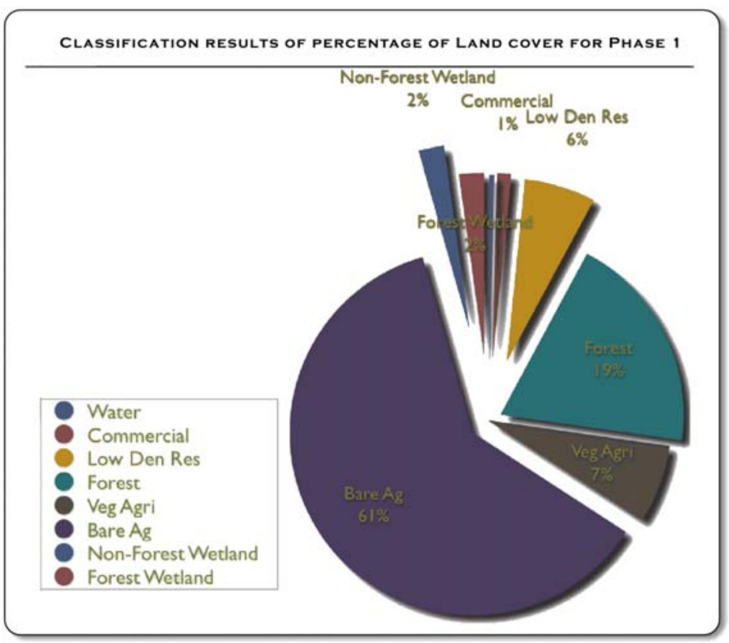

Figure X-5: The Phase 1 classification results as a percentage of total area. These results allow for initial assessment of accuracy. These percentages are in line with expected land use land cover rates found through empirical site analysis.

2. Phase 2 Crop Rotation Multi-temporal Multi-spectral Image Classifications

The type of crop planted by a farmer can significantly impact the amount of runoff of a given location. To accurately map the land use in terms of individual crop type it became necessary to explore a more complex classification and information extraction series of techniques. Based on the information created in the first phase of this project it was obvious that a single LANDSAT multi-spectral scene would not yield the desired level of detail for the AnnAGNPS modeling. We developed crop rotation including soybeans, corn and wheat. Beans, corn, and wheat cannot be differentiated with a single multi-spectral image scene. For this portion of the study it was necessary to involve a many image or multi-temporal approach in identifying crop types. Multiple scenes or multi-temporal satellite images can be used to detect the seasonal variation characteristics unique to each of the target species and thus be used to differentiate crop type.

LANDSAT 7 images were gathered for all of the years available of the study region, Path 20 Row 32 of the Worldwide Reference System 2. The study period covered the years 1999-2002 with a total of 16 images chosen for analysis (Table X-1). The primary requirement for image selection was cloud cover, the main consideration being the amount of clouds obscuring the view of the watershed. The images were subset spectrally—band 6 was removed from the stack before combining with other dates of the individual year. Images were masked as well to reduce the amount of data to be processed in the image processing and information extraction. ENVI was used to stack the images into single multi-temporal image stacks. Figure X-6 shows the total image processing scheme graphically.

1999	2000	2001	2002
Aug 16 Sept 17 Nov 4	May 14 July 7 Nov 22	Mar 14 Mar 30 June 18 Aug 21 Sept 06 Oct 08	May 04 Jun 21 Jul 07 Aug 8

Table X-1: The dates of the images used in the multi-temporal phase of the project

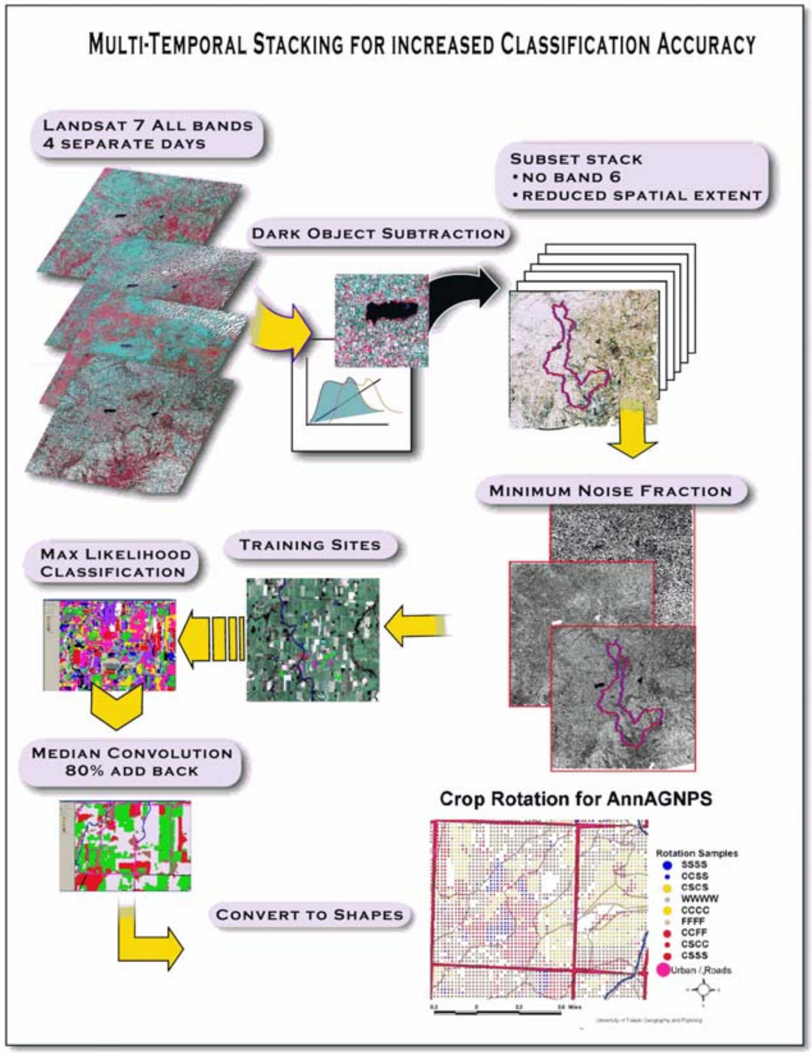

Figure X-6: The total image processing chain is shown graphically.

All images were either obtained from the UT archive or downloaded via the Ohio Library and Information Network (OhioLINK's) online data warehouse. OhioLINK currently purchases all available LANDSAT 7 imagery taken over Ohio for the OhioView Remote Sensing Consortium if the sky is less than 30 percent cloud covered. OhioView is a consortium of 11 universities in Ohio whose goal is to spread the use of remote sensing data. This imagery extends back to the beginning of the LANDSAT 7 collection period, June 1999. This multi-spectral imagery is made freely available through the OhioLINK and OhioView websites, http://dmc.ohiolink.edu/GEO/LS7 http://www.ohioview.org. The LANDSAT program extends back 30 years. The first LANDSAT went up in June 1972. Currently, LANDSAT 7 and LANDSAT 5 are both collecting multi-spectral data. The satellites are in a polar orbit. Both satellites have an array of passive scanners on board. The ETM+ is a multi-spectral scanner and produced the data used in this project. This scanner collects reflected electromagnetic energy from the 0.4 to 12.50 micrometer range of the Electro-magnetic spectrum. It collects this energy in discrete bands. Often associated with color, the data collected in this manner allows for an increased level of discrimination when isolating specific phenomenon or features. As well, the scanner records energy in the mid and thermal infrared ranges (MIR, TIR). The scanner records the entire earth every 16 days. At 485 miles of altitude, the ground resolution is 30 meters for the visible, NIR, MIR and 60 meters for the TIR as well as a 15-meter pan-chromatic band, which was not used for this project. OhioView receives the imagery geographically corrected to the 1T level. The imagery is projected to the Universal Transverse Mercator projection zone 17N for the study region.

The list of images was broken up into years.

3. Atmospheric Correction

Dark object subtraction uses the darkest object in the scene to adjust the brightness values of all of the pixels in the image. The dark object is considered the base or zero value in terms of Electro-magnetic energy reflectance. The value above zero of that feature in the image is considered to be due to atmospheric scattering. This value is considered the atmospheric scattering component and is then subtracted from all of the pixels in the image. ENVI by RSI Kodak was used to implement the dark object subtraction of all of the bands of all of the images.

Dark object subtraction assumes uniform scattering throughout the scene. Though this is a rather broad assumption, it did not detract from our choice to use this method. The region being processed is comparatively small so that this assumption can be considered valid. It is a simple straightforward method that proves easy to implement and reduces complex and time-consuming computations associated with more involved atmospheric modeling methods. Other more involved techniques may prove to increase the accuracy of the final product. However, the cost of implementing more complex atmospheric modeling should be weighed carefully against expected returns in increased accuracy.

Each band was atmospherically corrected using the dark object subtraction. It should be noted that dark objects may not remain the darkest object through the entire spectrum. Careful selection for each band and each date must be made to insure that a good dark object is chosen. The resulting appearance of a dark subtracted image is similar to a contrast stretched image. The former changes the digital value of each pixel where as contrast stretching changes only the appearance of the image.

4. Minimum Noise Fraction

Images made up of many discrete bands pose problems related to storage and processing of the data. Hyperspectral data, images made up of many—generally over 30—discrete bands pose unique challenges in terms of storage and processing. Given that the data held in the many bands of a single image scene is often redundant and thus contributes little to the final data extraction process, methods that can reduce the scale and noise of complex, many-layered data sets are indispensable in hyperspectral image processing.

Principal Components Analysis (PCA) provides a means of reducing the amount of data by focusing the variation of the many bands into a smaller dimensioned image data set. A further refinement on the PCA technique combines two PCA in a cascading manner that significantly reduces noise and concentrates the bulk of the inter-band variability into far fewer bands. This process is called Minimum Noise Fraction (MNF) and is a statistical noise reduction technique and key component of hyperspectral image processing. MNF was used to process the multi-temporal multi-spectral imagery created for this project.

Multi-temporal data also has many bands of data – much of it fairly redundant in terms of inter-band variation. To reduce both the size and noise of the data MNF was run on each of the multi-temporal stacks. A subjective analysis was done on the resulting Eigen—a measure of the contribution to the variation of the resulting PCA or MNF band. These values are used to determine the threshold of the resulting MNF bands on which to perform the supervised classification.

Each of the stacks resulted in a different number of bands in the final MNF file. This was due in part because the Eigen values differ from year to year on the multi-temporal stack. A natural break in the Eigen values was sought so as to determine the threshold or cutoff for usable MNF bands. More images in a given year increased the number of bands in the MNF. The MNF output for a given year with the higher number of bands was the initial output of the MNF transformation and had a total band number divisible by five (because the input images all contained five bands each). In the same year the MNF file with the lesser number of bands was the spectral subset of only the useful bands in that image. The MNF puts all the noise from the image in the higher resulting bands which are considered the noise component and discarded.

5. Supervised Classification

Extracting the information from the imagery involved a supervised classification in much the same manner as was done in the first phase of the project. Training for the supervised classification were pulled from a variety of sources (see Figure X-7).

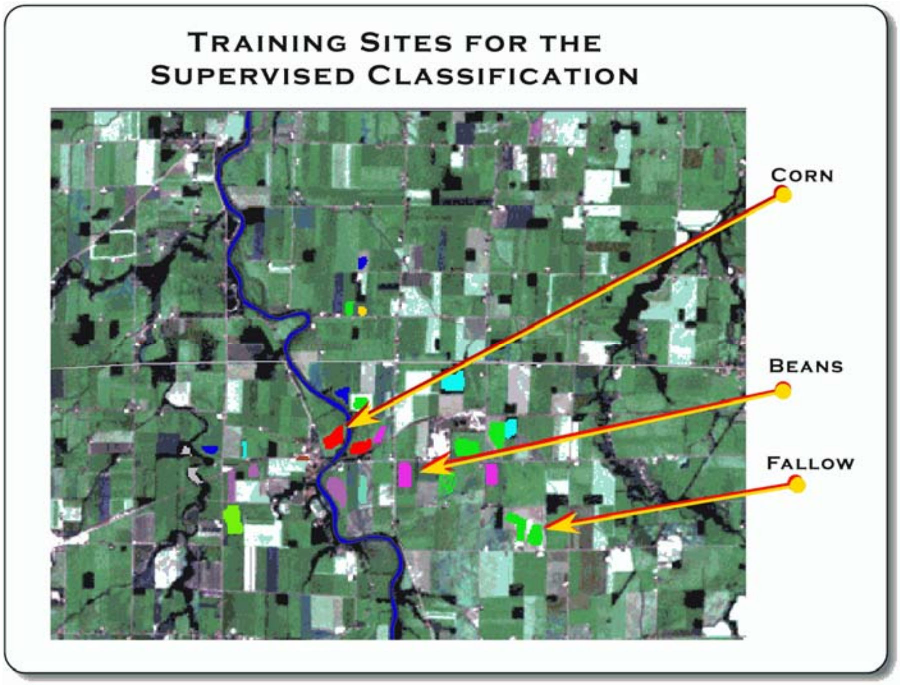

Figure X-7: These and many other sites were empirically derived and used to associate those pixel values with a particular feature type.

To develop the training set for images older than one year historical data was needed. This information is generally difficult to obtain. There is rarely in-situ data collection at the time of the over-flight of the scanner (Jensen et al. 1995). To develop the training set it was necessary to contact individual county governments. In addition, information was supplied by Steve Davis of the NRCS to help augment the information about what crops were grown in which fields and when. Site visits made initially for the first phase of the project were also utilized in developing the training set for the second phase.

Auglaize and Allen Counties recorded tillage data in 2002 by having an NRCS agent drive the roads recording crop type every half mile. Luckily, they also recorded a "previous crop code" that represented the crop in 2001. This was extremely valuable since no county ran tillage transects in 2001. The ground control crop data for 2001 was extracted from these files for Auglaize and Allen counties. We also decided to have a "grass" class, to classify golf courses, cemeteries, and residential yards in rural areas. It was thought that a grass class of one year of imagery (such as 2001) would increase the accuracy of this class for all of the years, under the assumption that there would be few changes for this particular class over the four years. This class could then be applied to the other images, reducing some of the error associated with the classification process. The ground control information was then applied to the supervised classification routine in RSI ENVI. A maximum likelihood classification was used to cluster pixels into specified classes. Each class represented a specific species of crop. This was possible because unlike the single date image pixel values, multi-temporal pixels vary with the seasonal variation specific to individual crop types.

The resulting classification of the image stack required some post processing to reduce errors associated with the classification process. Atmospheric anomalies, shadows, location and feature type all can contribute to a misclassification of the resulting thematic pixel. A convolution routine was used to help mitigate some of these errors. High frequency noise may appear as a single urban classed pixel placed in the middle of a cornfield. It is very unlikely that this pixel is truly representative of the actual ground feature. By comparing each pixel with its neighbors a more accurate classification may be achieved. Though some subjective consideration must be applied for each classed image, it was found that a median convolution with an 80 percent add back of original pixel values was the best at reducing high frequency classification errors, without obliterating patterns of features known to empirically exist and resulting in an overly generalized feature set (see Figure X-8).

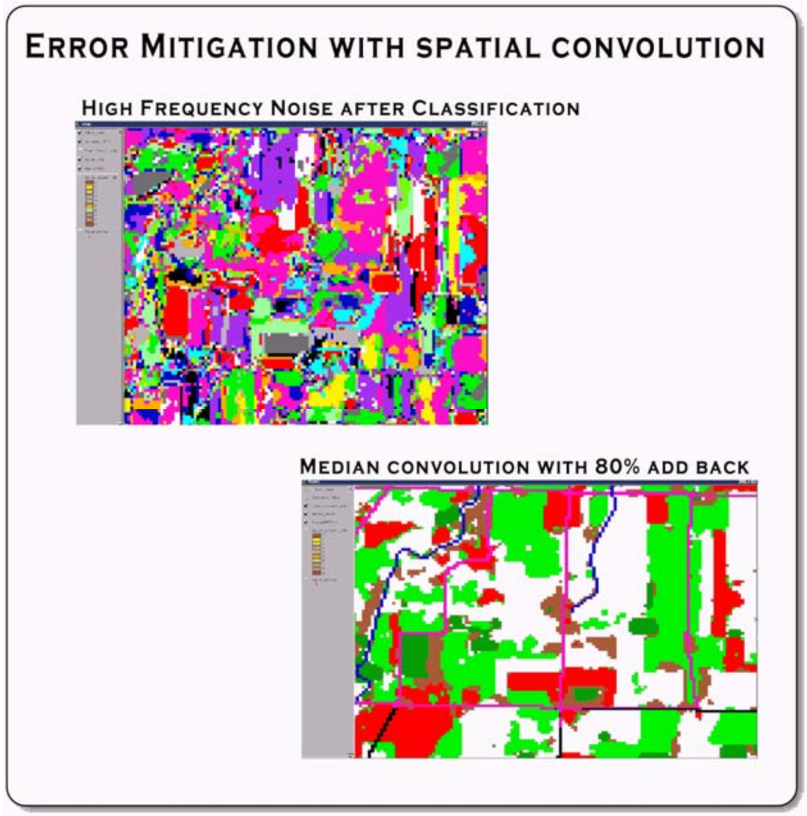

Figure X-8: An example of the effect of a median convolution.

Half of the original ground control points developed for the supervised classification were held back to use in an accuracy assessment. Initial assessments suggested a better than 87 percent accuracy. This accuracy rate was compiled using ERDAS Imagine Accuracy Assessment tool. For the AnnAGNPS model the image derived themed raster data was to be converted into ARCVEIW shape files. These shape files would then be combined creating an overall crop rotation shape file layer. With every step of this process a level of error is introduced into the data set when a significant conversion is applied to the data, and ultimately the process of overlaying the many shape files was not successful.

To make the data compatible with the AnnAGNPS model the information extracted from the satellite imagery had to be brought into a GIS. After processing in ENVI and assessment in ERDAS Imagine, the data was exported as an ArcView compatible image. The Spatial Analyst Extension of ArcView was then used to convert the image raster into a GRID Raster data layer. This proprietary data format allows for more advanced processing to be made on the data by ArcView than could otherwise be performed on an image file. The data in this stage existed as four separate raster GRID files corresponding to each year of the study. The information contained in each layer concerning the crop had to be imparted to a single layer so that the AnnAGNPS model could determine a predominate crop type rotation for each of the base cells.

Initially the processing involved converting each raster dataset into a vector shape file. ArcView allows for this conversion. The goal for this process was to convert all four years of raster data files into vector-based shape files, dissolve the borders within each year of like crop types, and overlay all of the layers to create a single shape file. This single shape file would have entities with attributes representing a specific crop rotation. There were, however, several problems that grew out of this processing chain. First, attempting to dissolve the boundaries of bordering features of the same class proved to be impractical for even a single year. Processing a single year, given the sheer number of polygon boundaries, caused the ArcView software to stop processing. In an attempt to pursue this technique the image was broken up into 10 by 10 kilometer sections and processed in a piecemeal fashion. Though the software was capable of finishing the reduced size data chunks, the workload and processing complexity increased exponentially.

The second issue to arise resulted from a combination of two factors. ArcView conversion of raster GRIDs into shape files proved to introduce another source of error. Polygons produced from GRIDs aren't simply constructed by delineating the raster cells. Rather, a weighting factor applied to the raster to vector conversion caused a truncation that took the form of triangular features. These eccentrically angular features did not represent the squared-off raster cells well. This effect is believed to address the nature of raster cells' inherent inability to accurately portray edges and a function of the ArcView software. Coupling the poor conversion from raster-to-vector format with remnants of high frequency noise that was not mitigated in the first convolution attempts, the combined final output file was unusable. Gaps and Slivers were being combined in the overlay process and resulting in unusable results (Figure X-9). The crop rotation shape file had too many crop rotation types to be considered useful. It was determined that another method needed to be explored for constructing the four years of crop data onto a single usable data layer.

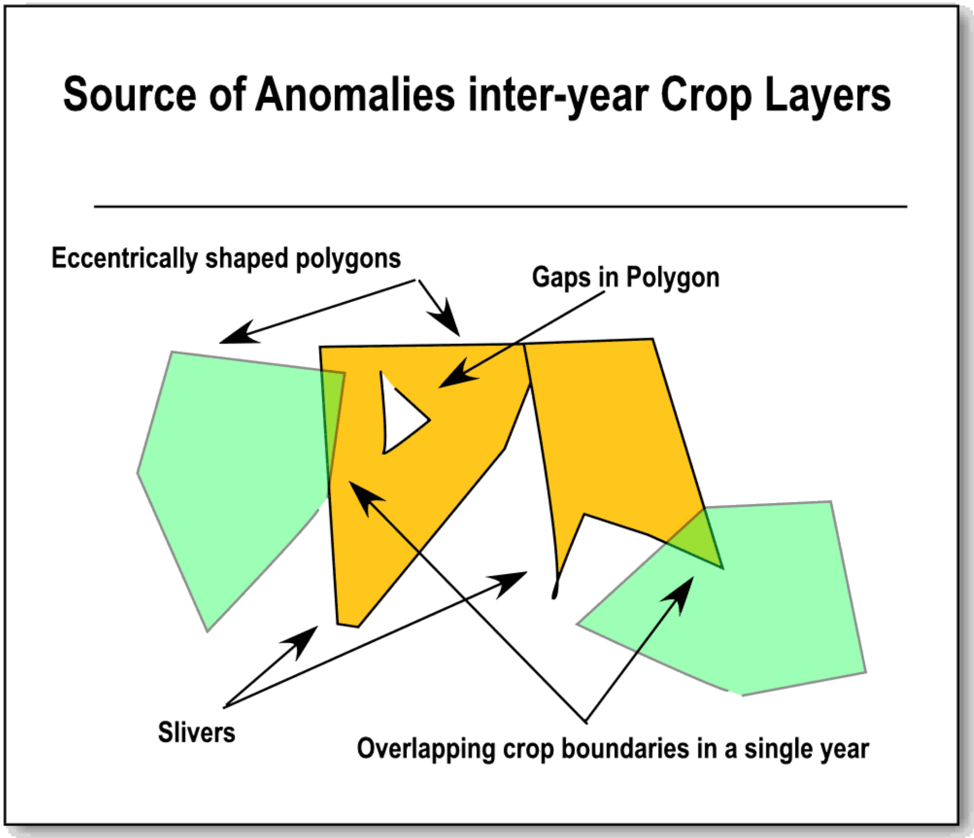

Figure X-9: Showing examples of the results of inter-year shape file overlay. Note the green and gold represent different crops of the same year.

To mitigate some of the remaining noise still present in the GRID layers for all four years, a reduction in the spatial resolution was made. The raster cells were convolved into 120-meter raster cells. This had the effect of dropping additional illogically placed themed pixels from the raster data. It was also decided to sample shape file data in a point data layer rather than trying to force a four-year layer polygon overly. The sample points would help to concentrate the data concerning the crop types and reduce the errors associated with logical inconsistencies.

Shape files were created from the GRID file. Four separate layers of corn, beans, wheat, and fallow, represented one-years worth of data. Sixteen layers were the result of this process. A sample layer of regular grid of points was then constructed using an ArcView Avenue script acquired from an online source. A sample grid of points with an interval of 40 meters was created as the final crop rotation layer. Generated points that were located over non-agricultural features were removed from the layer. The resulting point layer was then overlaid on the four years of crop data shape files. The Spatial Join function of the Geo-processing Wizard in ArcView was used to impart the crop type information from the agricultural shape files to the sample point layer. After each iteration of the Spatial Join function the point layer would inherit a new column of data corresponding to a single crop type for a single year. The points layer gained 16 attributes when the process was finished. Each attribute column contained a binary classification for the crop type and year. In other words, each column represented a crop type and year; an entry in a column would indicate that the point was located over a particular crop. No entry in the cell would indicate an absence of that particular crop type for that particular year. The total number of records for the Upper Auglaize was 431,690.

The state of the data, 16 separate binary attributes for nearly half a million records, demonstrated a low level of utility. To be of use to the AnnAGNPS model the layer needed to have all of the attributes collapsed into a single attribute that described crop rotation type. The solution allowed for a single index number that would describe rotation. As well, it could indicate when a sample point was missing data (no crop type for a year could be found located at a specific point). Figure X-10 shows a single point traced through all of the shape files of crop types.

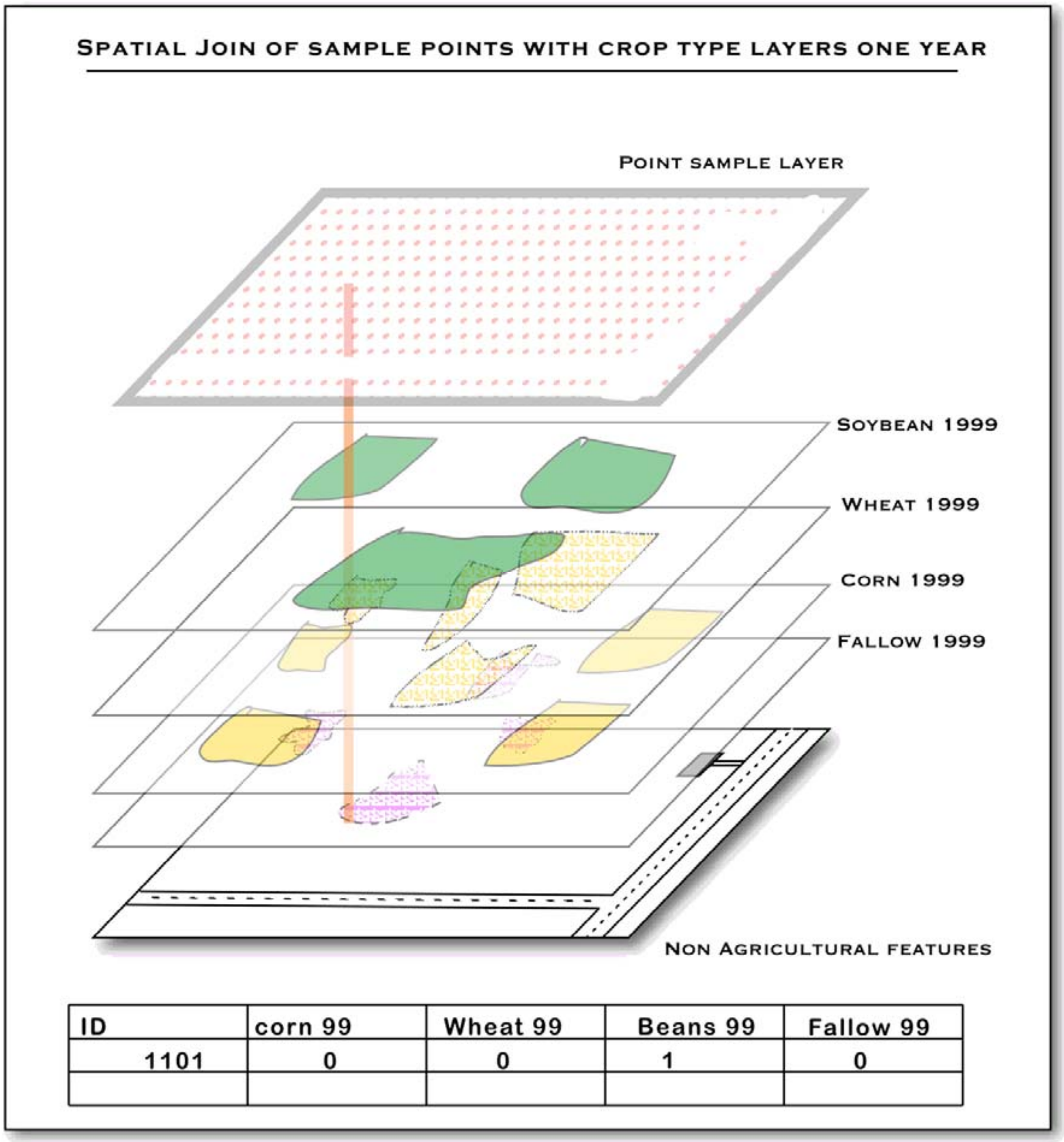

Figure X-10: A single point was traced through all of the shape files of crop types, one year shown here, and inherits the crop type attribute for that year.

The indexing scheme was useful for alerting when too many crop types were present in a single year. It was also important that the resulting index be intuitive to a multitude of users. Once the enumeration scheme is known the values of individual rotation may be reached intuitively.

To create the index each crop type was given a number. These values replaced the binary 1 or 0 of the initial Spatial Overlay process. The values were chosen specifically to insure that every rotation would produce a unique index value. CCCC rotation equals an index of four. No other crop combination would equal that value. The final numbering scheme is shown in Table X-2.

Corn	**Beans**	**Wheat**	**Fallow**
1	5	22	99

Table X-2 Demonstrates the final index values.

These numbers were chosen so that when summed their values would combine uniquely symbolizing a distinct crop rotation schedule. For instance, if a sample point had a year of beans, a year of corn, a year of wheat, and another year of corn, the sum of those crop indexes would be B+C+W+C which would equal 5+1+22+1=29. Thus 29 would equal a rotation of beans, corn, wheat and corn. This index is independent of the rotation schedule. This means that no matter where in the series that rotation was in 1999 the index would remain unchanged at 29. So, BWCC and BCCW or BCWC are all the same. The index could also alert when anomalies existed at a certain point.

An index value of three would indicate that a year was missing a value, or a condition of CCC and a missing value. And an index value of five is a single year of beans and nothing else. Incidentally both values three and five would be considered anomalies. Recall the earlier discussion of error propagation, the raster to vector conversion created certain types of errors that could cause anomalies. In this case if a single year contained crops that overlapped that would be considered an anomaly. This is not to say that a condition of multiple crop types in single year at the same location couldn't take place, they could. However, given the manner in which the algorithm and subsequent processing steps were made, any condition whereby multiple crop types exist under the same sample point is a condition of error. Image xa demonstrates some examples of error propagation of the type generated by this process. The index values could also be combined in such a way so as to indicate specific rotation types. This same procedure was also used to determine if a sample point existed over shape files in error. For instance, an index value of nine would indicate an error state. More specifically a condition of overlap existed with corn and wheat in a single year (CCCCB or 1+1+1+1+5 = 9). Index values that represented error were then removed.

Another problem arose from the specific needs of the AnnAGNPS model. The issue was raised that the model differentiates the rotation of CCBB from CBCB as distinctly different rotations. However, the index without additional processing would represent these as the same type of rotation. Any specific rotation may be isolated once it is identified. Using a simple additive process it was a straightforward process in culling out the CBCB from the CCBB. It should be noted that the unique crop type must be identified prior to processing; the factorial of possible combinations makes pulling out every unique combination infeasible. The final output resulted in a point shape file consisting of 431,690 records with a single attribute of rotation and 2 attributes of location. An example of a final product can be seen in Figure X-11.

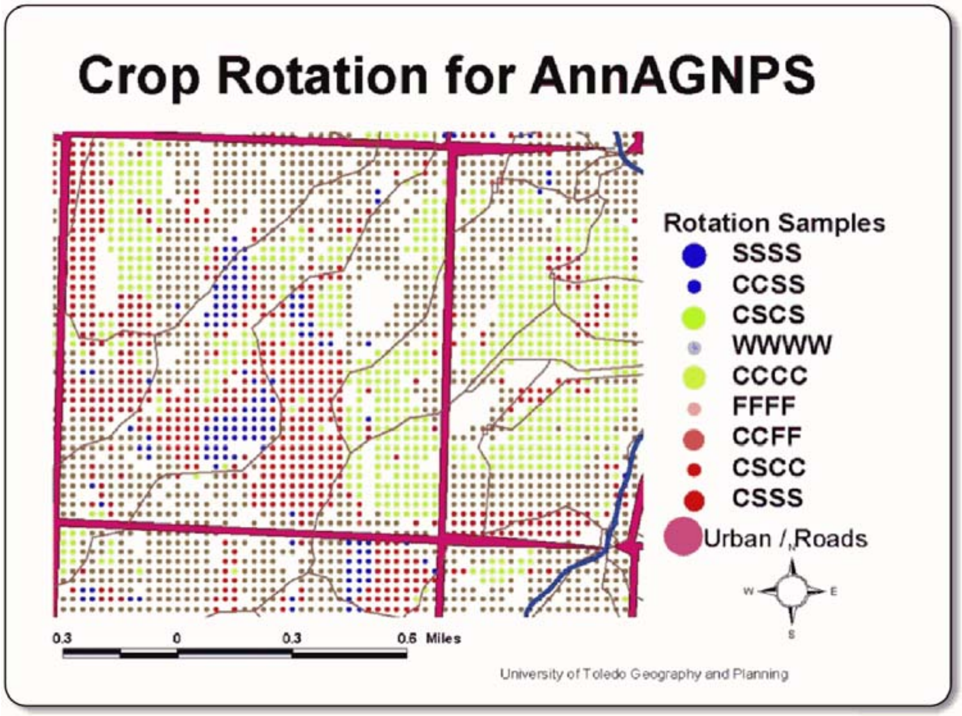

Figure X-11: Map showing close up of the sample layer with several rotations being highlighted.

The following four maps (Figure X-12, Figure X-13, Figure X-14, Figure X-15)show the dominant landuse used by the AnnAGNPS model as determined for each cell for the four years of 1999 through 2002.

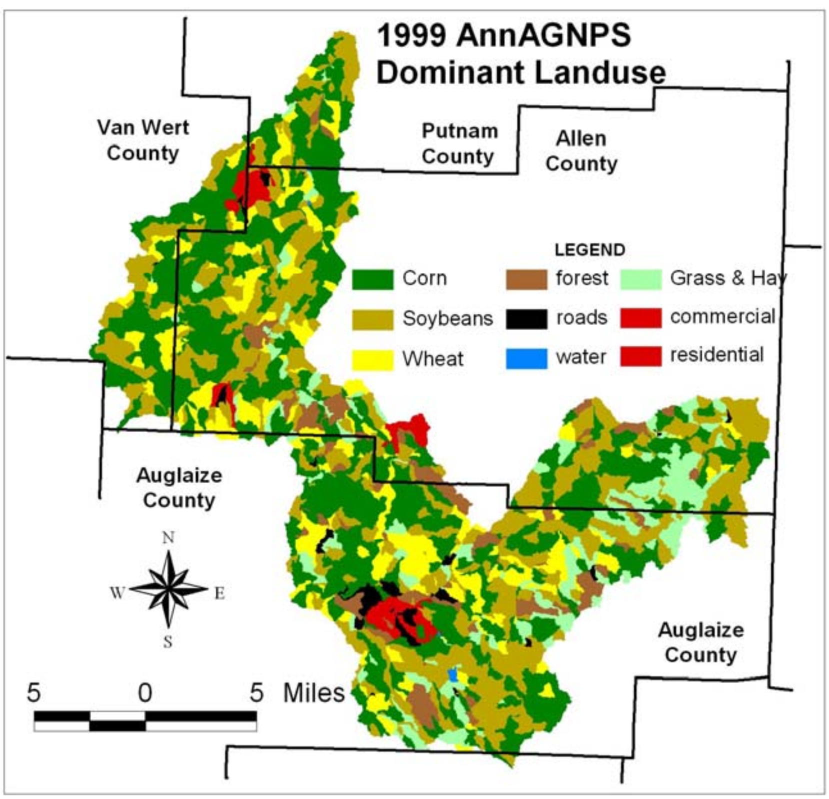

Figure X-12: 1999 Dominant landuse in the Upper Auglaize

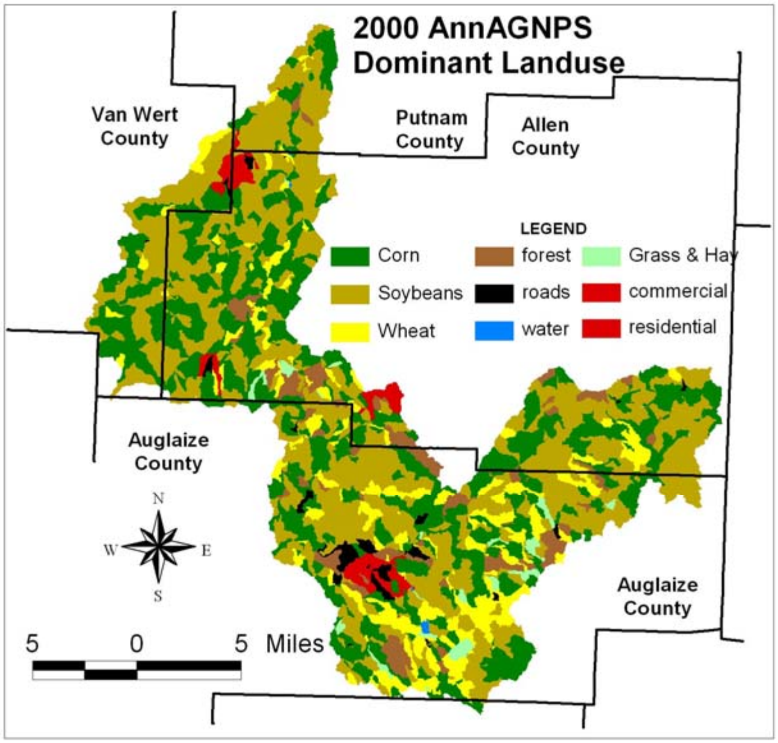

Figure X-13: 2000 Dominant landuse in the Upper Auglaize

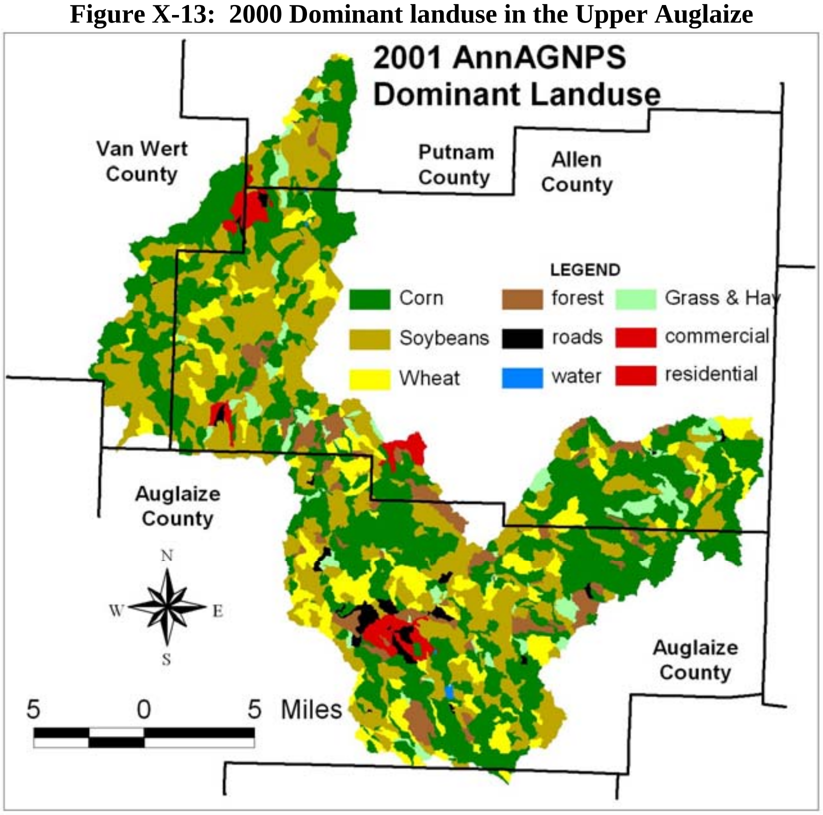

Figure X-14: 2001 Dominant landuse in the Upper Auglaize

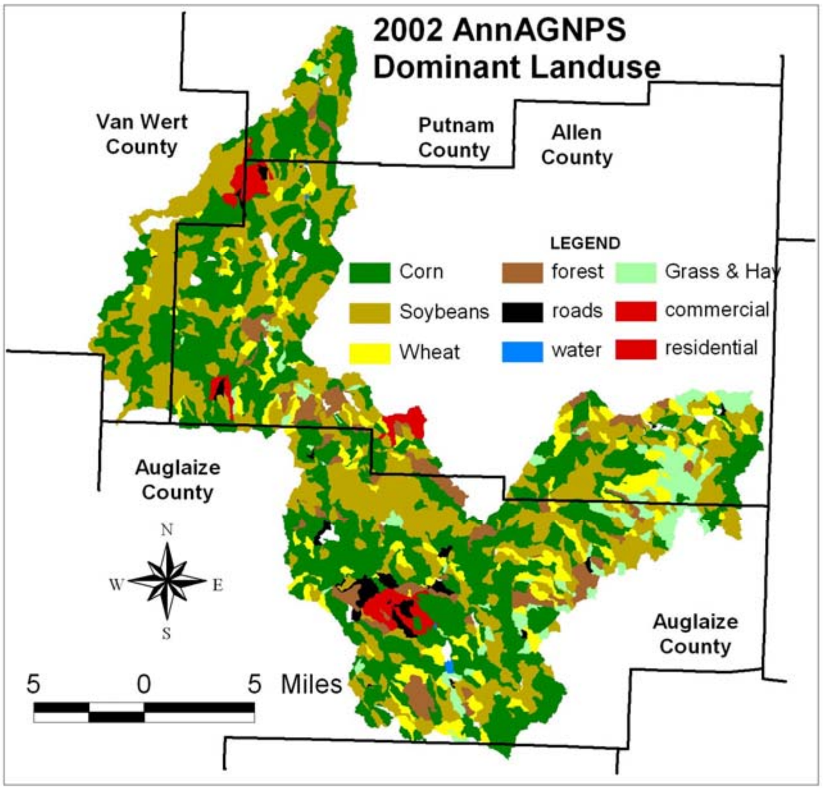

Figure X-15: 2002 Dominant landuse in the Upper Auglaize

A summary of the most prevalent crop rotations determined for the four-year landuse data are shown in the following tables. The tables combine four-year crop sequences that are equivalent except for the year in which they start. In other words, a rotation of CSCS is the same as SCSC for the sake of identifying existent crop rotations despite the fact that the sequences are offset by one year (the AnnAGNPS model keeps them separate by using an offset parameter). Rotation components are C (Corn), S (Soybeans), W (Wheat) and F (Fallow meaning permanent grass but including hay). Table X-3 gives the rotations as determined for the four-year landuse layer. Table X-4 gives the rotations as subsumed in the final cell layer used by AnnAGNPS to model the watershed. (Some rotations in the tables are only three years rather than four, reflecting missing determinations in some of the landuse interpretations.)

Table X-3: Crop Rotations as determined for the four-year landuse layer

Rotation	Sum of Acres	% of Ag. Land	Accum.%
CSCS	30,601	15.5%	15.5%
CCCS	20,595	10.4%	25.9%
CSSS	16,070	8.1%	34.0%
CCSS	13,141	6.6%	40.7%
CCSW	13,060	6.6%	47.3%
CSWS	10,022	5.1%	52.3%
CSSW	8,178	4.1%	56.5%
CSCW	7,572	3.8%	60.3%
SSSW	4,744	2.4%	62.7%
CSWW	4,511	2.3%	65.0%
CWSS	3,767	1.9%	66.9%
CCCC	3,628	1.8%	68.7%
CCWS	3,322	1.7%	70.4%
CWSW	3,066	1.6%	72.0%
FFWC	2,831	1.4%	73.4%

Rotation	Sum of Acres	% of Ag. Land	Accum.%
CCCW	2,772	1.4%	74.8%
CCSF	2,759	1.4%	76.2%
SSSS	2,683	1.4%	77.5%
CCFF	2,399	1.2%	78.8%
FFW	2,190	1.1%	79.9%
FFFF	2,055	1.0%	80.9%
CCWW	1,424	0.7%	81.6%
CFF	1,387	0.7%	82.3%
CWFW	1,357	0.7%	83.0%
FFFW	1,343	0.7%	83.7%
CFSS	1,279	0.6%	84.3%
SSWW	1,279	0.6%	85.0%
CSS	1,246	0.6%	85.6%
CSFS	1,186	0.6%	86.2%
CWWS	1,150	0.6%	86.8%
CFFF	1,133	0.6%	87.4%
SWSW	1,125	0.6%	87.9%
CCFS	1,061	0.5%	88.5%
CFCS	967	0.5%	89.0%
CSWF	925	0.5%	89.4%
FSWC	922	0.5%	89.9%
FSSW	838	0.4%	90.3%

Table X-4: Crop rotations as subsumed in the final cell layer

Rotation	Acres	% of Ag. Land	Accum.%
CSCS	41,744	21.9%	21.9%
CCCS	26,768	14.1%	36.0%
CSSS	15,533	8.2%	44.1%
CCSS	14,187	7.5%	51.6%
CCSW	14,036	7.4%	59.0%
CSWS	9,924	5.2%	64.2%
CSCW	8,418	4.4%	68.6%
CSSW	8,375	4.4%	73.0%
CCFF	3,437	1.8%	74.8%
CWSW	3,427	1.8%	76.6%
CWSS	3,201	1.7%	78.3%
SSSS	2,925	1.5%	79.8%
CSWW	2,920	1.5%	81.3%
CCCW	2,894	1.5%	82.9%
CCWS	2,771	1.5%	84.3%
CCCC	2,770	1.5%	85.8%
SSSW	2,728	1.4%	87.2%
FFWC	2,613	1.4%	88.6%
CCSF	1,422	0.7%	89.3%
CWFW	1,382	0.7%	90.1%
FFFW	1,066	0.6%	90.6%

C. CONSERVATION TILLAGE TRANSECTS

Tillage transect data was used to determine the percent type of tillage practice presently used. Then by random allocation, the cells were assigned tillage types of conventional, mulch till and no-till to match the total percentage of each tillage type known through the tillage transect data. Table X-5 and Table X-6 summarize the landuse and tillage breakdown for the four-year existing-condition landuse. Figure X-16 shows the existing condition simulation of tillage for the years 1999-2002.

Table X-5: Upper Auglaize 4-Year Crop, Tillage, and Landuse Distribution in Acres

Landuse	Tillage	1999 Acres	2000 Acres	2001 Acres	2002 Acres
Corn	Plow	21,366	27,706	22,166	22,216
"	Mulch till	39,707	36,131	43,068	37,837
"	No till	22,120	29,883	25,907	29,674
"	Total	83,194	93,719	91,142	89,726
Beans	Plow	18,335	12,672	15,623	19,853
"	Mulch till	20,360	35,693	24,354	29,008
"	No till	24,959	23,432	28,949	23,703
"	Total	63,655	71,798	68,927	72,563
Wheat	Plow	3,922	5,473	7,800	3,344
"	Mulch till	11,286	8,043	9,142	5,669
"	No till	11,037	9,650	6,663	7,954
"	Total	26,245	23,166	23,605	16,967
Grass	Plow	3,002	774	1,035	1,212
"	Mulch till	8,918	405	3,708	7,759
"	No till	5,661	812	2,259	2,447
"	Continuous	928	928	928	928
"	Total	18,509	2,919	7,929	12,346
Forest		11,888	11,888	11,888	11,888
Residential		4,314	4,314	4,314	4,314
Roads		2,991	2,991	2,991	2,991
Commercial		956	956	956	956
Water		199	199	199	199
Grand Total		211,951	211,950	211,951	211,951

Table X-6: Upper Auglaize 4-Year Crop, Tillage, and Landuse Distribution in Percent

Landuse	Tillage	1999 Percent	2000 Percent	2001 Percent	2002 Percent
Corn	Plow	10.1%	13.1%	10.5%	10.5%
"	Mulch till	18.7%	17.0%	20.3%	17.9%
"	No till	10.4%	14.1%	12.2%	14.0%
"	Total	39.3%	44.2%	43.0%	42.3%
Beans	Plow	8.7%	6.0%	7.4%	9.4%
"	Mulch till	9.6%	16.8%	11.5%	13.7%
"	No till	11.8%	11.1%	13.7%	11.2%
"	Total	30.0%	33.9%	32.5%	34.2%
Wheat	Plow	1.9%	2.6%	3.7%	1.6%
"	Mulch till	5.3%	3.8%	4.3%	2.7%
"	No till	5.2%	4.6%	3.1%	3.8%

Landuse	Tillage	1999 Percent	2000 Percent	2001 Percent	2002 Percent
"	Total	12.4%	10.9%	11.1%	8.0%
Grass	Plow	1.4%	0.4%	0.5%	0.6%
"	Mulch till	4.2%	0.2%	1.7%	3.7%
"	No till	2.7%	0.4%	1.1%	1.2%
"	Continuous	0.4%	0.4%	0.4%	0.4%
"	Total	8.7%	1.4%	3.7%	5.8%
Forest		5.6%	5.6%	5.6%	5.6%
Residential		2.0%	2.0%	2.0%	2.0%
Roads		1.4%	1.4%	1.4%	1.4%
Commercial		0.5%	0.5%	0.5%	0.5%
Water		0.1%	0.1%	0.1%	0.1%
Grand Total		100.0%	100.0%	100.0%	100.0%

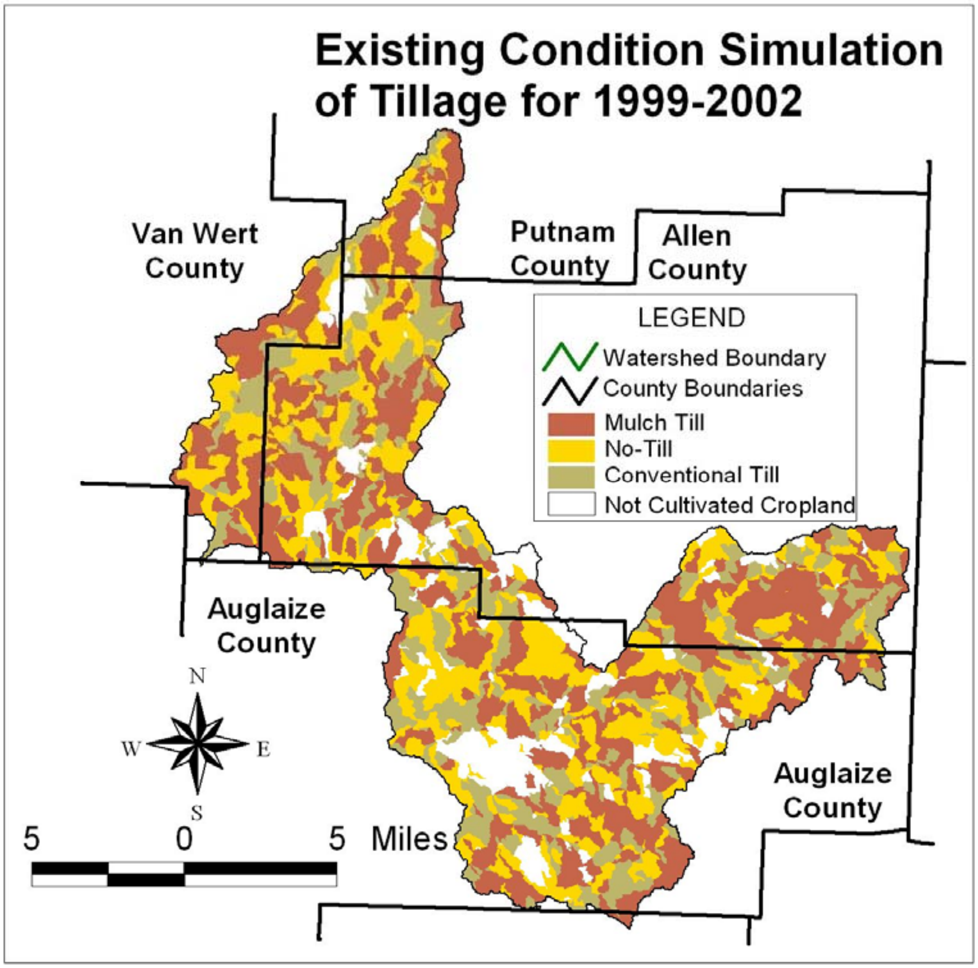

Figure X-16: Existing Condition Simulation of Tillage for 1999-2002

D. Ephemeral Gully Erosion

As mentioned in the main report, the Ephemeral Gully Erosion Model (EGEM) was used to calculate the gully erosion values outside of the AnnAGNPS model. Specifically, a modified version of the program was written by Bill Merkel (Hydraulic Engineer, NRCS) that calculated values for a batch of input data. Thus, once all the input data were developed, calculations could be run for all cells at one time. Specifically, the input data included rainfall for five different storms in order to develop a relation of runoff to gully erosion that would envelop all storm values. Additionally, this program included the additional step of developing a power curve relationship between runoff and tons of ephemeral gully erosion. In this way, AnnAGNPS, which uses just this relationship to model ephemeral gully erosion, could be made to duplicate the results of EGEM. A graphical representation of the process of developing the power curve coefficients and exponents is shown below (Figure X-17). By performing a log transform on the runoff and erosion values, a linear curve fit could be used to develop the power curve values. The only other input that needed to be obtained besides the power curve was the delivery ratio for gully erosion to gully yield. AnnAGNPS was modified during this modeling process to accept a delivery ratio as another value to the gully modeling input. The delivery ratio was obtained by an iterative process during calibration of the sediment loading with the available sediment gage data.

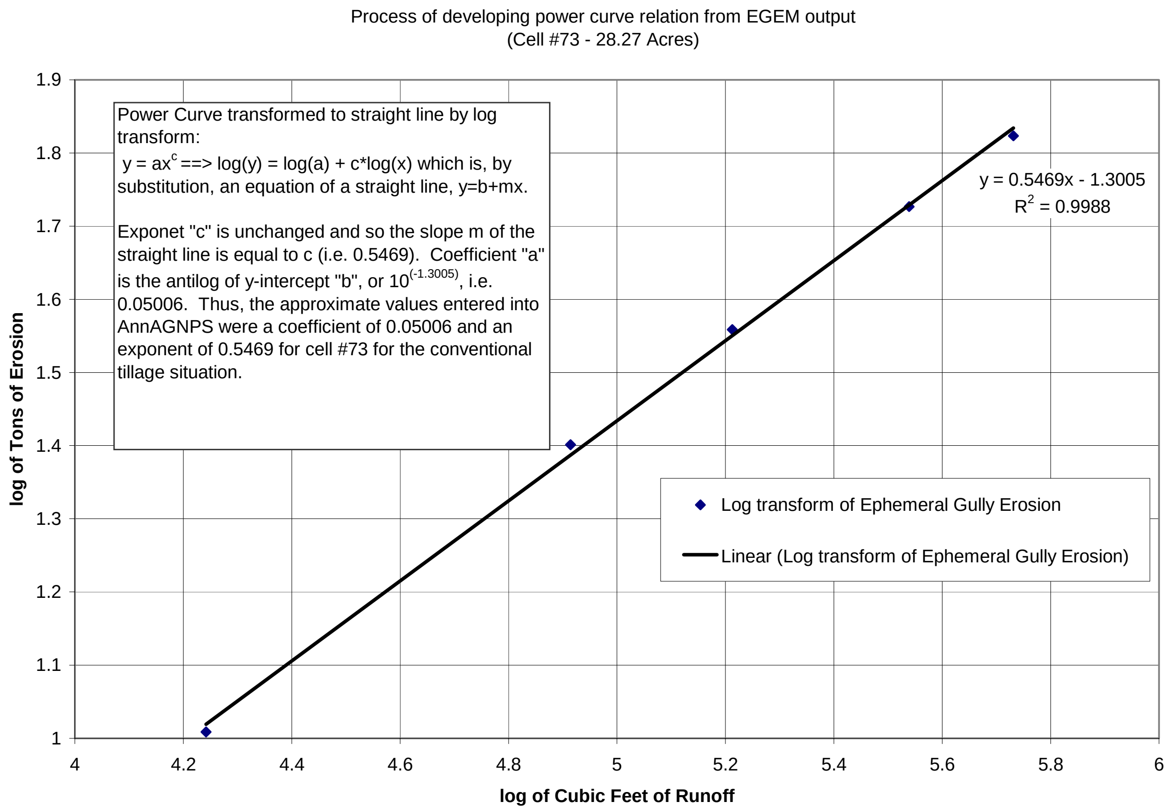

Figure X-17: Process used to develop the power curve relation from EGEM output

E. HYDRAULIC GEOMETRY

Table X-7: Hydraulic geometry characteristics of select sites on streams in the upper Auglaize River basin.

Site #	Decimal latitude	Decimal longitude	Site description	Drainage area (mi2)	Cross-section area (ft2)	Top width (ft)	Hydraulic depth (ft)	Width of 100-year floodplain (ft)
1	40.9497	-84.2667	Auglaize River at Ohio State Route 224	332	787	105	7.50	1200
2	40.8936	-84.3068	Jennings Creek near Ft. Jennings	69	373	71	5.25	850
3	40.8445	-84.2870	Auglaize River at State Route 66	243	928	147	6.31	900
4	40.8599	-84.3609	West Branch Jennings Creek near Delphos	12.5	122	40	3.05	Nd
5	40.8473	-84.3503	Jennings Creek near Delphos	42.2	286	53	5.40	600
6	40.7675	-84.3881	Jennings Creed at Kill Rd	27.5	202	42	4.81	250
7	40.7427	-84.3154	Auglaize River at Shaffer Rd	217	1169	134	8.72	800
8	40.6779	-84.2642	Auglaize River at State Route 198	198	743	131	5.67	800
9	40.5827	-84.2442	Auglaize River at Glynwood Road	149	641	112	5.72	300
10	40.5387	-84.2013	Pusheta Creek at Hardin Pike	18.4	223	52	4.29	
11	40.6193	-84.1222	Auglaize River at Mudsock Rd	88	288	65	4.43	600
12	40.6070	-84.1131	Blackhoof Creek at State Route 33	11.6	153	40	3.83	40
13	40.5566	-84.1023	Blackhoof Creek at U.S. Route 33	1.8	98	34	2.88	Nd
14	40.6639	-84.0465	Auglaize River at Indian Treaty Boundary Rd	40	184	54	3.41	700
15	40.6845	-83.9083	Auglaize River at Napoleon Rd	1.67	118	33	3.58	200
16	40.4978	-84.1128	Pusheta Creek at Santa Fe-New Knoxville Rd	8.75	176	47	3.74	220
17	40.6591	-84.2421	Twomile Creek at Bowsher Rd	27.4	258	60	4.30	600
18	40.6282	-84.2118	Twomile Creek at Holden Rd	10.2	223	59	3.78	450

[Nd = not determined, Rd = road]

Table X-8: Bed material particle-size data for selected sites on streams in the upper Auglaize River basin.

Site No.	Station number	Date	Percentage of bed material finer than indicated sieve diameter size										
			0.062 mm	0.125 mm	0.250 mm	0.500 mm	1.00 mm	2.00 mm	4.00 mm	8.00 mm	16.0 mm	32.0 mm	64.0 mm
1	Auglaize River at State Route 224	7/18/2002	2	3	5	8	14	26	36	40	45	76	100
6	Jennings Creed at Kill Rd	7/18/2002	51	61	73	82	87	92	97	100	--	--	--
9	Auglaize River at Glynwood Road	7/16/2002	0	0	1	6	11	18	28	39	58	80	100
14	Auglaize River at Indian Treaty Boundary Rd	7/16/2002	0	2	8	30	52	76	92	96	96	100	100
15	Auglaize River at Napoleon Rd	7/17/2002	10	14	22	31	38	46	58	80	85	100	--
17	Twomile Creek at Bowsher Rd	7/17/2002	2	3	6	20	35	48	63	83	100	100	--

F. WORK PLAN DEVELOPMENT

A detailed work plan was prepared as part of the development of the project. Individual tasks are listed in Table X-9 to describe the task , what time period the task was to be completed, any preceding tasks that were required, and the responsible agency.

Table X-9: Detailed plan of work for the Upper Auglaize Watershed project.

ID	ℹ	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1		Start Project	0 days	Mon 6/3/02	Mon 6/3/02		COE
2		Workshop	5 days	Mon 7/8/02	Fri 7/12/02	1	ARS,NRCS
3		**Soils**	**150 days**	**Mon 6/3/02**	**Fri 12/27/02**	**1**	**NRCS**
4		**Digitized Maps**	**150 days**	**Mon 6/3/02**	**Fri 12/27/02**	**1**	**NRCS**
5		**Obtain SSURGO by County**	**150 days**	**Mon 6/3/02**	**Fri 12/27/02**	**1**	**NRCS**
6		Auglaize	150 days	Mon 6/3/02	Fri 12/27/02	1	NRCS
7		Allen	120 days	Mon 6/3/02	Fri 11/15/02	1	NRCS
8		Putnam	120 days	Mon 6/3/02	Fri 11/15/02	1	NRCS
9		Van Wert	150 days	Mon 6/3/02	Fri 12/27/02	1	NRCS
10		Attribute Database	60 days	Mon 6/3/02	Fri 8/23/02	1	NRCS
11		**DEM**	**30 days**	**Mon 6/3/02**	**Fri 7/12/02**	**1**	**U. of Toledo**
12		Obtain Standard USGS (30x30x1)	5 days	Mon 6/3/02	Fri 6/7/02	1	U. of Toledo
13		Determine Watershed cell map (Preliminary)	10 days	Mon 6/10/02	Fri 6/21/02	12	U. of Toledo,OSU
14		Correct Standard USGS DEM	10 days	Mon 6/24/02	Fri 7/5/02	13	U. of Toledo
15		Determine Watershed Cell Map (Final)	5 days	Mon 7/8/02	Fri 7/12/02	14	U. of Toledo,OSU
16		Landuse	**120 days**	**Mon 6/3/02**	**Fri 11/15/02**	**1**	**U. of Toledo**
17		**Obtain Digitized Map**	**120 days**	**Mon 6/3/02**	**Fri 11/15/02**	**1**	**U. of Toledo**
18		Classification	40 days	Mon 6/3/02	Fri 7/26/02	1	U. of Toledo,OSU
19		Validation	40 days	Mon 7/29/02	Fri 9/20/02	18	U. of Toledo,OSU
20		Evaluation	40 days	Mon 9/23/02	Fri 11/15/02	19	U. of Toledo,OSU

Table X-9: Detailed plan of work for the Upper Auglaize Watershed project.

ID	ℹ	Task Name	Duration	Start	Finish	Predecessors	Resource Names
21		**Create Attribute Database**	**30 days**	**Mon 6/3/02**	**Fri 7/12/02**	**1**	**NRCS**
22		RUSLE Databases	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
23		Field Data	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
24		Operations Data	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
25		Operations Reference	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
26		Crop	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
27		Non-Crop	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
28		Strip Crops & Contours	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
29		Runoff Curve Number	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
30		Fertilizer	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS,USGS,WQL
31		Pesticide	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS,USGS,WQL
32		Tile Drains	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
33		Impoundment	30 days	Mon 6/3/02	Fri 7/12/02	1	NRCS
34		Linking Attribute Database	30 days	Mon 6/10/02	Fri 7/19/02	21FF+5 days,1	U. of Toledo
35		**Gully**	**20 days**	**Mon 6/3/02**	**Fri 6/28/02**	**1**	**NRCS**
36		**Ephemeral**	**20 days**	**Mon 6/3/02**	**Fri 6/28/02**	**1**	**NRCS**
37		EGEM	10 days	Mon 6/3/02	Fri 6/14/02	1	NRCS
38		Develop Power Curves	10 days	Mon 6/17/02	Fri 6/28/02	37	NRCS
39		Identify locations	10 days	Mon 6/3/02	Fri 6/14/02	1	NRCS
40		**Hydraulic Geometry**	**100 days**	**Mon 6/3/02**	**Fri 10/18/02**	**1**	**USGS**

Table X-9: Detailed plan of work for the Upper Auglaize Watershed project.

ID		Task Name	Duration	Start	Finish	Predecessors	Resource Names
41		Natural	100 days	Mon 6/3/02	Fri 10/18/02	1,13FF	USGS
42		**Man-Made**	**100 days**	**Mon 6/3/02**	**Fri 10/18/02**	**1**	**USGS**
43		Heavily Maintained Channels	100 days	Mon 6/3/02	Fri 10/18/02	1	USGS
44		Near Natural (First Phase)	100 days	Mon 6/3/02	Fri 10/18/02	1	ODNR/OSU,USGS
45		Hydraulic Geometry - Bench (Second Phase)	180 days	Mon 6/3/02	Fri 2/7/03	1	ODNR/OSU
46		**Climate**	**125 days**	**Mon 6/3/02**	**Fri 11/22/02**	**1**	**USGS**
47		**Historical**	**120 days**	**Mon 6/3/02**	**Fri 11/15/02**	**1**	**USGS**
48		Data Aggregation	60 days	Mon 6/3/02	Fri 8/23/02	1	USGS
49		Create GEM Database	60 days	Mon 8/26/02	Fri 11/15/02	48	USGS
50		Synthetic	5 days	Mon 11/18/02	Fri 11/22/02	49	USGS
51		**Point Sources**	**90 days**	**Mon 7/15/02**	**Fri 11/15/02**	**1**	**OEPA**
52		Identify Locations	30 days	Mon 7/15/02	Fri 8/23/02	11	OEPA
53		How Much	30 days	Mon 8/26/02	Fri 10/4/02	52	OEPA
54		Withdrawls	30 days	Mon 10/7/02	Fri 11/15/02	53	OEPA
55		**Feedlots**	**60 days**	**Mon 6/3/02**	**Fri 8/23/02**	**1**	**OEPA**
56		Locations	60 days	Mon 6/3/02	Fri 8/23/02	1	OEPA
57		Amounts	60 days	Mon 6/3/02	Fri 8/23/02	1	OEPA
58		**Input Calibration**	**100 days**	**Mon 6/3/02**	**Fri 10/18/02**	**1**	**USGS**
59		**Water (Volume, Qp)**	**100 days**	**Mon 6/3/02**	**Fri 10/18/02**	**1**	**USGS**
60		Analyze existing data	1 day	Mon 6/3/02	Mon 6/3/02	1	USGS

Table X-9: Detailed plan of work for the Upper Auglaize Watershed project.

ID		Task Name	Duration	Start	Finish	Predecessors	Resource Names
61		Channel Roughness, Manning's n	100 days	Mon 6/3/02	Fri 10/18/02	41FF	USGS
62		**Sediment**	**100 days**	**Mon 6/3/02**	**Fri 10/18/02**	**1**	**USGS**
63		Data Analysis of existing data by partic	100 days	Mon 6/3/02	Fri 10/18/02	1	WQL
64		Bed & Bank Material In-situ	100 days	Mon 6/3/02	Fri 10/18/02	40SS	USGS
65		Channel Sediment Transport	100 days	Mon 6/3/02	Fri 10/18/02	1	ODNR/OSU
66		**Chemicals**	**35 days**	**Mon 6/3/02**	**Fri 7/19/02**	**1**	**USGS**
67		Nutrients	5 days	Mon 6/3/02	Fri 6/7/02	1	USGS,OEPA
68		Pesticides	5 days	Mon 6/3/02	Fri 6/7/02	1	USGS,OEPA
69		Statistical Analyses	30 days	Mon 6/10/02	Fri 7/19/02	68,67	WQL
70		**AnnAGNPS/Arcview**	**165 days**	**Mon 12/30/02**	**Fri 8/15/03**	**1**	**NRCS**
71		Consolidate Input (First Phase)	10 days	Mon 12/30/02	Fri 1/10/03	13,3,16,35,40,46,51,55	NRCS,USGS
72		First Phase Simulation Runs	10 days	Mon 1/13/03	Fri 1/24/03	71	NRCS,USGS
73		Consolidate Input (Second Phase)	5 days	Mon 1/27/03	Fri 1/31/03	15,72	NRCS,USGS
74		Preliminary Second Phase Simulation Run	5 days	Mon 2/3/03	Fri 2/7/03	73	NRCS,USGS
75		Meeting	2 days	Mon 2/10/03	Tue 2/11/03	74	COE
76		Calibration	5 days	Wed 2/12/03	Tue 2/18/03	75	NRCS,All Partners
77		Final Runs	10 days	Mon 7/28/03	Fri 8/8/03	76,79	NRCS,USGS
78		Validation	5 days	Mon 8/11/03	Fri 8/15/03	77	USGS,All Partners
79		**Riparian**	**300 days**	**Mon 6/3/02**	**Fri 7/25/03**	**1**	**ARS**
80		REMM	300 days	Mon 6/3/02	Fri 7/25/03	1	ARS

Table X-9: Detailed plan of work for the Upper Auglaize Watershed project.

ID	❶	Task Name	Duration	Start	Finish	Predecessors	Resource Names
81		**Actual Riparian**	**7 days**	**Mon 6/3/02**	**Tue 6/11/02**	**1**	**OEPA**
82		Location	7 days	Mon 6/3/02	Tue 6/11/02	1	OEPA
83		Dimensions	7 days	Mon 6/3/02	Tue 6/11/02	1	OEPA
84		Type(s) of Vegetation	7 days	Mon 6/3/02	Tue 6/11/02	1	OEPA
85		**Reports**	**190 days**	**Mon 1/27/03**	**Fri 10/17/03**	**1**	**NRCS,COE,USGS**
86		First Phase Report	15 days	Mon 1/27/03	Fri 2/14/03	72	COE,All Partners
87		Second Phase Draft Report	15 days	Mon 8/18/03	Fri 9/5/03	78	COE,NRCS,USGS
88		Final Report	30 days	Mon 9/8/03	Fri 10/17/03	87	COE,NRCS,USGS
89		End Project	0 days	Fri 10/17/03	Fri 10/17/03	85	COE

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