USING GIS TO MODEL NONPOINT SOURCE POLLUTION IN AN AGRICULTURAL WATERSHED IN SOUTHEAST MICHIGAN

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A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science

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[1996]

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Table of Contents

Building the Model

Using the Model: A Case Study

Appendices

List of Tables

List of Figures

ABSTRACT

Distributed parameter hydrologic models offer many advantages over lumped parameter models in tracking and controlling nonpoint source pollutants, but they are constrained by the excessive data input and processing they require. However, rapidly emerging technology in the form of geographic information systems (GIS) and the increasing availability of digital spatial databases are greatly reducing these constraints and expanding the range of applications of these models. This study describes the coupling of a distributed parameter agricultural nonpoint source pollution model (AGNPS) with a GIS (ERDAS) to evaluate the impact of nonpoint source pollution on water quality in a mid-sized (334 km^2) agricultural watershed in southeast Michigan. ERDAS is used to integrate spatial data sets from multiple sources into a single GIS database from which parameters needed to run the AGNPS model can be generated. The AGNPS model estimates the amounts, origin and distribution of sediments and nutrients across the watershed in response to a storm of a specified magnitude. By integrating the GIS and by using existing statewide and national spatial databases, the AGNPS model is easily employed to run iterative simulations of hypothetical landscape scenarios. These simulations indicate the agriculturalization of land and the loss of forested cover significantly alter sediment and nutrient budgets across the watershed. The expansion of urban land cover appeared to have the greatest overall impact on runoff and nutrient fluxes, while agricultural expansion generated the largest increases in sediment concentrations and sediment yields. Forest expansion dramatically reduced the generation and delivery of all forms of nonpoint source pollution modeled. This integration of GIS with distributed parameter landscape modeling has considerable potential to aid in land-use planning and in identifying locations most vulnerable to storm-driven runoff and erosion.

Introduction

The control of industrial effluents, municipal sewage discharges, and other point sources of water pollution has greatly improved the quality of our aquatic resources over the last several years, yet water quality still falls below acceptable standards in many regions of the United States (USEPA 1984). In many of these cases, pollution originating from diffuse sources, such as sediment eroded from cropland and excess nutrients accumulated in storm runoff, continues to degrade the lakes, rivers, and streams into which they flow (Clark et al. 1985, Waters 1995, Chesters and Shierow 1985). Acknowledging the threat that these nonpoint source pollutants pose to aquatic resources, scientists and environmental managers have since begun to look beyond instream processes and more at how surrounding valley and landscape characteristics and processes might influence water quality and ecological integrity of streams (Hynes 1975, Hunsaker and Levine 1995). Many believe that this more holistic approach to the study of aquatic systems will not only provide a better mechanism for controlling nonpoint source pollution, but also lead to a more complete and thorough understanding of stream ecosystems (Minshall 1988, Johnson et al. 1995).

This holistic approach, however, will require a new set of tools and methods for stream research. If we are to look at streams from a landscape perspective, we must first develop the means to characterize differences among landscapes and then determine how these differences manifest themselves in the lotic environment. More precisely, we need to devise a set of technologies that enables us to better understand how the spatial arrangement and interaction of various landscape features can affect the biology and ecology of stream systems. These technologies must be capable of storing and relating data collected over broad spatial scales and with varying levels of accuracy. Moreover, if they are to be successfully integrated into the scientific and management communities, these technologies must be easy to use, cost-effective, and flexible enough to tackle a variety of different research questions.

Although meeting these diverse needs will be no small undertaking, rapid improvements in desktop computer systems and information technologies should significantly speed progress towards this goal. In particular, the capabilities afforded by geographic information systems (GIS) should be especially useful in the development of such tools. Briefly, GIS is an organized collection of computer hardware and software designed to collect, store, manipulate, retrieve, analyze and display spatially referenced data (ESRI 1995). Its automation of many operations on spatial data is well suited to meet the requirements of landscape-scale studies of stream systems. GIS, however, is a relatively young technology; we are only beginning to realize its wide range of capabilities (Burrough 1986). Consequently, if we are to fully realize its potential, we must continue to pursue new and innovative uses of GIS. That is the underlying purpose of this research.

In this thesis, I demonstrate how GIS can be used to develop an easy-to-build and easy-to-use, yet powerful tool capable of examining landscape influences on aquatic systems. Specifically, I show how GIS can be integrated with a hydrologic model to simulate the effects of landscape-scale alterations on the generation and movement of nonpoint source (NPS) pollutants (runoff, sediments and nutrients) across a typical mid-sized watershed in the lower Great Lakes region. I begin by describing the steps needed to build the model, including a description of the study area, the hydrologic model chosen, and how coupling GIS with a NPS model makes this approach much more powerful and easy to use. I then use this integrated model to compare the terrestrial and aquatic impacts of three hypothetical scenarios of landscape alteration, specifically, increases in the extent of urban land, of agricultural land, and of forested land. The results of these scenarios are used to evaluate the effectiveness of the model, both in terms of accuracy and overall utility. Finally, using the capabilities and findings of this model as a basis for evaluation, I comment on the overall usefulness of GIS and this approach to the study of streams from a landscape perspective. In particular, I discuss how such technology can be improved and what direction future research along these lines should take.

Building the Model

Study Area

The Saline River basin, a 334 km^2 (129 mi^2) watershed draining portions of Washtenaw and Monroe counties in southeastern Michigan (Figure 1), was chosen to represent a typical rural landscape in the lower Great Lakes area. The upland portion (the northern two-thirds) of the watershed is characterized by gently rolling till plains and ground moraines mixed with broad, flat outwash channels and gravel plains (Figure 2). Soils in this part of the basin are mostly well-drained sandy loams with some very sandy soils (Figure 3). Pockets of muck and peat soils are also scattered across small depressions in the hilly uplands. The lower portion of the watershed crosses a glacial lake plain of extremely low relief. Soils in this portion are predominantly poorly-drained loams and clay loams developed on top of former lake-deposited sediments. The total range of elevation in the Saline watershed extends from 314 m (1060 ft) in the northeastern uplands, to 192 m (630 ft) at the river's confluence with the River Raisin, a tributary of Lake Erie.

The climate of the Saline River area is characterized by warm summers and cold winters, with extremes buffered by the surrounding Great Lakes. The average annual temperature is 9°C (48°F) with an average summer high of 22°C (72°F) and a winter low of -6°C (22°F). The growing season averages 180 days, with the first freeze usually arriving around October 21, and the last freeze on April 23. Precipitation is distributed evenly throughout the year, but is slightly higher in summer than in winter. May has the highest monthly average precipitation with 76 mm (3.0"), and January has the lowest with 51 mm (2.0"). Brief showers usually occur every three days in summer months,

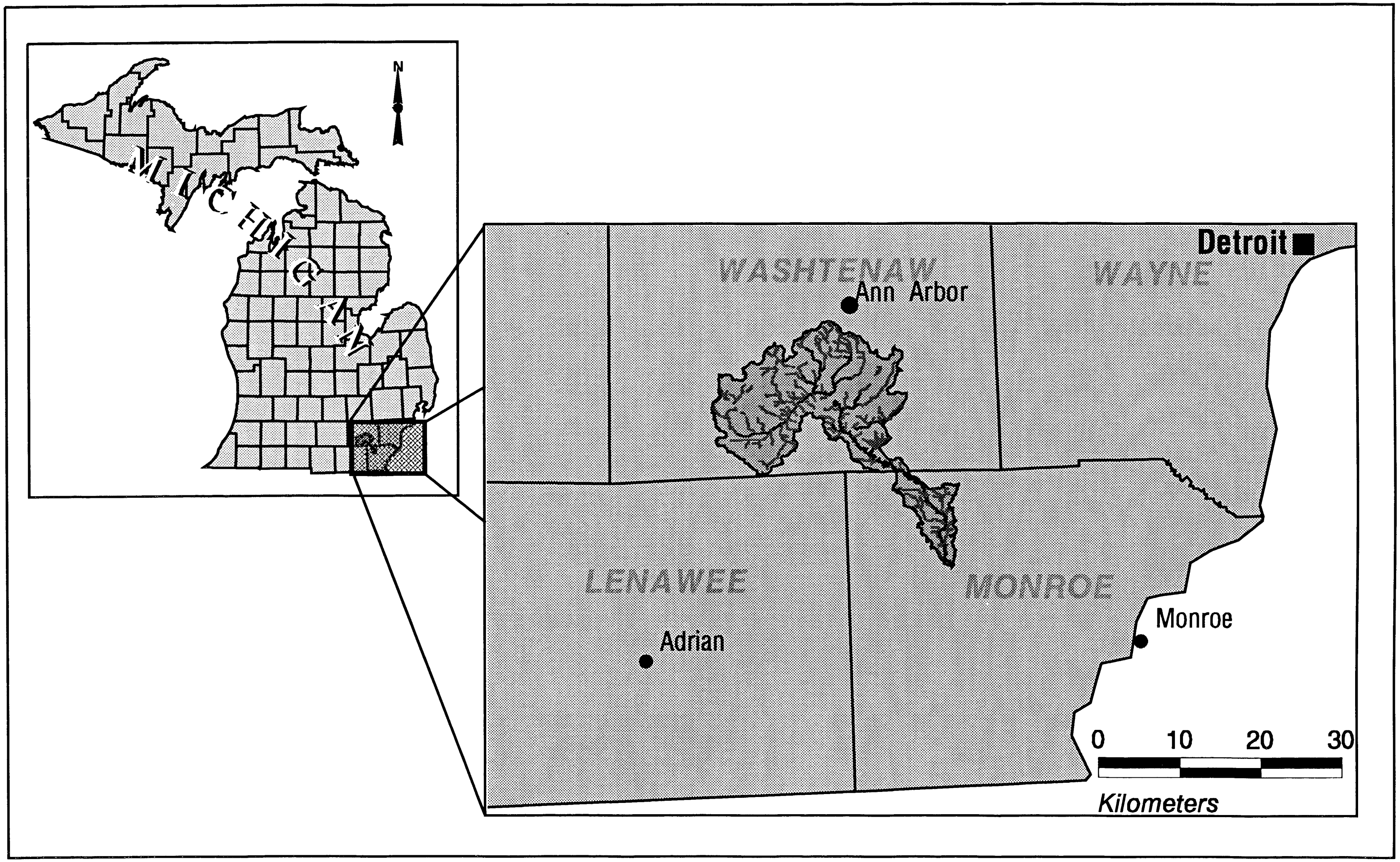

Figure 1. The Saline River Basin, Southeastern Michigan

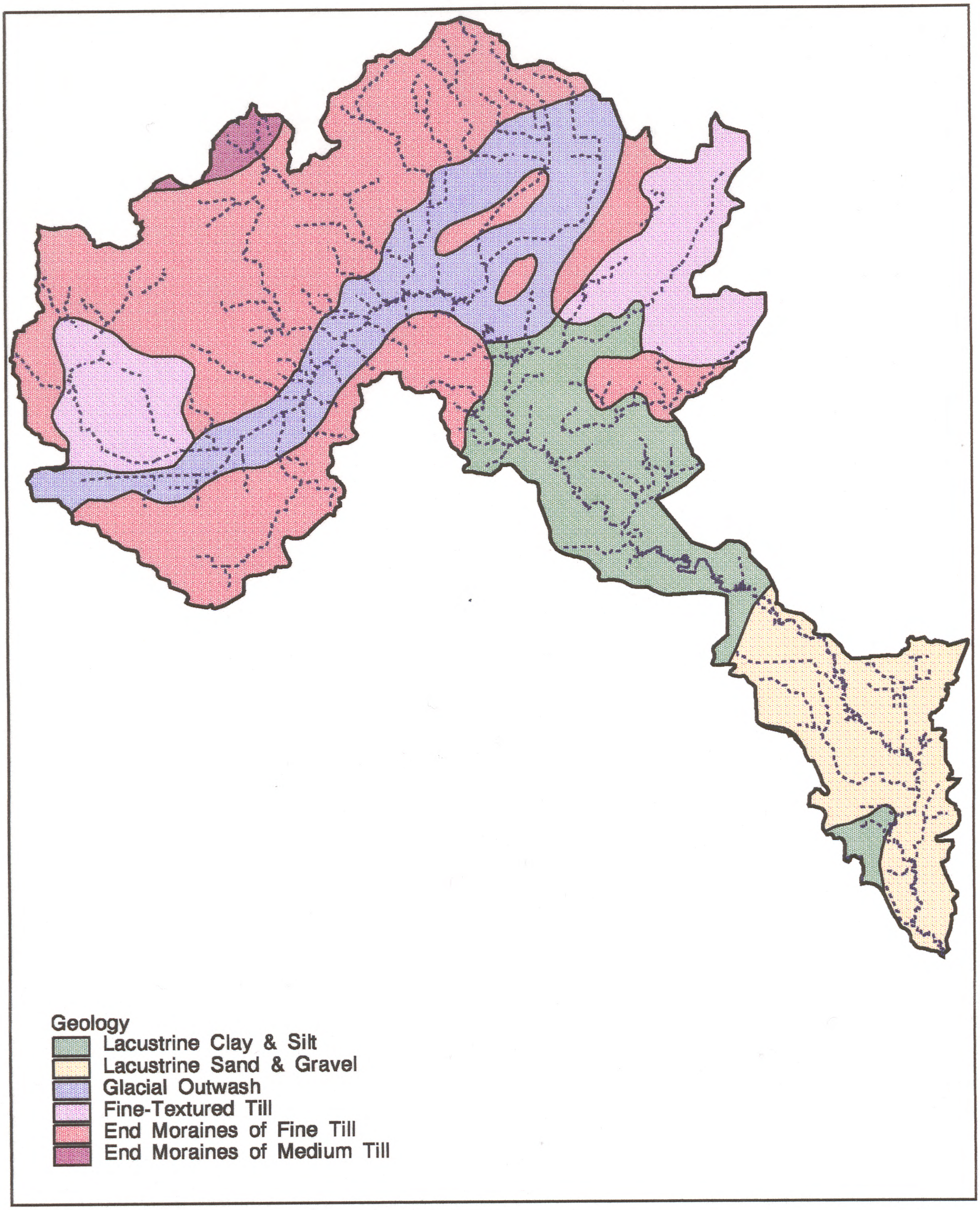

Figure 2. Surficial Geology of the Saline River basin (Farrand 1996).

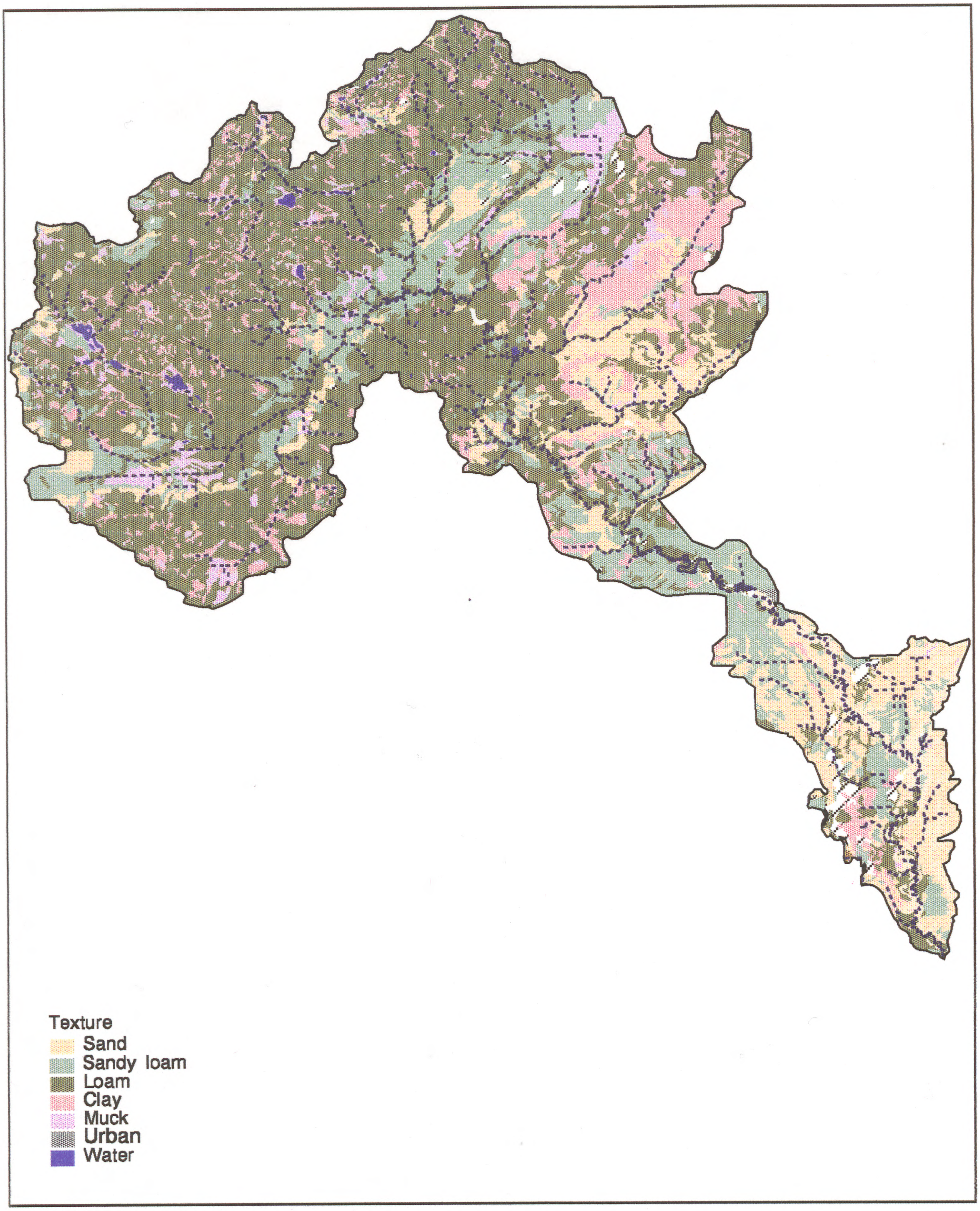

Figure 3. Soil textures of the Saline River basin (MIRIS 1993).

but are often highly localized. The heaviest 1-day rainfall for the period of 1944 to 1990 was 94 mm (3.71") in December, 1965 (NOAA, 1990).

The landscape of the Saline River watershed, once covered in wetlands and hardwoods forests (Roth 1994), is now dominated by agricultural usages (Figure 4). Two-thirds of the land area in the basin is intensively cropped, with a mixture of corn (50%), small grains (25%), pasture (13%), and soybeans (12%). An estimated 350 farms operate within the basin, supporting approximately 9500 head of livestock (Johengen et al. 1991). The potential soil erosion and nutrient pollution from these operations pose serious threats to water quality in the watershed. The basin has already been identified as having the highest areal phosphorous loading rate in southeast Michigan (Johengen et al. 1991), and other water quality studies also have indicated the Saline River habitat to be significantly degraded (Allan et al. 1996; Smith et al. 1981).

More recently, the Saline's rural landscape has undergone significant urbanization and suburbanization. Growth in Ann Arbor to the north, metropolitan Detroit to the northeast, and in the towns of Saline and Milan from within are causing more and more land to be converted to residential, commercial, and industrial land uses. The population of Saline alone has grown over 38% in the period of 1970 to 1990 (US Census). Preliminary studies have shown that agricultural land area is declining, while forested area actually is increasing, although not nearly as rapidly as urban land (Erickson 1995).

Overall, the size, topographic variation, and degree of human influence on the Saline River watershed make it an ideal subject for a nonpoint pollution study. The landscape changes and NPS pollution problems occurring here are characteristic of many of the rural watersheds in the lower

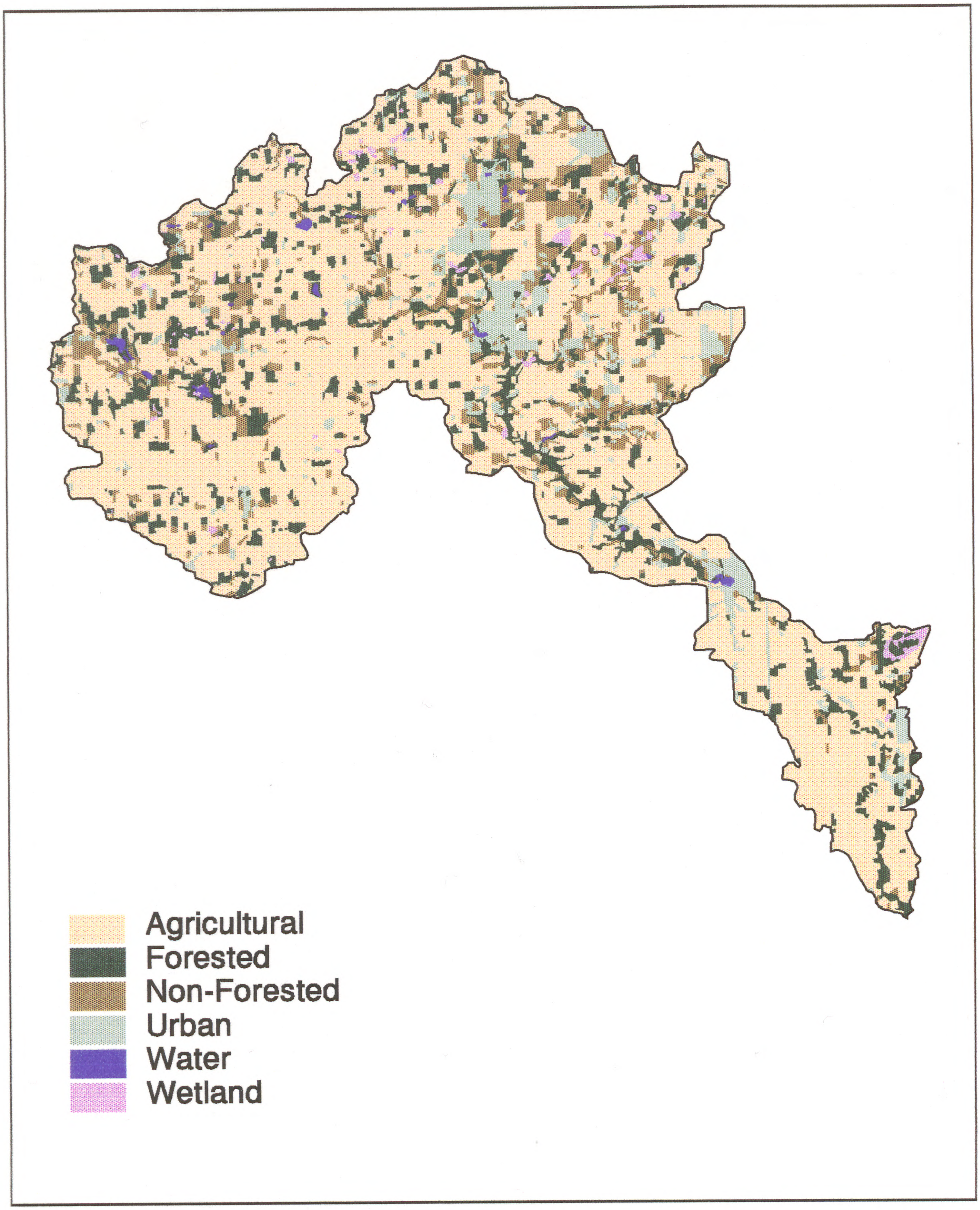

Figure 4. Land Use/Land Cover of the Saline River Basin (MIRIS 1985).

Great Lakes region. Consequently, the knowledge gained from this study should prove helpful for other watersheds in the area.

The AGNPS Model

Hydrologic models are of great value in stream research. Lotic systems are complex, and hydrologic models offer a means to integrate the numerous interacting factors that shape these systems. A number of hydrologic models have been developed over the past several years, and as more is understood about the physical processes that affect hydrologic systems, these models become more and more complex. The hydrologic model used in this study, the Agricultural Nonpoint Source (AGNPS), is one of the more sophisticated and consequently more accurate models available today (Gordon and Simpson 1990).

The AGNPS model (version 2.65), a FORTRAN-based program that runs on a 386 or higher PC, was developed in the early 1980's by the Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and the Natural Resources Conservation Service (then Soil Conservation District) to simulate runoff, sediment, and nutrient transport arising from storm events in agricultural watersheds (Young et al. 1987). It has been applied extensively to midwestern conditions and has been found to give reasonably accurate estimates of soil erosion, sediment yield, and nutrient transport in landscapes similar to the Saline River watershed (Gordon and Simpson 1990; Tim and Jolly 1994; Prato et al. 1989).

AGNPS uses a distributed parameter approach, subdividing the watershed into a gridwork of uniformly sized cells and handling all inputs and calculations at the cell level. Cells can range in size from 0.4 ha to 16 ha, with smaller cells more accurately reflecting spatial variations in the landscape, but requiring greater input and computational effort. This cell-based approach enables nonpoint pollution to be examined at any location within the watershed and allows easy identification of pollution "hotspots", or localized areas of high pollution potential. More importantly, however, this approach permits manipulation of specific landscape characteristics, allowing nonpoint pollution to be evaluated under a number of different landscape scenarios.

The model requires twenty-two specific inputs for each grid cell (Table 1). Most input variables can be derived from one or a combination of four spatial data sets: land use/cover, soils, topography, and hydrography. These variables are used in a sequence of calculations that (i) determines the amount of runoff, soil erosion, and sediment yield generated within each cell, (ii)

Table 1. Cell variables required by the AGNPS model to simulate runoff, sediment and nutrient transport for specified storm events. Italicized variables were set to uniform values across the watershed (given in parenthesis).

Variable #	Description	Source (Set value)
1	Cell ID number	User defined
2	Receiving Cell number	DEM
3	SCS Curve number	Land Use/Soils
4	Slope	DEM
5	*Slope Shape*	*(1)*
6	Field Slope Length	Soil
7	Channel Slope	DEM/Hydrography
8	Channel Side Slope	DEM/Hydrography
9	Manning's Roughness	Land Use
10	Soil Erodibility	Soils
11	Cropping factor	Land Use
12	*Practice factor*	*(1)*
13	Surface condition constant	Land Use
14	Aspect	DEM
15	Soil texture	Soils
16	*Fertilization factor*	*(2)*
17	*Availability factor*	*(10)*
18	*Point source indicator*	*(0)*
19	*Gully source level*	*(0)*
20	COD factor	Land Use
21	*Impoundment indicator*	*(0)*
22	Channel indicator	Hydrography

estimates the amount of nutrients (N and P) and chemical oxygen demand (COD) either adsorbed by these sediments or dissolved in the runoff, and (iii) simulates the routing of these sediments and nutrients from cell to cell, downslope, until reaching an outlet cell at the base of the watershed. AGNPS uses a modified universal soil loss equation (Wischmeyer and Smith, 1978) to determine soil erosion and sediment yield, while runoff, sediment and nutrient transport are calculated using a set of hydrologic equations developed for an earlier nonpoint pollution model, the Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980).

Simulations are run for a specified storm event, defined either by its energy-intensity (EI) value or by the duration of the storm and the amount of precipitation. The model produces a number of output parameters (Table 2),

Table 2. Hydrologic, sediment and nutrient output information generated by the AGNPS model. These data are available for each cell within the watershed as well as for the complete watershed, measured at the watershed outlet cell.

Variable Group	**Output Information (unit)**
Hydrology	Runoff Volume (inches) Peak Flow (cfs)
Sediments	Upland [Cell] Erosion (tons) Sediment Concentration (ppm) Sediment Yield (tons/acre) Rate of Deposition (%) Sediment into Cell (tons) Sediment out of Cell (tons) Channel Erosion (tons/acre) Delivery Ratio (%) Enrichment Ratio (%)
Nutrients (soluble) [N, P, COD]	Cell contribution (lbs/acre) Cumulative at cell (lbs/acre) Concentration at cell (ppm)
Nutrients (in sediment) [N, P]	Cell contribution (lbs/acre) Cumulative at cell (lbs/acre)

which can be obtained for a single cell, a subset of cells, or the entire watershed. Results are generated either in tabular or spatial formats, or can be written to a spreadsheet file that is easily imported into other applications for further analysis.

Integrating GIS with the AGNPS model

The distributed parameter (cell based) approach used by AGNPS offers several distinct advantages over lumped parameter models, but these advantages come at the cost of greatly increased input and computational effort. For example, subdividing the Saline River watershed (334 km^2) into the maximum cell size recommended for use with AGNPS (16 ha) would result in 2,088 total cells. At 22 inputs per cell, each run of the model would therefore require over 45,000 inputs - a clear limitation if handled manually.

Fortunately, geographic information systems offer many unique features that can greatly reduce the effort required to generate such a massive database. More specifically, each of the 22 cell inputs can be organized as individual spatially-referenced map layers. GIS can be used both to generate these layers from existing spatial databases and to perform the spatial operations needed to reclassify and organize these maps into a format readable by the AGNPS model program. Furthermore, since the map layers are stored digitally, the input values can easily be modified to represent a variety of different landscape scenarios.

Using GIS to Build the AGNPS Database

One goal of this research was to develop a procedure for easily repeating simulations of nonpoint pollution under a variety of landscape scenarios, capitalizing on GIS' capability to integrate spatial data sets from a number of different sources, its capacity to perform operations on multiple layers of spatial data to create new map layers, and its power to easily update or modify particular data layers. The following text describes how these capabilities of GIS were used to facilitate building the AGNPS model database. A more detailed, step-by-step account of these procedures is given in Appendices A – J.

Integrating Data from Multiple Sources

The use of pre-existing spatial data sets to derive most of the 22 input variables required by AGNPS is one of the key features that make this model so easy to build. Many federal, state, and local organizations are currently assembling enormous archives of digital spatial data from satellite images, aerial photos and other sources. Many of these archives contain data useful for various stream and landscape investigations, but often the data are collected and stored at scales, resolutions, and projections that make them difficult to use for particular purposes. In this study, making use of existing digital data sources via GIS has dramatically reduced the time necessary to collect and organize the massive database required by the AGNPS model.

Fifteen of the 22 input variables can be derived from one or a combination of four available spatial data layers. Three of these data layers - land use, soils, and hydrography - were extracted from the Michigan Resource Information System (MIRIS), a statewide digital archive of spatial data maintained by the Michigan Department of Natural Resources and the Library of Michigan. The fourth layer, topography, was derived from 1:250,000 scale digital elevation models (DEM) generated by the United States Defense Mapping Agency and distributed by the United States Geologic Survey.

Two GIS software packages, C-Map (Michigan State University 1991) and ERDAS (Earth Resources Data Analysis Systems 1990), were used to import these data layers and combine them into a single, multi-layer spatial database. The MIRIS data layers, which are stored as vector GIS files, first had to be converted into raster coverages. This was done by importing each MIRIS layer into C-Map where they were cleaned and built into topologically meaningful coverages. These coverages were then converted into ERDAS files and gridded into 1 ha raster cells georeferenced to the southern zone of the Michigan State Plane coordinate system.

The DEM topographic data, already in raster format, were imported directly into ERDAS and georectified to the Michigan State Plane coordinate system as 1.0 ha cells, the highest resolution afforded by the 1:250,000 DEM data. Also, to keep measurements consistent with the AGNPS model, cell elevation values of the DEM data, originally in meters, were converted into feet using a simple ERDAS recode command. The final result of these efforts, then, was a four layer GIS database consisting of MIRIS land use, soils and hydrography, and DEM topography, all referenced to the same Michigan State Plane coordinate system. This GIS database could then be used as a master database to derive many of the specific input variables required by the AGNPS model.

Using GIS to generate the AGNPS database from the master GIS database

While GIS is a useful tool for integrating data from a number of different sources into a uniform database, a more powerful application of GIS is its ability to generate new information from existing map layers through various spatial operations and analyses. One of the simplest GIS operations is recoding cell values of an existing database to new cell values based on information specified by the user. Eight of the 22 AGNPS input variables were created by recoding layers contained in the master database. The recode tables used to convert these cell values were obtained from a variety of published sources (Table 3).

A slightly more complex GIS operation, which assigned new cell values based on a matrix of cell values in two or more existing layers, was used to compute cell runoff curve values. This variable is based on specific combinations of land cover and soil hydrologic regimes. To calculate cell values, a recode table based on information contained in Young et al. (1987) and Nelischer (1989) was set up to assign appropriate curve number values to each cell based on the information contained in the land use and the soil layers for that cell.

More sophisticated GIS operations were used to calculate values for other AGNPS variables. Cell slope and aspect were determined using GIS operations that compare one cell's elevation value to the values of surrounding cells. AGNPS channel slope and channel side slope variable values were calculated using the proximity analysis capabilities of GIS: the hydrography layer was used as a reference to locate cells within certain distances of waterways and these cells were assigned values as set forth by

Table 3. Several of the AGNPS input variables were derived by recoding values of cells in the land use, soils, and hydrology data layers. This table lists the variables derived by recoding, the data layer from which they were recoded, and the source of the information used to recode them.

Variable	Derivation	Recode Table
Manning's Roughness Coefficient	Land Use	Young et al. (1987), Nelischer (1989)
Cropping Management ("C")Factor	Land Use	SEMCOG (1979)
Surface Condition Constant	Land Use	Young et al. (1987), Nelischer (1989)
Chemical Oxygen Demand	Land Use	Young et al. (1987), Nelischer (1989)
Soil Erosivity ("K") Factor	Soils	NRCS Soil Surveys
Soil Texture	Soils	NRCS Soil Surveys
Field Slope Length	Soils	SEMCOG (1979)
Channel Indicator	Hydrology	Young et al. (1987)

AGNPS documentation based on their distances from the stream course.

GIS operations can also be combined to compose maps of new information, as illustrated in the creation of cell identification and receiving cell variable layers. Cell identification numbers, a set of sequentially increasing integers used to label each cell, were assigned using a macro program written in C programming language (Appendix K). Then, the receiving cell numbers, indicating which adjacent cell would receive the majority of runoff of that cell, were determined using a GIS subroutine that used the aspect layer to identify and insert the appropriate cell identification number.

Fifteen of the twenty-two AGNPS input variables were created and stored as individual GIS layers using the various GIS operations described above. The remaining seven inputs were either set to uniform values representing worst-case scenarios or were not used in analyses. Practice management ("P") factor and fertilization incorporation factor were both set to 1, representing worst-case pollution scenarios, and fertilizer application was set to a mid-range background rate of 50 lbs/acre. Determining the actual cell values for these parameters would have required a comprehensive survey of agricultural practices, which was beyond the scope of this research. Furthermore, these values vary widely from year to year, making such surveys accurate only for short durations. Setting them to worst-case scenarios allows a more general application of the model and is still useful for qualitative comparisons of nonpoint pollution events (Young et al. 1987).

Four other input layers – slope shape, point source indicator, gully source level, and impoundment factor – were also set to uniform values across the watershed. Slope shape was set to represent uniformly shaped (non-convex or concave) cells across the watershed. Point source indicator, gully source level, and impoundment factor inputs were all set to zero, omitting them from the analyses. This procedure has been used in other applications of the AGNPS model where such data were not readily available (Young et al. 1987, Gordon and Simpson 1990).

GIS and its spatial analyses capabilities have thus proven extremely valuable in creating the AGNPS input database. Fifteen of the twenty-two variables were easily extracted from the four data layers in the master database, and the remaining seven were created as needed to meet other model requirements. Once all of the twenty-two input map layers were completed, they were reorganized and converted into an AGNPS spreadsheet data input file using a file conversion program (Appendix L). Additional information, including storm precipitation and duration data, were added to the data file, and the AGNPS model was run. For most runs, a twenty-five year storm event (3.71 inches over 24 hours – NOAA 1990) was used.

Using GIS to modify the AGNPS database to test different landscape scenarios

Beyond the data integration and spatial analysis capabilities of GIS, this technology also enables the user to interactively update and modify maps. This feature adds great power to GIS-driven hydrologic modeling by allowing easy manipulation of data layers to reflect different landscape configurations. These modified layers can then be run through the model to compare their relative impacts on the terrestrial and aquatic systems.

Some of the more basic data manipulation techniques include recoding data in one of the master data layers to reflect basin-wide changes. For example, all cells coded as forest in the land-use master layer could be recoded as cropland cells to represent total conversion of forest land uses to agricultural uses. Using this modified land use layer, the 22 AGNPS input variables can be automatically recalculated using the GIS procedures described above to create an alternative landscape scenario that can then be put into the model to generate a new set of results.

The GIS is also capable of many more complex hypothetical landscape scenarios. For instance, the GIS can be directed only to change cells within a certain distance of a given feature. This technique is used later in this paper to simulate growth of certain land use types: cells identified as being within a certain distance of urban-labeled cells, for example, are overwritten as urban cells to reflect urban sprawl of that distance. This technique can also be used to simulate different types and widths of riparian buffers by specifying that only cells within a certain distance of stream corridors be altered.

The number of different landscape scenarios that can be modeled is up to the creativity of the user. Input data can be manipulated on a cell-by-cell basis or through any number of combined spatial operations such as buffering, overlaying, and proximity analyses. The ease with which these modifications can be done and re-run through the model truly makes for a much more powerful and comprehensive analytical tool.

In sum, then, the benefits of incorporating GIS with the AGNPS model are indeed profound. First, the ability of GIS to incorporate data from multiple existing sources such as MIRIS and the USGS spatial data archive greatly reduces the time and effort required to assemble the massive database needed to run AGNPS. Second, the range of spatial analyses of which GIS is capable enables these data to be quickly and accurately recoded and reorganized into the specific formats required by the model. And lastly, because GIS stores its information digitally, input data can be easily modified to represent a wide number of possible scenarios. The following section should show how these benefits combine to produce an extremely useful and powerful tool for ecological research.

Using the Model: A Case Study

To demonstrate the utility of GIS-driven hydrologic modeling as a robust and efficient tool for studying landscape-stream interactions, the model was used in a case study examining how runoff, sediment and nutrients respond to changes in land use within the Saline River basin. While the model is capable of many more applications, this case study illustrates the ease and flexibility with which the model can be adapted to explore a specific research question. It also provides a sampling of the model's wide range of analytical capabilities and offers an opportunity to identify where improvements in such modeling techniques might be made.

Evaluating the Impacts of Land Use Change in the Saline River Basin

Like many regions of the midwestern United States, the landscape of the Saline River basin is constantly changing, whether from the sprawl of nearby cities, the cultivation of more cropland, or the slow encroachment of forests back onto fallow land. Understanding how these changes affect underlying physical processes such as storm runoff, soil erosion and nutrient transport is essential if we are to manage our natural resources effectively. This study demonstrates how GIS-driven hydrologic modeling can be an important and useful tool in helping us gain such an understanding.

In this study, model output from a set of hypothetical land use scenarios was used to evaluate the effects of different changes in the landscape on the generation and transport of runoff, sediments and nutrients in the Saline River basin. While changes in the landscape can take many shapes and forms, this study focuses on the impacts of expanding urban, agricultural, and forested lands -- the three dominant land use types in the Saline River basin. Under the assumption that such expansion likely could occur around the perimeter of existing land use types (i.e., urban land is likely to increase via the expansion of existing urban areas), 100 m buffers up to 500 m were created around existing urban, agricultural, and forested cell clusters in the original land use cover and recoded into each respective type (Figure 5). The process was easily accomplished using a set of basic GIS operations described in Appendix C.

The rates of increase in urban, agricultural and forested cover under the respective land use expansion scenarios are shown in Figure 6. The differences among these curves arise from the relative proportions of land use types in the original land use layer. Agricultural lands, which comprise two-thirds of the Saline River basin area, have a larger total perimeter than

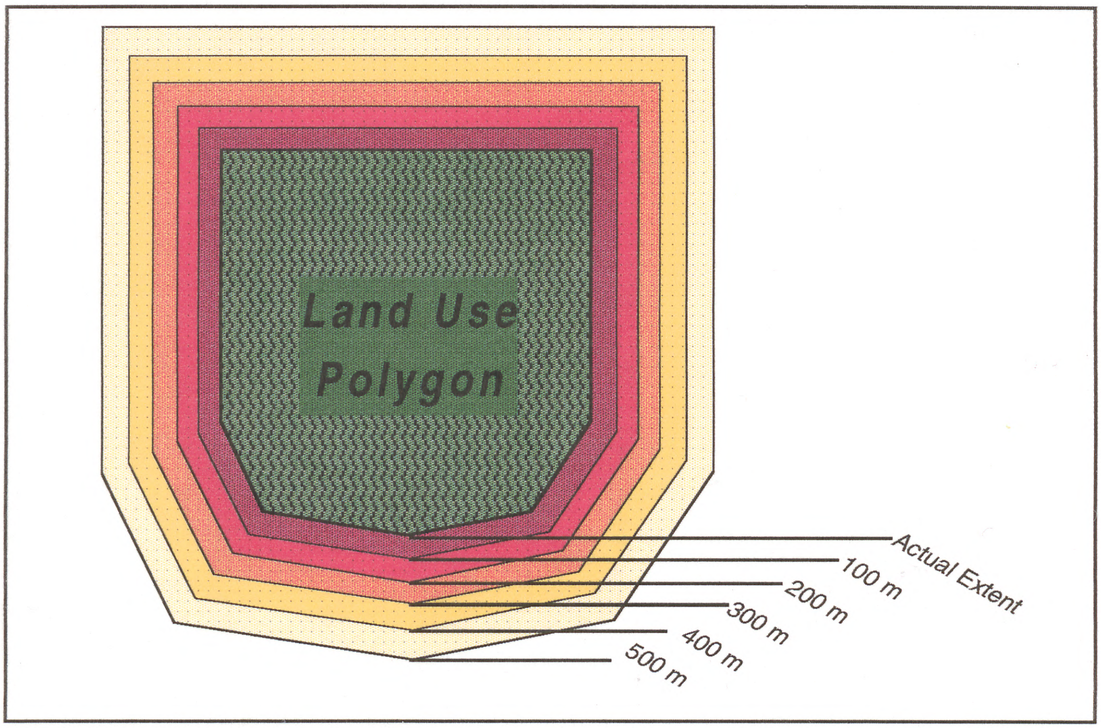

Figure 5. Diagram of buffering method used to simulate land use expansion. Each land use polygon of a specific type was expanded outwardly in hundred meter increments to a maximum distance of 500 m.

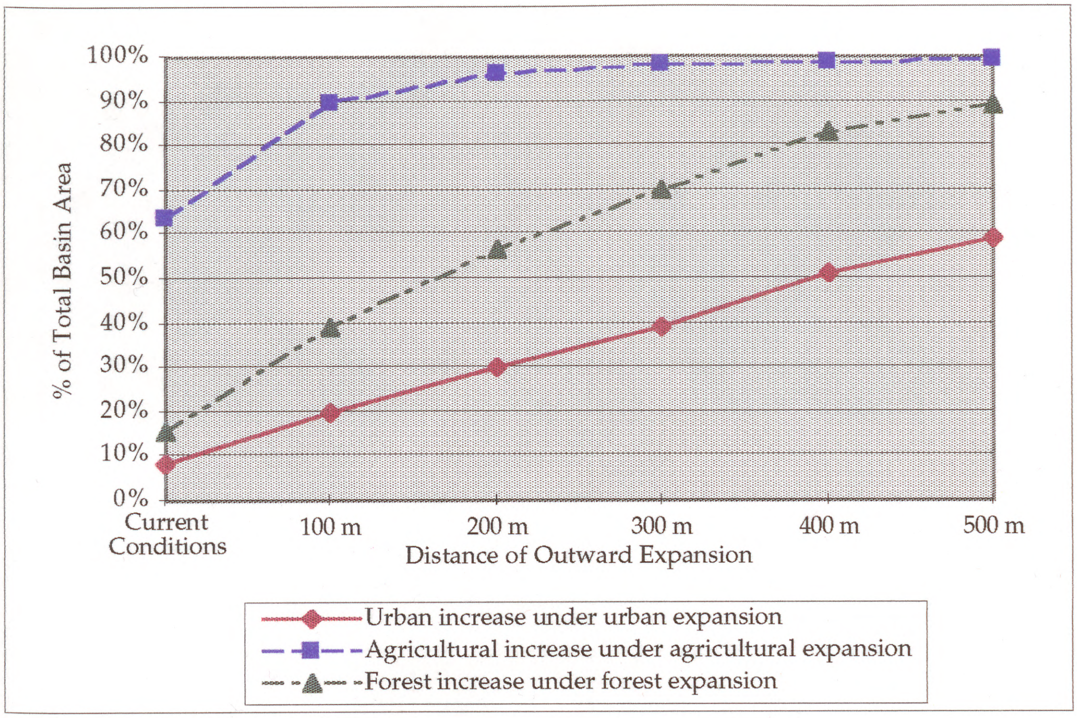

Figure 6. Rates of change in basin land use under the different land use scenarios. Each scenario was modeled by expanding all urban, agricultural and forested polygons in 100 m increments up to 500 m. Note that in the case of agricultural land, such expansion quickly results in the entire catchment becoming agricultural.

does either urban or forest land and thus engulfs more land per buffer distance than does the other types (Figure 7). However, with two-thirds of the watershed area originally agricultural, only the remaining third can be converted from other land uses. Thus, after its initial rapid rate of change, agricultural expansion slows as it nears the point where the entire basin has been recoded into agricultural usages, which occurs at the 500 m buffer distance. Urban and forest cover, in contrast, have much more room to expand and thus can continue to expand at much more gradual and consistent rates.

The nonpoint source impacts associated with these land use changes, as predicted by the model, were used to construct a more complete and detailed account of the influence of landscape structure on environmental processes.

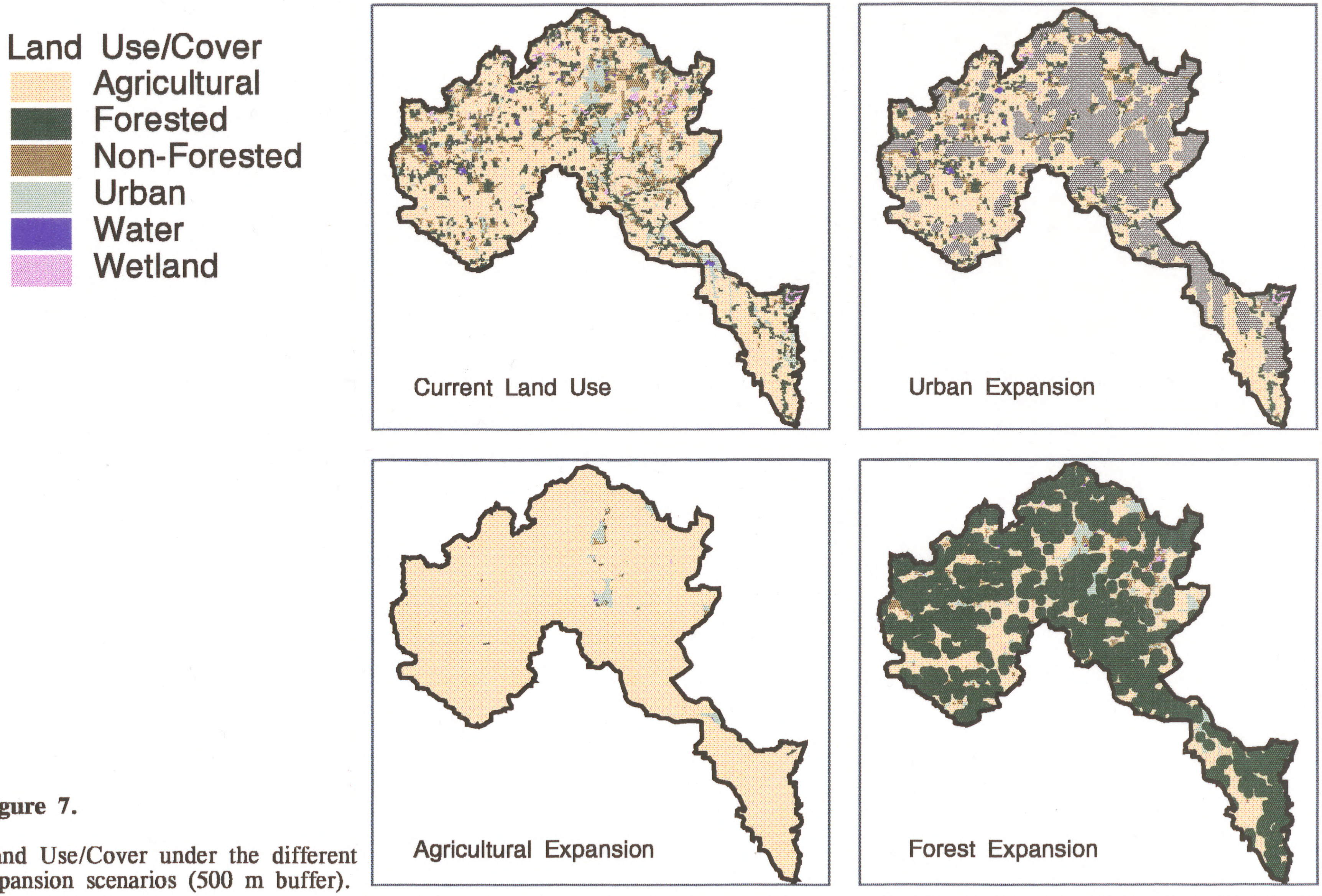

Figure 7.

Land Use/Cover under the different expansion scenarios (500 m buffer).

Predicted levels of runoff, sediment and nutrients measured at the watershed outlet cell were used to evaluate the basin-wide cumulative impacts of the different land use changes, while thematic maps of the watershed and model output from selected upstream locations were used to examine spatial differences in the responses to the alternative landscape changes. These findings were then merged to formulate a better understanding of the degree to which modified landscapes can alter runoff, sediment, and nutrient fluxes, and also to identify specific locations within the basin that appear particularly sensitive to certain landscape changes. In addition, these findings were compared to observations of other watersheds and to our current understanding of these processes to confirm the viability of the predictions made by the model developed here and to identify possible shortcomings of the model structure.

Basin-wide impacts

Examination of changes in runoff and transport of sediment and nutrients at the watershed outlet suggest that the three land use changes studied can have widely different cumulative impacts on the generation and movement of materials within the Saline River basin. Charts of model output (runoff volume, peak flow rate, sediment concentration, sediment yield, nutrient concentration and nutrient yield) plotted against the total area of land recoded under the different land use scenarios reveal differences in the relative rates at which the respective land use changes either increase or decrease the given variable (Figure 8).

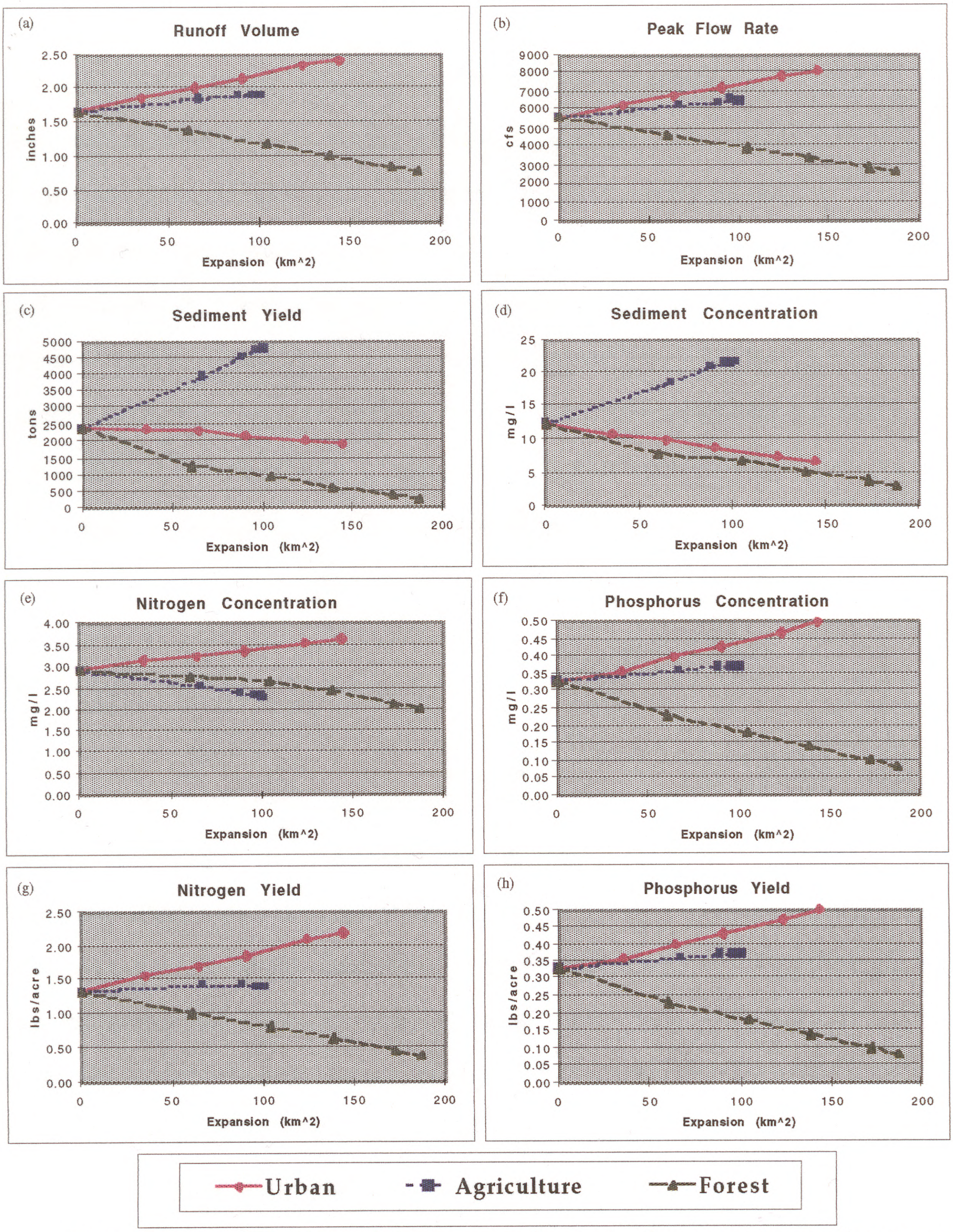

Figure 8. Predicted relationships between land use change and nonpoint source pollution levels at the Saline River basin outlet. Existing parcels of urban, agricultural and forested lands were expanded outwardly to simulate the expansion of individual land use types. Changes in runoff, sediments and nutrients as predicted by model runs of these scenarios plotted against the area of land converted into the respective land use type indicate the rate of change corresponding to urban, agricultural and forest expansion.

Hydrologic Response

Runoff volume, a measure of the amount of precipitation not intercepted, infiltrated, or otherwise prevented from moving downslope across the ground surface, and peak flow, an indication of the velocity at which this runoff moves, are markedly affected by land use change. Runoff and peak flows increase steadily as urban land cover is expanded from 9% of the catchment area to 59%. Expansion of agricultural land resulted in a smaller rate of increase in these variables, and increasing forest cover markedly decreased runoff and peak flow rate (Figure 8a-b).

Model prediction of gradual increases in runoff volume and peak flow rates with increased urban cover are expected. The preponderance of impermeable surfaces such as paved roads and rooftops in urban areas dramatically reduces infiltration rates and thus converts more rainfall into runoff, resulting in high runoff volumes and increased flow rates (Anderson 1968, Hammer 1972). Urban land also contributes to high runoff volumes and flow rates through the implementation of sewers and other drainage systems (Leopold 1972). AGNPS, however, was designed for predominantly agricultural watersheds and does not incorporate factors other than surface characteristics into its equations (Young et al. 1987). Thus, these results probably underestimate the hydrologic impacts of urban expansion.

Model predictions of decreased runoff volume and flow rate as forest cover is increased also concur with existing knowledge of hydrologic processes. Undisturbed forested lands generally have high infiltration capacities and may thus generate less runoff by absorbing more rainfall into the soil (Kostadinov and Mitrovic 1994, Gray 1973). Forest cover also reduces peak flows by increasing interception and by lowering the antecedent moisture condition in the soil through increased evapo-transpiration rates

(Anderson et al. 1976, Hornbeck et al. 1986). Protruding roots and other vegetative structures on forest floors can also pool rainfall and slow its lateral movement, further reducing runoff volume and peak flows (Cheng 1975).

The less pronounced but still notable increases in runoff volume and peak flow rate due to agricultural expansion can also be understood in terms of ground surface characteristics. The high degree of exposed soil in most agricultural land reduces the infiltration capacity of the soil, again resulting in larger amounts of surface runoff (Burwell 1969). Agricultural areas, especially those supporting row crops, generally also have smoother surfaces than more densely vegetated covers and therefore generate higher peak flows (USDA 1972). The implementation of subsurface drainage systems (drainage tiles) may also contribute to accelerated fluxes of water to streams (Burkart et al. 1994). However, the effect of drainage tiles are not expressly incorporated in the AGNPS model and thus these results could underestimate the hydrologic impacts associated with agricultural expansion.

Sediment Response

Changes in sediment concentrations and sediment yields predicted by the model suggest that agricultural expansion has the largest impact of the three land-use scenarios, dramatically increasing both variables (Figure 8c-d). Forest and urban expansion, in contrast, decrease sediment yield and concentration at the outlet cell. Forest expansion lowers concentration slightly more and yield much more than does urban expansion, and decreases yield to a greater degree.

Model predictions of increases in sediment concentration and yield associated with agricultural expansion conform to a number of other studies monitoring the impacts of agriculture on stream water quality (Costa 1975, Lenat et al. 1979, Clark 1987). Row crop cultivation, in particular, is known to be strongly associated with high instream sediment levels (Robinson 1971). Such high sediment concentrations and yields generally are attributed to the relatively high degree of direct exposure of soil surfaces to the impact of rain drops and to the scouring of surface flow, both of which act to dislodge sediment particles that eventually reach stream channels (Brooks et al. 1991). The increased runoff and flow rates noted above can also accelerate both the erosion process and the delivery rate of these materials to stream courses (Lenat and Crawford 1994).

The model's predictions that increased forest cover should lower sediment concentrations and yields also are supported by studies conducted on other catchments (Patric et al. 1984, Likens et al. 1978). The differences are believed to be attributable to surface vegetation and root structure, both of which inhibit surface and channel erosion, the source of high sediment concentration and yields (Hornbeck et al. 1986). Decreased runoff volume and peak flow in forested areas may also decrease channel erosion and sediment delivery by reducing the scouring energy of the flow as well as allow some suspended particles to settle out of the water column.

Reductions in sediment concentration and yield with increased urban cover has also been reported in other catchments. In a Piedmont region stream undergoing landscape changes from forest to agriculture to urban, Wolman (1967) observed urbanization to cause a sharp initial increase in sediment yields, then a reduction nearly back to levels observed under forested conditions. The initial spike is believed to result from a construction phase, where much of the ground surface is exposed and dislodged by heavy construction machinery. The subsequent stabilization of sediment sources by pavement or similar structures then begins to inhibit the dislodgment of sediment, lowering sediment concentrations in rivers and streams. The AGNPS model does not account for construction activities, and thus should not show any spike in sediment output corresponding to urban growth. The decline in sediment levels shown by the model then likely reflects the stabilization phase of urbanization which is represented as the cropping management (C-factor) value (Appendix E).

Lenat and Crawford (1994), however, found yearly suspended sediment levels to be consistently higher in urban-dominated catchments under high flow conditions than in either agricultural or forested watersheds. These findings may suggest that the AGNPS model either is failing to consider important factors relating to urban surface characteristics, or that the spatial arrangement of urban, forest, agricultural and other land use types in the landscape can have significant impacts on the generation and transport of sediments. Direct comparison of model output and water quality data collected from the same stream system should provide more insight into these discrepancies.

Nutrient Response

Model predictions of the effect of landscape change on nitrogen and phosphorus concentration are highly dependent on how the land is altered. Increasing urban cover appears to significantly increase both the concentration and total yield of each nutrient, while forest expansion causes nearly equally dramatic decreases (Figure 8e-f, g-h). Increasing the extent of agricultural land slightly lowers nitrogen and slightly increases phosphorus concentrations in runoff, but has little effect on total yield of both nutrients.

Model predictions of an increase in nutrient levels with increased urban cover agree with several studies on urban nonpoint source pollution

(USEPA 1990). However, the AGNPS model does not expressly incorporate specific urban non-point sources into its calculations; instead, predicted nutrient levels primarily reflect contributions from rainfall, a background fertilization rate and interactions (adsorption and leaching) with soils (Young et al. 1987). The model-generated increase in nitrogen and phosphorous concentrations in runoff associated with increased urban cover thus most likely is due to the low infiltration rates of urban surfaces which prevent leaching of nitrogen and phosphorus into the soil (Brooks et al. 1991, see Figure 9 for a diagrammatic explanation of this model behavior). Also, the influence of higher concentrations coupled with higher runoff volumes should increase the total yield of both nutrients as urban cover increases. The addition of urban nonpoint pollution processes not currently included in the AGNPS model, such as combined sewer overflows and concentrated storm runoff, would likely cause an even greater response.

Declines in nutrient concentrations with increased forest cover have also been observed in a number of studies. When streams draining urban, agricultural and forested lands were compared, forested areas in the eastern United States were found to have the lowest mean total nitrogen and total phosphorus concentrations (Omernik 1976). Low nutrient concentrations are attributed to higher rates of nutrient uptake to support vegetation growth combined with decreased nitrification rates resulting from cooler soils shaded by the canopy (Likens et al. 1978, Martin et al. 1984).

Perhaps the most surprising prediction made in these modeled scenarios is the decrease in nutrient concentration and near constancy of yields associated with increased agricultural cover. Although the predicted decreases in nitrogen and phosphorus concentration are only slight, most studies report agricultural lands to contribute to high nitrogen and

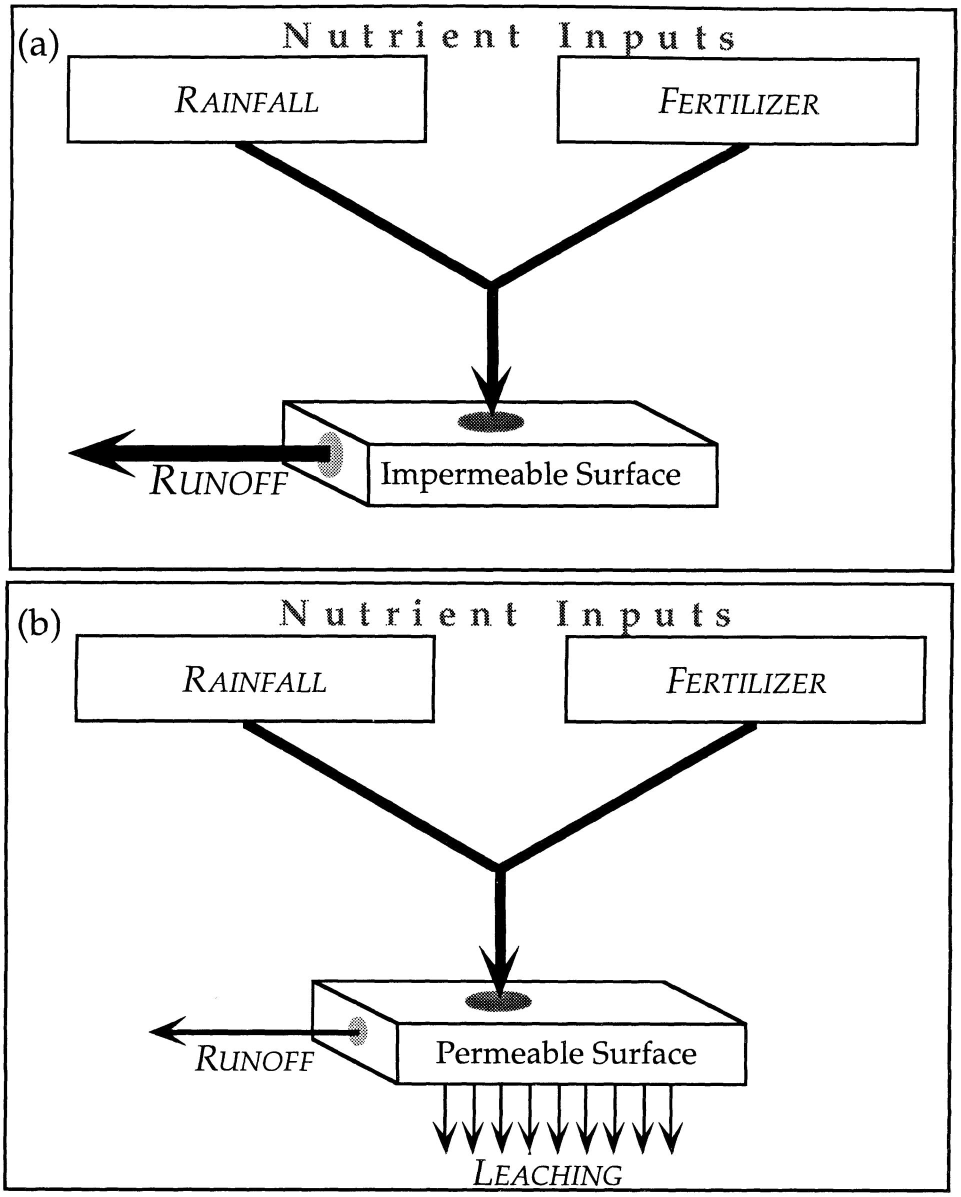

Figure 9. Diagram of nutrient outflow as modeled under impermeable (urban) and permeable (agriculture and forest) conditions. Impermeable surfaces (**a**) prevent leaching of nutrients downward into the soil surface, thus contributing to higher concentrations in surface runoff. Permeable surfaces (**b**) allow leaching of nutrients into the soil which reduces nitrogen and phosphorus concentrations in runoff.

phosphorus levels in runoff and receiving streams (Omernik 1976, Burkart et al. 1994, Lenat and Crawford 1994). This discrepancy is likely due to the omission of fertilizer as a variable input in these model runs. AGNPS permits input of fertilizer application and incorporation rates, but these were set to uniform levels regardless of land use because of the difficulty in acquiring specific data for localized land practices. Inclusion of land-use specific fertilizer data would almost certainly boost nutrient levels associated with agricultural and possibly urban land use.

Still, these predictions which suggest agricultural expansion will reduce nitrogen concentrations even more than does expansion of forest cover (Figure 8e), initially appear contrary to the model mechanics. AGNPS computes nutrient concentrations based on the interactions of rainfall and fertilizer inputs with characteristics of the land surface (flow rate and soil porosity; Young et al. 1987). With forested surfaces generally being more rough and porous than agricultural surfaces (Nelischer 1987), nutrients in runoff would be more likely to be lost to leaching and adsorption (Brooks et al. 1991), which is contrary to the predictions of the model. A possible explanation for this apparent contradiction may be that agricultural expansion displaces more urban land than does forest expansion, which would result in a slightly larger decrease in nutrient concentrations.

Clearly, further examination of the model mechanics and these results are necessary to reveal the cause of the apparent inconsistency between model nutrient predictions and empirical observations. First, data on fertilization application and incorporation rates should better reflect actual land use practices, thus enabling the model to more accurately compute the accumulation and movement of nutrients across different land types. Even without detailed information on the fertilization practices of individual farmers, additional scenarios where fertilization levels are increased in agricultural lands but not in urban and forested lands could provide useful insight into nutrient-runoff dynamics. Alternatively, fertilizer application could be omitted entirely from the model to explore the impact of land use alone. Furthermore, analyses of model output should also include information on which types of land are being replaced in the different land use scenarios, as disproportionate replacement of given land types may significantly alter findings. Finally, the model itself may be improved with better accounting for specific types of urban nonpoint sources.

In summary, the AGNPS model coupled to different scenarios of changing land use predicts widely different outcomes in terms of hydrologic, sediment and nutrient responses. Generally these outcomes conform well to empirical studies of watersheds actually undergoing such changes, although some nutrient predictions should be further investigated. The model scenarios probably underestimate nutrient responses to increased agriculture because fertilizer inputs were not included. This shortcoming can be rectified by obtaining further information on the practices of local farmers, using survey or interview methodologies. However, the AGNPS model does not allow inclusion of some factors that are considered important based on empirical studies. Specifically, artificial drainage systems in urban (sewers) and agricultural (drainage tiles) lands may increase runoff and peak flows more than is represented in these scenarios. In addition, construction, combined sewer overflows, and urban nonpoint source pollution dynamics may cause model predictions to underestimate effects caused by urban land use changes.

Spatial Variation in Response to Land Use Change

The next stage of this case study used the model to investigate spatial variation in the response variables to the various land use changes. Spatial variation was examined in two ways. First, thematic grid maps were constructed using shading to display levels of runoff, sediment and nutrients to investigate spatial patterns. Second, model outputs at specific upstream locations were compared to identify any noticeable differences among selected sub-watersheds within the Saline River basin.

Thematic Grid Maps

Grid maps of the predicted levels of each variable at the 500 m expansion increment provide easy visualization of the impacts of the different land use changes across the basin. Under current conditions, levels of runoff appear slightly lower in the upper (northern and western) regions of the watershed (Figure 10). Urban expansion intensifies this pattern and also dramatically increases runoff across the entire basin, except perhaps for some regions in the extreme upper portions of the basin. Agricultural expansion also increases runoff volume, but less intensively and more consistently across the watershed, perhaps because much less land is actually converted in the agricultural scenario (Figure 6). Forest expansion reduces runoff and has a more noticeable effect in the upper reaches of the catchment.

Grid maps of soil loss under the different scenarios suggest that the southern and extreme western reaches of the upper watershed are the most susceptible to erosion under severe storm events (Figure 11). The expansion of urban cover appears to stabilize much of the eastern side of the basin as well as small portions of the upper western regions, while agriculture, in sharp contrast, dramatically increases soil loss throughout the entire basin. The expansion of forest cover markedly reduces soil loss across the entire watershed.

Grid maps of nitrogen and phosphorus concentrations also show high values under current conditions to be clustered in the northeastern edge of

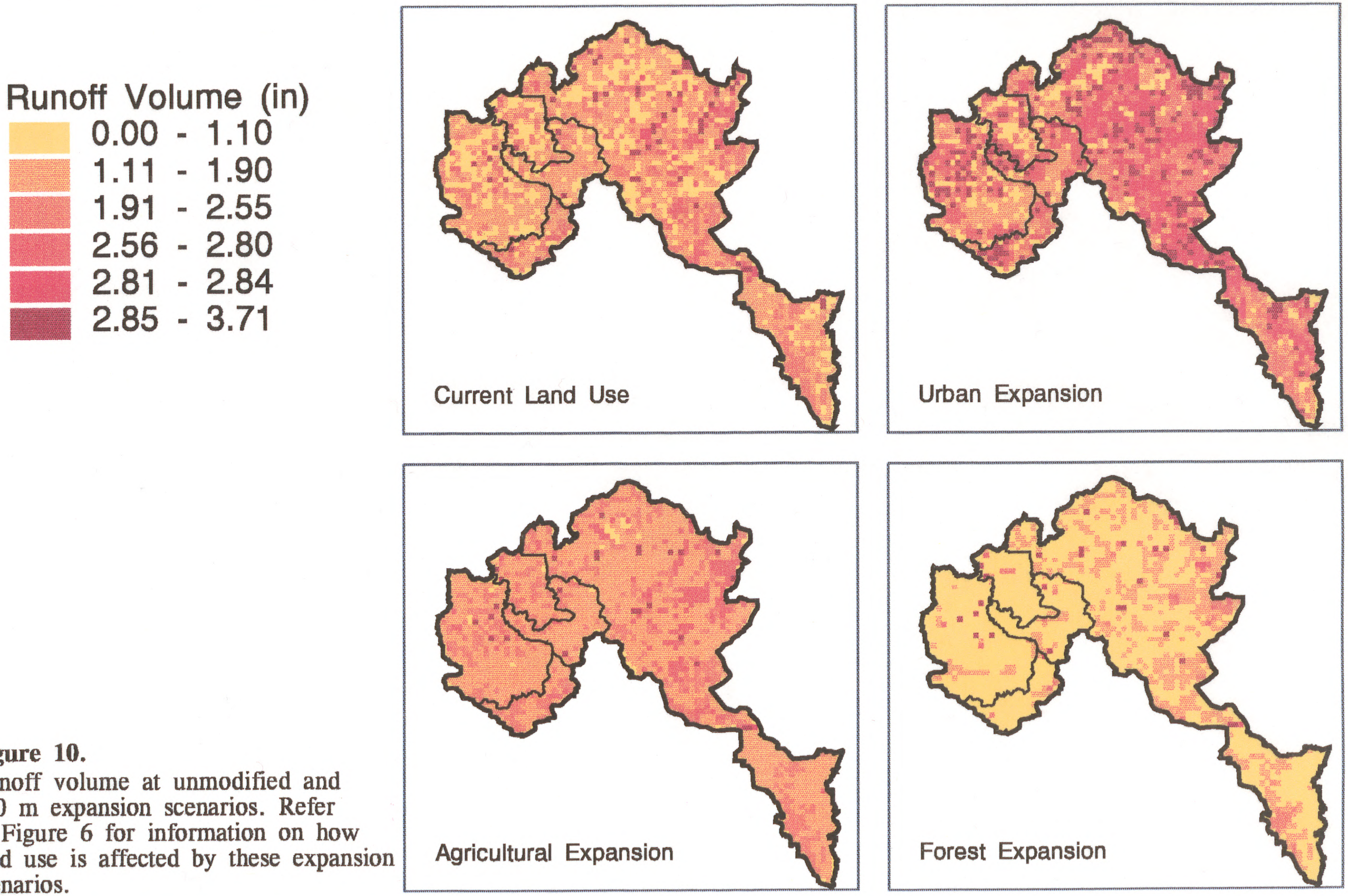

Figure 10.
Runoff volume at unmodified and 500 m expansion scenarios. Refer to Figure 6 for information on how land use is affected by these expansion scenarios.

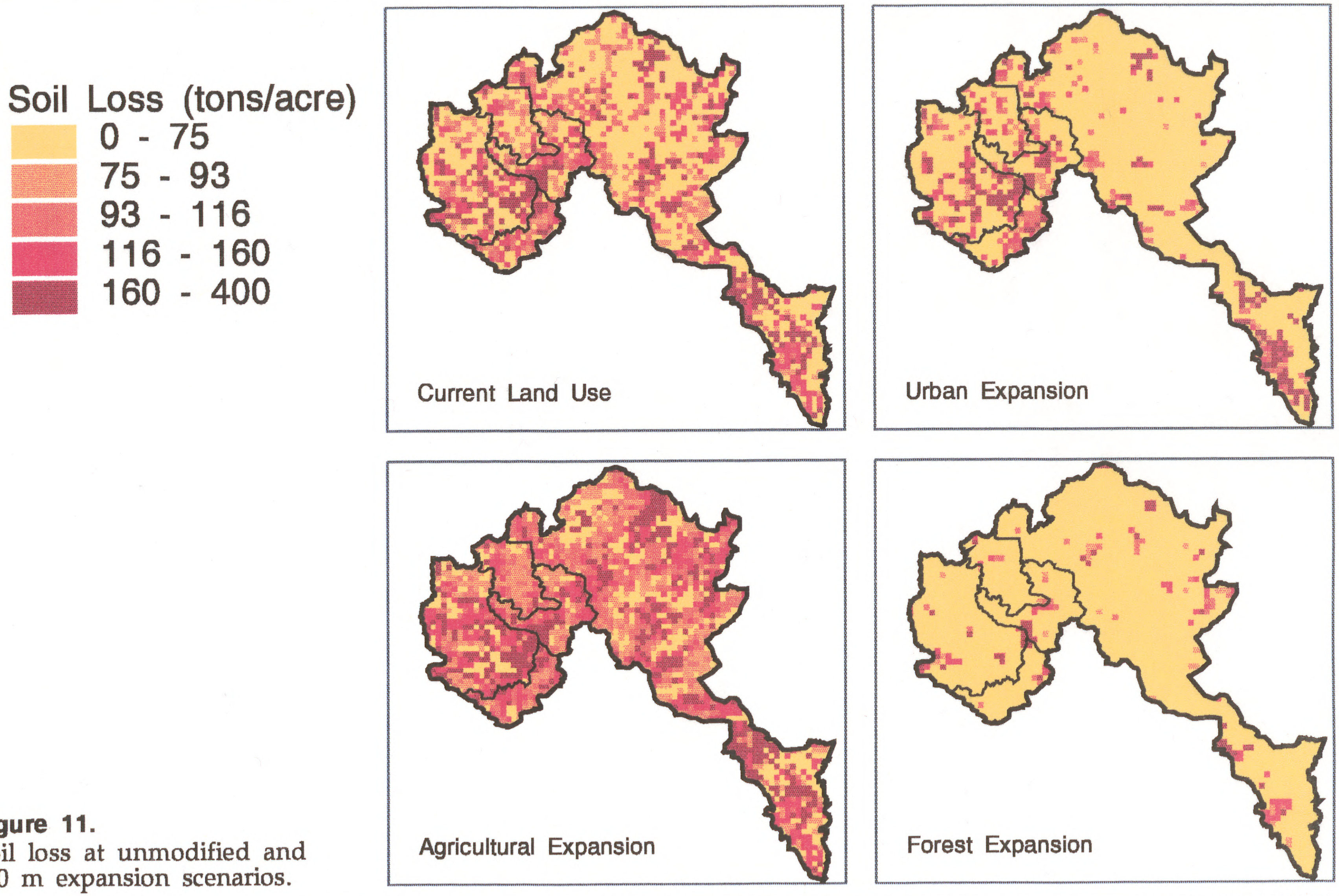

Figure 11.
Soil loss at unmodified and 500 m expansion scenarios.

the catchment. Urban expansion intensifies this effect and generally increases levels across most of the watershed (Figures 12 & 13). Agricultural expansion results in slight decreases in nutrient concentrations that are fairly evenly distributed throughout the watershed. Forest expansion results in dramatic decreases in concentrations across much of the watershed, although some noticeably high concentrations still remain in parts of the eastern and southeastern portions of the watershed.

In general, most of these patterns of change are consistent with the changes in land use occurring under the different scenarios (Figure 7). The concentration of urban cover in northeastern and central regions of the watershed under current conditions and the intensification of this pattern when urban land is expanded corresponds well to locations of high levels of runoff and nutrient concentrations. Agricultural and forested land cover are much more evenly distributed across the watershed, and thus the expansion of these land types affect runoff, sediment and nutrient levels in a much more consistent fashion. Thus, the patterns of change appear strongly to reflect the current mosaic of land use types of the watershed and also indicate where management efforts to control the different forms of nonpoint pollution might best be directed.

Sub-Watershed Comparisons

Comparisons of the impacts of land use change among selected sub-basins within the Saline River (Figure 14) provide more detailed evidence of spatial variation in model response to changes in land use. The average predicted percent increase or decrease in each nonpoint source variable against the percent of sub-basin area converted into urban, agricultural or forested land, respectively, is shown in Figure 15. A greater height

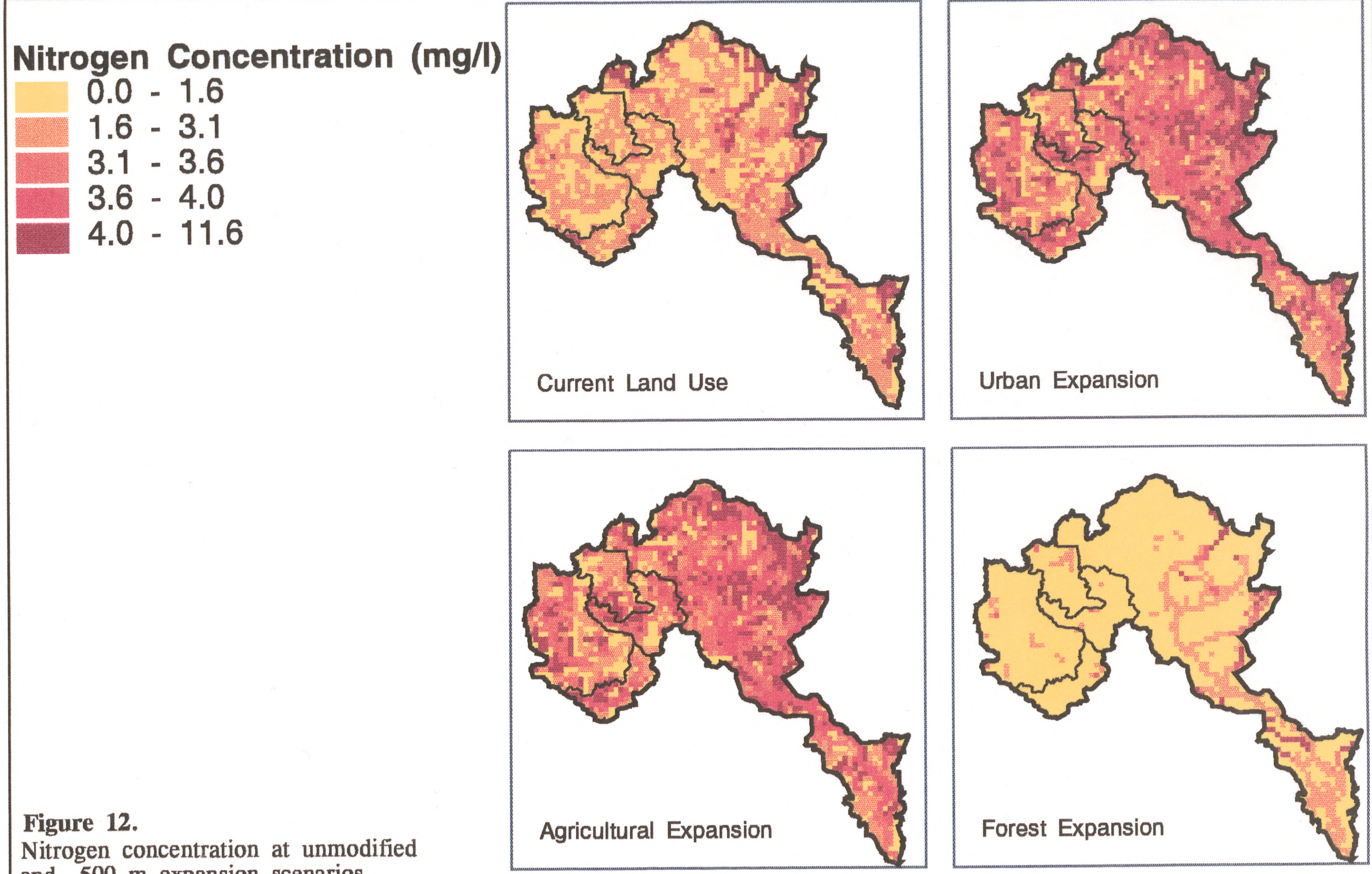

Figure 12.
Nitrogen concentration at unmodified and 500 m expansion scenarios.

Phosphorus Concentraton (mg/l)

- 🟨 0.0 - 2.0
- ▨ 2.0 - 6.0
- ▨ 6.0 - 7.0
- 🟥 7.0 - 8.0
- ▨ 8.0 - 46.0

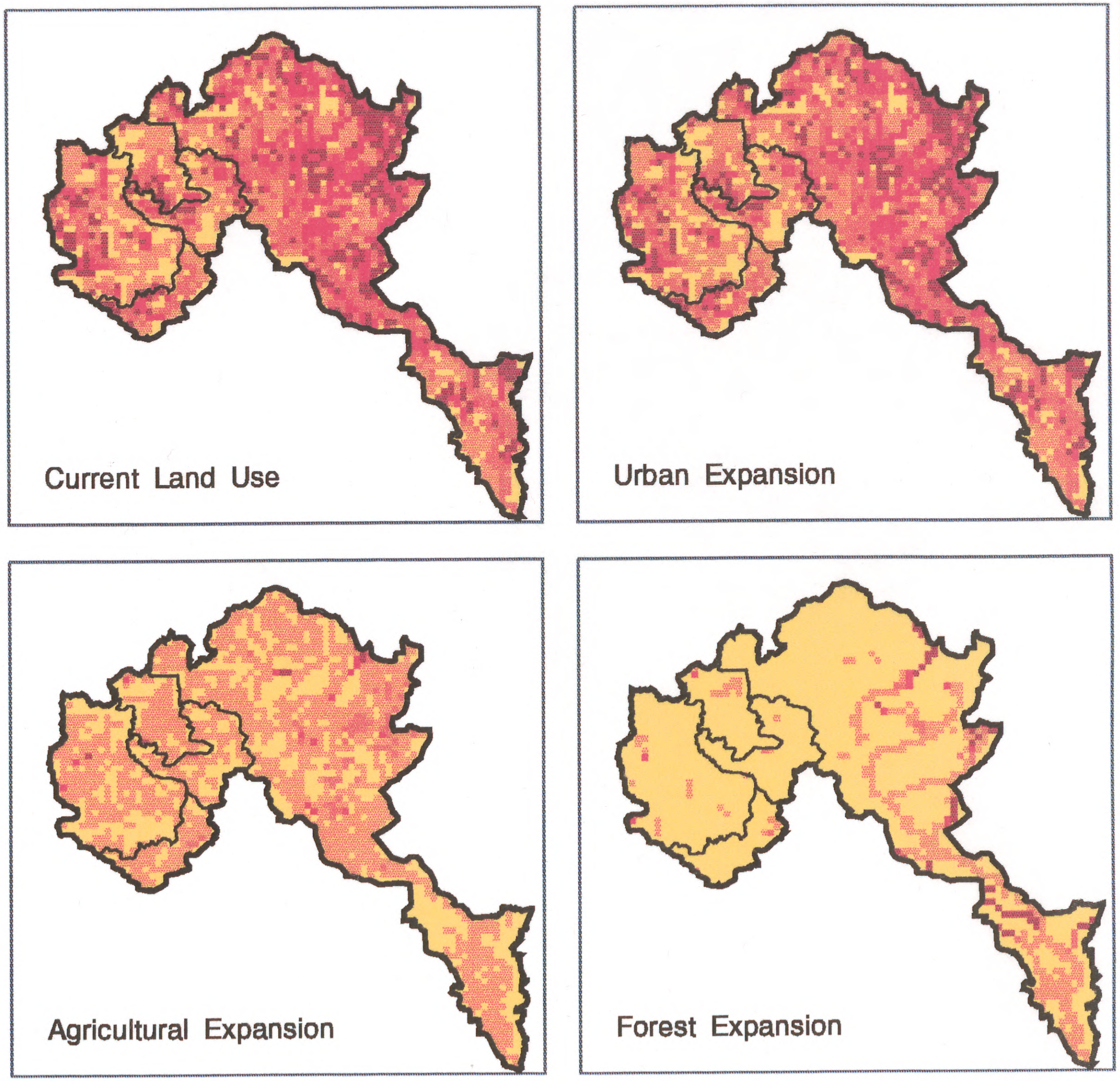

Figure 13.
Phosphorus concentration at unmodified and 500 m expansion scenarios.

Figure 14.

Sub-basins of the Saline River modeled to examine spatial variation in delivery and routing of NPS pollution.

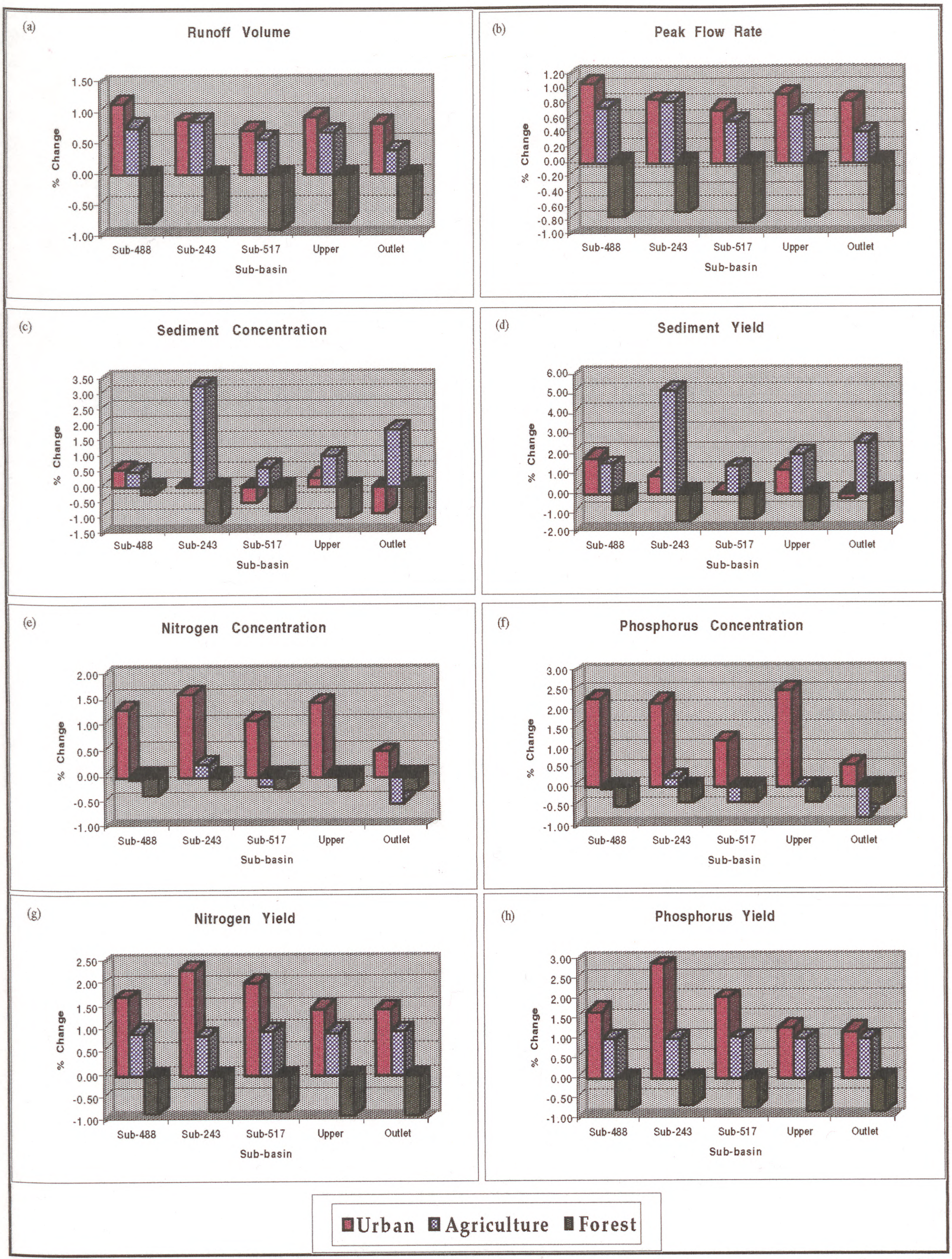

Figure 14. Average rates of change in runoff, sediment and nutrient generated within different sub-basins of the Saline River basin. Bar values reflect the average percent increase or decrease of pollution levels from current levels per fraction of sub-basin area converted into urban, agriculture or forest under the different land-use scenarios.

indicates a greater response per equal proportion sub-basin area modified under the given scenario.

Runoff volume and peak flow rates appear to respond fairly consistently across the different sub-basins. The slight variation in response likely reflects the unequal displacement of land use types by the expanding land use. For example, because the difference in runoff volume and peak flow rates generated under urban and forest cover types is much larger than the difference between urban and agricultural types (see previous section), urban expansion that displaces forest land will have a much larger impact than expansion that displaces agricultural land. This would explain why urban expansion in sub-basin 488, which has the highest initial percentage of forest land (Figure 15a-b), appears to be the most sensitive to urban expansion. Similarly, the relatively small response to agricultural expansion seen at the watershed outlet likely reflects the high proportion of urban land downstream of the Upper Saline station: because the new agricultural land is overtaking more urban land than forest in the lower watershed, agricultural expansion in this part of the basin will appear to have a lesser impact on runoff volume and peak flow rates.

The impacts of land use change on sediment concentrations and yields show a much higher degree of spatial variability among the sub-basins (Figure 14c-d). Particularly striking is the extreme sensitivity of sediment concentrations and yields to agricultural expansion in sub-basin 243. While disproportionate land use displacement may explain the elevated sensitivities of the upper Saline and the watershed outlet (converting urban land into agriculture will have the largest impact), it is an unlikely explanation for the extreme case of sub-basin 243. Instead, the relatively erosive soils (Figure 16) and steep slopes (Figure 17) of sub-basin 243 may cause its heightened

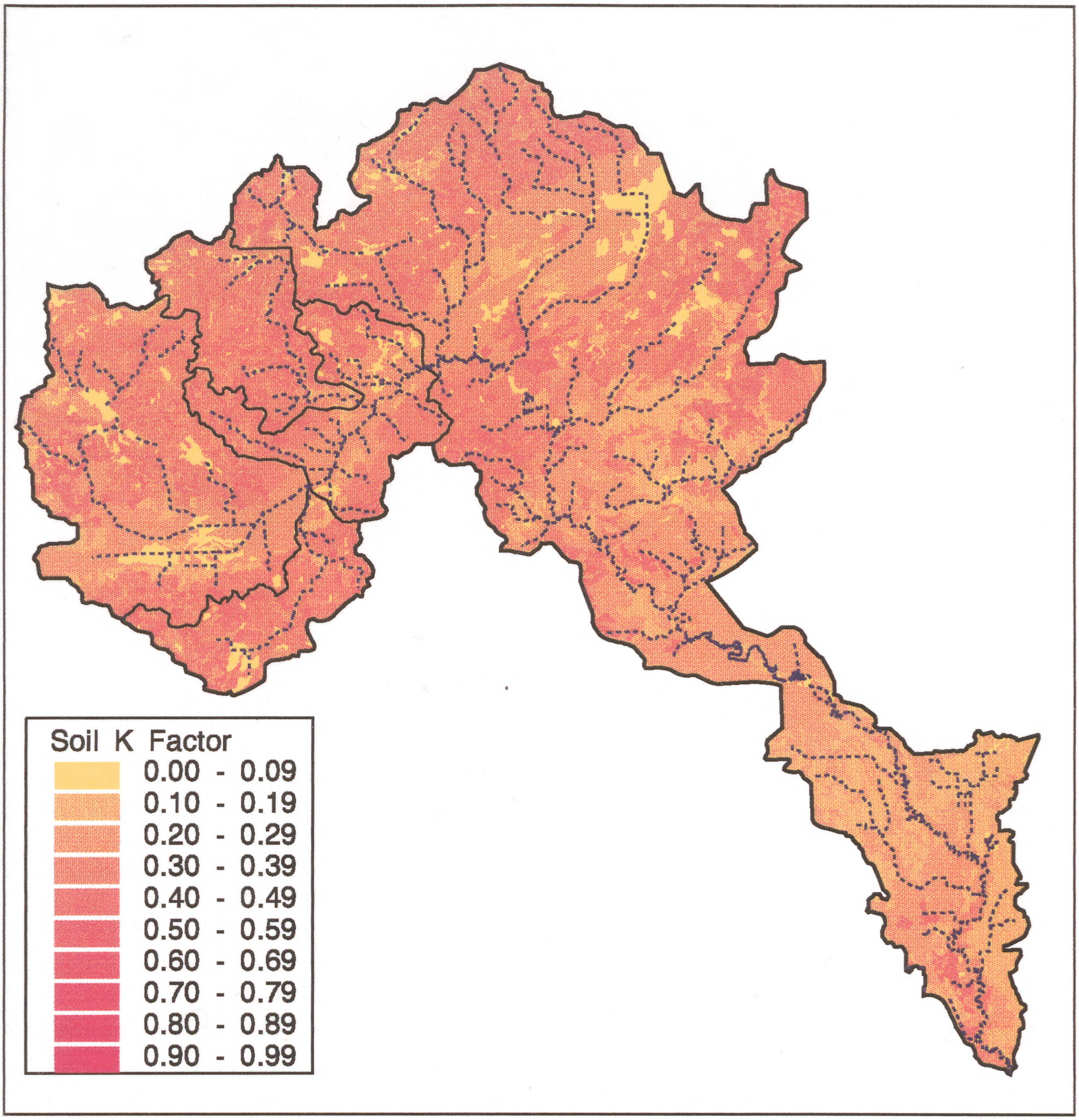

Figure 16.

Soil Erosivity ("K") Factor (NRCS Soils Surveys).

Figure 17.

Digital elevation relief map of the Saline Basin (Derived from 1:100,000 USGS Digital Line Graph data).

sensitivity to the erosive impacts of agricultural land. Further research is needed to confirm this explanation.

Nitrogen and phosphorus concentrations also show some distinctly different responses to land use change among the different sub-basins (Figure 15e-f). In particular, urban expansion appears to have much a larger impact on concentrations in the upper sub-basins than it does at the watershed outlet. One explanation for this pattern may be the relatively small proportion of forest cover displaced by urban expansion in the lower reaches of the basin. Also surprising are the increases in nutrient concentration from agricultural expansion in sub-basin 243. Like sediment concentration and yield, this peculiarity may result from combinations of steeper slopes and highly erodible soils particular to this catchment. Further research into other potential characteristics would be necessary to determine the exact cause for these observations.

Rates of change in nitrogen and phosphorus yields appear remarkably consistent under agricultural and forest cover expansion scenarios. Responses to urban expansion show minor variation among the sub-basins with basins 243 and 517 appearing slightly more sensitive to urban expansion than the other sub-basins (Figure 15 g-h). Again, further analyses into the specific characteristics of these sub-basins should reveal the specific reasons behind the observed variation and, in the case of agricultural and forest expansion, lack of variation.

In summary, these sub-basin analyses document spatial variation in expected responses to storm events, and also that different variables exhibit different degrees of spatial variation. Variation in the two hydrologic variables, runoff volume and peak flow rate, possibly are driven by the disproportionate displacement of certain land types during the expansion of another land cover type. Variation in sediment concentration and sediment yields appears to be driven by other properties of the landscape, possibly soil and topographic characteristics. Finally, variation in nutrient concentrations and nutrient yields also may be driven by interacting landscape factors. In short, these analyses prove useful in revealing specific spatial differences among selected regions within the larger Saline basin, but further research is required to explore the actual landscape interactions that drive these different sensitivities to changing land use. Without further analysis, it also is difficult to rule out model error as a factor behind the observed differences. However, the consistency between results predicted at the basin outlet and empirical observations of actual catchments undergoing land use changes as described in the previous section suggest that the model results are qualitatively accurate.

Summary/Conclusions

The responses of hydrology, sediments and nutrients to the several scenarios of land use change included in the case studies together provide insight into the various interactions involving the landscape and the generation and transport of nonpoint pollutants. Predictions made at the watershed outlet indicate that urban sprawl may be the largest threat to hydrologic and nutrient stability in the watershed, while posing little threat to sediment pollution. The cultivation of more cropland in the Saline may dramatically increase the amount of sediment entering the stream, while having relatively minor impacts on the other variables. Forest expansion, as expected, reduces the amounts of each pollutant entering the stream course.

Thematic maps of sediment and nutrient responses to a storm reveal which regions of the watershed are most likely to be affected by changes in land use. The northeast portion of the basin generally appears most susceptible to urban and agricultural changes while the northwest portion appears most responsive to forested changes.

Strong spatial differences were observed in model response to different land-use changes, and through comparison of selected sub-watersheds in the Saline River basin. Specific characteristics of sub-watersheds can result in greater responsiveness of some variables, such as sediment yield to agricultural expansion, while other variables exhibit little spatial variation in their response to the respective landscape change.

In short, these analyses, although confined only to evaluating the impacts of urban, agricultural, and forested land cover expansion, provide us with a much more detailed and thorough understanding of the potential impacts of landscape change in the Saline River basin. Although many of the predictions made by the model, such as the increase in runoff volume and peak flow with urban expansion and the raised sediment yields with agricultural expansion, may seem somewhat intuitive given our existing understanding of runoff and erosion, this model also allows us to compare the relative magnitude of responses and to gauge effects on a spatial scale. Furthermore, by generating additional scenarios using GIS, one can further explore initial model predictions such as why agricultural expansion had opposite effects on some variables at different locations in the Saline basin. In all, the GIS-based modeling approach provides a simple but powerful tool capable of examining landscape interactions on scales that otherwise are virtually impossible to address.

Discussion

The integration of geographic information systems technology with the AGNPS hydrologic model has proven crucial to the development of an easy-to-build and easy-to-use analytical tool with a wide range of modeling capabilities. The power of GIS to incorporate data from multiple existing sources such as MIRIS and the USGS spatial data archive greatly reduces the time and effort required to assemble the massive databases often required to drive complex hydrologic models. Furthermore, the ability of GIS to manipulate and rearrange these spatial data not only allows the transformation of information into the exact specifications required by a given hydrologic model, but also allows for the controlled modification of specific variables in ways that can represent a multitude of hypothetical scenarios.

Prior to the development of GIS-driven hydrologic modeling, landscape influences on stream systems were primarily determined by rigorous water sampling programs followed by varying levels of statistical analyses on the data collected (Johengen 1991, Bright 1995). While these studies often provide quantitative data on existing conditions that is much more accurate than modeled data, they do not permit exploration of likely changes under alternative land use scenarios. Conversely, the development and application of the model presented in this research allows a broad range of terrestrial-aquatic analyses for widely different landscape scenarios, but does so with accuracy limited by the model's inputs and mechanics. Thus, the question arises: given the two approaches (intensive stream sampling versus GIS-driven watershed modeling), how should stream ecology and watershed management proceed?

Certainly, the answer is to continue pursuing both approaches, but we must pay more attention to how each approach might complement the other.

For example, although the output of a model such as the one presented here may be less than accurate in some instances, it can be quite useful in determining *where* to focus stream sampling sites and *what* should be sampled, making such sampling efforts much more efficient. On the other hand, a hydrologic model can always be improved with better validation of its principles, which are frequently derived empirically based on actual stream and landscape measurements. In fact, between the time this research was first initiated and its completion, the AGNPS model had been revised to include improved flow, sediment, and nutrient decay equations (Young et al. 1994). Thus, the two approaches working cooperatively should produce mutual benefits that eventually should provide scientists and managers with research tools that are overall both more accurate and capable of a much broader range of analytic scenarios.

Additionally, it is also worth mentioning that, while water sampling programs will certainly continue to contribute a great deal to the advance of GIS-driven watershed modeling, several other technological advances will almost certainly improve the modeling approach to studying landscape-stream interactions. These include advance in desktop computing power, remote sensing capabilities, global data sharing networks, and geographic information system software.

Desktop computers, which continue to increase in affordability, speed, and overall capability at astonishing rates, are quickly diminishing concerns over the ability of such machines to handle the enormous number of computations required by increasingly complex models.

The availability and accuracy of remotely sensed data are also improving at unprecedented rates. At present, satellite images are available for the entire globe at 10 meter resolutions and are obtained repeatedly approximately every 18 days. Before the end of the decade it is likely that images at the resolution of 1 meter will be publicly available (Corbley 1996). Such data will not only improve the accuracy of model inputs for hydrologic models, but also will relieve the limitation of data being available only for regions of the world with developed mapping programs.

In addition to improved satellite imagery, developing global data sharing networks and spatial data archives will also become an increasingly valuable asset to the development of GIS-driven modeling. Just as the Michigan Resource Information System (MIRIS) and the USGS digital spatial data archive greatly assisted the development of this model, similar such data archives, which are rapidly emerging at internet sites across the world, will provide the inputs necessary for present and future modeling efforts.

Finally, enhancements in the functionality of GIS software applications and in techniques used in spatial analyses will provide the basis for new capabilities of data capture, data visualization, and spatial modeling that may not even be understood today.

In conclusion, geographic information systems appear to have a role of growing importance not just in examining the processes behind nonpoint source pollution or in determining the influence of landscape structure on aquatic systems, but in helping us examine and better understand the world around us. GIS has the potential of being a revolutionary tool in the scientific community and it is essential that people continue to move forward in research that explores new uses for this application.

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Appendix A: *Data Acquisition and Conversion: Building the Master Database*

The first step in building the AGNPS model database was to acquire the necessary digital spatial data layers and translate them into ERDAS-readable formats. Two types of data were used to build the database: MIRIS data and DEM data. This section provides step-by-step methodology on how these data were obtained, converted to ERDAS raster GIS files, and then prepared for further processing into the twenty-two specific input variables needed to run the AGNPS model.

MIRIS Data

The Michigan Resource Information System (MIRIS) data, which were used to generate the land use/land cover, soils association, and hydrographic master data layers, are distributed by the Michigan Department of Natural Resources as Intergraph design files grouped by county. Each county file contains arc and attribute data for individual townships which must be merged together and topologically cleaned and built before further processing. These steps were executed in C-Map, a vector-based GIS developed by the Michigan State University's Center for Remote Sensing.

The MIRIS files for Monroe and Washtenaw counties were first loaded into C-Map format using C-Map's IMPORT module. Land use/land cover filenames were automatically assigned standard two-digit number codes of 05 and 50 for arc and attribute data, respectively. Soils filenames were likewise given codes of 26 and 27. The hydrography layer, a subset of the MIRIS base map layers, were given codes of 07 for perennial rivers and 08 for drains and intermittent streams. No attribute data are included with the hydrographic layers; they contain only arc data for rivers and streams. Once imported, the township files for each layer, including both arc and attribute data layers, were merged together to create basin-wide coverages.

Both the land use/land cover and the soils data were then cleaned and built into polygon topologies using C-Map's CLEAN and BUILD modules. Default values of 40.0 ft. for the node tolerance and 5.0 ft. for the point tolerance were used in the cleaning process. Some editing was necessary to correct mislabeled and sliver polygons. The hydrographic layers were cleaned, but not built, as building is inappropriate for non-polygon data.

Exporting C-Map files to ERDAS requires that all attribute labels be converted to integers if not already existing as such. The land use/land cover labels do exist as integers, but the class values needed to be coordinated so that all classes were designated to the same level (Level III). Thus, any two-digit (Level II) labels such as those for cropland polygons ("21") were multiplied by ten ("210"). Likewise, the few Level IV classified categories were reduced to Level III by dropping the fourth digit (e.g. "1131" became "113").

Converting the soils layer was slightly more complicated as two sets of data – soil type and slope class – had to be exported. Both sets of data are contained in the single three character soils labels; the first two characters indicate soil type and the third represents slope class. To export them as separate coverages, these labels had to be split into separate fields and then recoded as integers. This was accomplished by first importing the C-Map polygon attribute table (*.POL) into a spreadsheet utility (Microsoft Excel) where the label field was parsed into separate components for soil type and slope class. C-Map recode tables (*.RTB), consisting of each soil type or slope category linked with a unique integer recode, were then created using a text editor (MS-DOS Editor) and used with C-Map's RECODE module (MANAGE menu) to convert character codes into the integer values.

The hydrography layer required no additional processing before being converted to ERDAS. All three coverages were exported using C-Map's EXPORT module (ERDAS sub-option, under the GIS MENU). The land use/land cover layer was exported as polygons, using the label field as the export attribute. Soils polygon layer was exported twice into ERDAS, once using the soil type as the export attribute, then a second time using slope class. The two hydrographic layers were exported individually as separate arc files, assigning perennial rivers (07) to lines with an attribute value of 1, and intermittent streams a value of 2.

The final step in processing the MIRIS data into master database layers involved converting the land use, soil type, and slope category files, still in vector format, into a raster gridwork. This was accomplished using the ERDAS GRDPOL command. Cell resolutions were set to 330 x 330 ft. (2.5 acres), which represents the minimum size of features included in the MIRIS land use/land cover database. Each new raster layer required as many classes as integer recode values in the initial C-Map export files: land use required 650; soils for Washtenaw and Monroe counties required 250; and slope class needed 10 classes. This produced three raster GIS files serving as land use, soils, and soil slope class layers in the master database. The hydrography layers remained in vector format for later processing.

Digital Elevation Model (DEM) Data

The remaining component in the master database is the topographic data layer, which is derived from 1:250,000 digital elevation models generated by the United States Defense Mapping Agency. These data are available free of charge and can be obtained electronically by downloading them from the USGS internet archive (anonymous ftp from edftp.cr.usgs.gov). The data are downloaded in 1-degree sections containing 1,441,201 cells in a 1200 x 1201 cell grid. At the latitude of lower Michigan, each cell thus works out to be roughly 225 x 225 ft (68.58 x 68.58 m).

Although ERDAS (version 7.5) is able to read DEM data directly, it can only do so from digital tapes. Therefore, other methods were used to get the data into ERDAS. The original DEM data were first downloaded to a Macintosh supporting the MapII GIS application. MapII can readily import DEM data files and convert them into SPANS format, a standard data format common to both MapII and ERDAS. These SPANS files were then imported into ERDAS using the RDSPANS command, and georectified to the Michigan State Plane system, keeping them consistent with the other layers in the master database. Rectifying the DEM data consisted of first assigning the latitude/longitude coordinates of the upper-left cell of each DEM coverage (FIXHED), and then performing a second-order rectification (NRECTIFY using cubic convolution) with a coordinate file matrix (PROGCP, COORDN) to convert the file from planimetric to State Plane zone 6401 (southern Michigan). These steps were done for each DEM section included in the basin area. All sections were then merged together (STITCH) into a basin-wide topographic coverage containing 225 x 225 ft cells.

An additional elevation layer, consisting of enhanced topographic features, was also included in the master database. Because DEM data indicate elevational changes only at meter intervals, much of the Saline River landscape, which can stretch for great distances without changing a full meter in elevation, appears as a series of flat terraces separated by sudden ridges found where two elevation intervals meet. This terracing effect, in turn, creates problems in the model's attempts to determine hydrologic routing as so many cells appear to have a flat aspect. An enhanced topographic layer, in which valleys were amplified by artificially lowering cells containing watercourses, was developed to overcome this problem.

The first step in creating the enhanced topographic layer was to increase the vertical resolution of the original (unrectified) DEM data file by rescaling the elevation values from meter to millimeter intervals, i.e., multiplying all cell values by 1000. Increasing the vertical resolution enabled slight differences in cell elevations to be preserved rather than be rounded to the nearest meter interval. Thus, when the DEM file was resampled during the rectification process (NRECTIFY), elevations are represented much more smoothly since a new terrace occurs at every millimeter change rather than at every meter.

Even with this change, however, resampling the data using the 225 x 225 ft. cells still results in significant terracing. The resampling process in the rectification procedure only affects cells in close proximity to the "ledges," or where elevation changes occur in the original DEM data. To circumvent this problem, a larger output cell size (2000 x 2000 ft.) was used when rectifying the original elevation layer. Increasing the output cell size boosts the probability that two abutting cells have different elevation values, thus spreading the elevation changes over a broader area.

The above steps greatly enhance elevation for the purposes of computing cell aspect, but also sacrifices cell accuracy to some degree. In regions where terrain is naturally varied enough to generate working cell drainage paths, these modifications are artificially smoothing the elevation data where it is unnecessary. Thus to preserve the accuracy in these cells a composite map was created in which the modified elevation cells were used only where necessary, i.e., when the aspect of the original elevation layer was flat. This map was created simply by masking out all the flat regions of the unaltered elevation map, and overlaying the remainder (the acceptable cells) on top of the modified layer.

The resulting map provided much improved drainage patterns compared to the sink-hole riddled map generated from the original elevation layer, but it still had some problems in surface flow direction. In cases where river channels flowed along, rather than across, topographic gradients the elevation model would interpret surface flow incorrectly, generating drainage paths that flowed in and out of river channels.

This problem was remedied by creating artificial river valleys in the modified elevation layer, a modification based on the principle that water runs downhill towards streams. A ten-cell buffer was created along rivers and made to drain such that cells farther away from a watercourse would have a higher cell value. Thus, river cells would have a value of 0 and cells 10 cell lengths away from a waterway would have a value of 10; cells greater than 10 cell lengths away from any river or drain were all given a value of 11. This buffer layer was then combined with the modified elevation using the following equation: (A-(11-B)*10), where A is the modified elevation layer and B is the buffer file. The result was a new elevation layer with valleys ranging from 110 ft. below normal at the base [(11 - 0) * 10 = 110] to 10 ft. below normal [(11 - 10) * 10 = 10] ten cell lengths away from the waterway.

Admittedly, these changes to the original elevation data seem drastic. However, they are based on sound principles: the first modification is simply an enhancement and resampling of existing topographic information using the same techniques used to generate the original digital elevation model data, and the second is based on the principle that surface water generally moves towards the nearest waterway. Comparisons between these modified maps and 1:24,000 USGS topographic quadrangles also showed good conformity, indicating that the modifications did not significantly sacrifice data integrity. In short, the modifications appear to be a valid means of adapting an existing spatial data set to meet the requirements of an unusually flat watershed.

Preparatory Files

Also included in the master database were a set of files designed to prepare the master data layers for further processing into the twenty-two specific input parameters used in the AGNPS model. These files include a descriptor librarian, land use/cover descriptor file, a soils descriptor file, and a GIS model librarian.

The Descriptor Librarian

The descriptor librarian (AGNPS.DSL) contains six scripts (Appendix E) used to recode MIRIS land use/cover classes into AGNPS input variables. It was designed specifically to work with MIRIS data and thus can be used universally with any MIRIS-based AGPNS model database. The first of these scripts, "MIRIS->NAME," groups the Level III land use classes in the master land use/cover coverage into sixteen categories for which AGNPS recode values exist. Most groupings were made simply by truncating the Level III attribute data to Level II; however, certain Level III classes for which specific AGNPS recodes could be found were preserved (e.g., cemeteries, open space). The second script, "NAME->CODE," assigned a numeric code, used in generating the runoff curve number, to each of these land use name classes. The five remaining scripts, "NAME->SURFACE," "NAME->ROUGHNESS," "NAME->CROPPING," and "NAME->COD," each recoded the land use groupings with appropriate values for the respective fields.

The Land Use/Cover Descriptor File

The land use/cover descriptor file (LAND.DSC) stores the variable recodes created by the descriptor librarian. Four descriptor fields were defined: "Class Code," "Surface Condition," "Manning's Roughness," "Cropping Factor," and "COD." Recodes values were inserted into these fields by enabling the AGNPS descriptor librarian and running the appropriate script for each variable.

Descriptor files are especially useful in this instance because they link these recode data to the land use/cover *classes* and not to particular cells. Thus, if the land use/cover layer is later modified to represent an alternative landscape scenario, the recodes in the descriptor files will be updated automatically since the classes remain the same; only the spatial distribution is altered.

The Soils Descriptor File

The soils descriptor file (SOILS.DSC) also stored variable recodes, but was developed in a slightly different way. Five descriptor fields were defined: "Texture$", "Symbol," "Texture," "Hydrologic Group," and "Kfactor." Data were inserted into these fields by reading in an ASCII file containing soil recode values (SOILS.TXT). The ASCII file, typed in manually, contained each of the above fields in their respective order separated by commas (Appendix F).

The GISMO Model Library

The ERDAS modeling language, GISMO, was used in several instances to combine, recode, and otherwise reshape data layers to fit the requirements of the AGNPS model. A total of thirteen models were stored in the AGNPS model librarian (AGNPS.MLB). These models are similar to the descriptor librarian in that they were designed to work with MIRIS- and DEM-based input data and thus can work with any master database constructed from these data sources. Each model is listed in Appendix D.

Summary

The results of the data acquisition and conversion process include a total of seven GIS layers stored as the master database. Land use, soil types and soil slope class, each derived from MIRIS data, are stored as ERDAS raster files with a cell resolution of 330 x 330 ft. Two other layers also derived from the MIRIS data, perennial and intermittent streams, are kept as ERDAS vector files for later processing. And finally two elevation layers, one standard for calculating slope, and one modified for calculating aspect, are stored as raster image files at a 225 x 225 ft. resolution. Descriptor files for the land use and soil type coverages, which contain recode values for certain AGNPS input variables, and a GISMO model library also are included to aid in the subsequent processing of these master data layers into the AGNPS model databases.

Appendix B: *Generating AGNPS Input Variables: The Subwatershed Databases.*

Once all the necessary source data were captured and stored in the master database files, the twenty-two specific variables required to run AGNPS were created simply by recoding, recombining, or otherwise transforming these master data files into AGNPS-readable subwatershed databases. This process involved three steps: (1) generating a set of basin-wide input layers, (2) generating a complete set of AGNPS input layers at the subwatershed scale, and (3) converting these ERDAS databases into proper AGNPS-formatted data files. This section outlines the specific procedures involved in each step, including some discussion as to why each step was included.

Generating Basin-Wide Input Layers

Rationale

As previously explained, the Saline River watershed is too large to be processed by the AGNPS model as a whole and therefore was processed as a series of subwatersheds, each modeled separately. However, to avoid having to continually reprocess the master data into the twenty-two AGNPS inputs for each subwatershed, many of the input layers were generated just once, but for the entire watershed area, and then divided into the smaller subwatershed databases. This two-stage process not only reduced the overall number of processing steps, but for many layers, it also preserved greater accuracy throughout the resampling process, as explained below.

To extract data from the high resolution master data layers to the lower resolution subwatershed data layers, the smaller cells of the master data layer must be grouped, or resampled, into larger cells. For cells containing quantitative values (i.e., where cell values represent actual measured quantities, such as soil erosivity) the resampling process uses a weighted average of the values of the smaller cells to determine the values of the larger ones. However, cells containing *qualitative* data (i.e., where cell values represent discrete categories or types, such as soil textures) cannot be averaged as these averages would be meaningless: the "average" of type 1 and type 3 is not necessarily type 2. Instead, resampling of qualitative data is accomplished by assigning the dominant or most frequent data type of the group of smaller cells as the value of the larger cell.

The distinction between the two resampling processes is subtle but important. The quantitative approach of using weighted averages retains more accuracy during the resampling process than does the qualitative method, and thus it is the preferable of the two. Because many of the AGNPS inputs are quantitative variables recoded from qualitative maps, it makes sense to recode them first, and then resample them as qualitative values rather than discrete classes. For example, soil erosivity, a quantitative variable, is generated by recoding qualitative soil type classes. By recoding the qualitative soils data into quantitative soil erosivity values, the resampling process can take the more accurate weighted averages approach instead of the qualitative approach it would have if the soil type map were resampled first. Hence, not only did the two-stage process save steps, it also proved to be a more accurate procedure in many respects.

The MASTER.AUD Batch File

Creating the basin-wide input layers was further simplified by combining all the ERDAS commands needed to generate them into a single batch file named MASTER.AUD (Appendix G).

The first procedure contained in the MASTER.AUD batch file was generating the runoff curve number, a variable reflecting specific combinations of land use and the soil types. This process began by running the "SCSCN PREP" GISMO model (Appendix D) which extracts two sets of information contained in the descriptor files, class code from the land use/cover file and hydrologic group from the soils file, and inserts them into separate GIS layers. Then, using the ERDAS MATRIX command, these maps were overlaid and specific combinations of land uses and soil types were assigned appropriate curve number values determined from a table supplied by the USDA (1972).

The remaining procedures contained in the MASTER.AUD batch files were straightforward recodes of master map layers executed by running three separate GISMO models: "LAND.DSC->VARS." "SOILS.DSC->VARS," and "SLOPE->VAR6" (Appendix D). The "LAND.DSC->VARS" model extracted Manning's roughness, cropping management, surface condition constant, fertilization index, and chemical oxygen demand factor from the land descriptor file, and placed each into a separate GIS data layer. Similarly, the "SOILS.DSC->VARS" model extracted soil erosivity and soil texture from the soils descriptor files and placed these data into their own coverages. And finally, the "SLOPE->VAR6" model simply recoded the slope class master data layer into field slope length categories based on a table supplied by the Southeast Michigan Council of Governments (SEMCOG, 1979).

The outputs of the MASTER.AUD batch file then were seven new data layers, each constructed at the basin-wide scale and each still retaining the same resolution as the original master data layers (330 x 330 ft.). Subsets of these layers would later be re-rectified into individual subwatershed databases, as explained below. Some AGNPS variables were not created at the basin-wide scale for one of two reasons. Elevation-based variables (slope, channel slope, channel side slope, and aspect) were not because these variables are more accurately calculated if done so from elevation layers sharing the same cell resolutions as the final data sets. Other layers not created at the basin-wide scale included those variables either not used in the analysis or set to uniform values; these variable layers were more easily created directly in the subwatershed databases themselves.

Building the subwatershed databases

The process for building each subwatershed database began with creating a subdirectory within the master database directory, and inserting an ERDAS vector file of the subwatershed boundary, created by digitizing watershed boundaries delineated from 1:24,000 USGS topographic maps, into the subdirectory. Once this subdirectory was made and the boundary file inserted, the remaining procedure consisted of running a sequence of batch files explained below.

SUB1.AUD

The first batch file, SUB1.AUD (Appendix H), executed five steps. First, it generated a series of empty map layers of the subwatershed area by converting the digitized watershed boundary file into a blank raster grid and then copying this raster grid into a number of additional empty coverages for individual AGNPS input layers. The second step involved filling many of these empty coverages with data extracted either from the master data layers or from the basin-wide variable layers discussed above. This was done by re-rectifying the original layers directly into the subwatershed layers, a process that would automatically subset and resample the master data into the appropriate cell sizes of the subwatershed database. The third step included calculating cell slope and aspect from a re-rectified elevation layer, done easily with specific ERDAS commands. Fourth, the SUB1.AUD batch file created a raster layer of the river and drain network by rasterizing the vector hydrographic files from the master database, and subsequently combined this layer with the slope layer to generate the channel id, channel slope, and channel side slope data layers. The final step included overlaying a river aspect file, where the aspects of river and stream containing cells were, when necessary, redirected to slope downstream, on top of the original aspect file. This step was one final aspect modification created to ensure that cells routed properly in a landscape as flat as the Saline River's.

SUB2.AUD

Before the second batch file, which was designed to determine the receiving cell numbers, could be run, the cell id layer had to be produced.

No simple ERDAS procedures were able to create cell id number (sequential integers assigned to each cell within the watershed), so this procedure could not be included in a batch file. Instead, it was created by exporting (DATATAB) a coverage of the watershed into a tabular text file from which a DOS executable batch file programmed in ANSI-C (Appendix K) would recode all cells within the watershed (i.e., non-zero cells) with a sequentially increasing integer value. The batch output file was then reconverted into ERDAS and restructured back into a GIS layer using the ERDAS TABDATA command.

The SUB2.AUD (Appendix I) batch file then used this cell id layer and the aspect layer generated in the previous batch file to determine the receiving cell id for each raster in the subwatershed area. This process began by creating eight new coverages consisting of the cell id file offset one cell in each of the eight cardinal directions. Thus, one layer where all cell id numbers were shifted one cell east, for example, would represent the receiving cell number if all cells faced west. Next, three GISMO models ("VAR2 I," "VAR2 II," and "ASPFIX", Appendix D) were run[1]. VAR2 I and VAR 2 II were used to determine which shifted cell id layer should be inserted into a particular cell based on the aspect of that cell. The ASPfix model adjusted the remaining cells with a flat aspect (sink hole cells) to a format required by the AGNPS model: aspects were set to 0 and receiving cells were assigned to their own cell id numbers.

---

[1] Problems arose during many model runs when these model were included in the SUB2.AUD batch file and thus these models were run manually (not within the batch files) by calling up the ERDAS GISMO routine.

SUB3.AUD

At the completion of the second batch file, all of the twenty-two AGNPS input variables were stored in individual, spatially referenced GIS map layers. The final batch file, SUB3.AUD (Appendix J), merged these GIS layers into a single twenty-two layer coverage, which was converted into a large tabular data file and eventually translated into the specific format needed by the AGNPS program. The merging of the data files was done simply by creating an empty twenty-two layer image file, and then subsetting each variable file into a separate layer in this image file in the order used by the AGNPS model database. This multi-layer file was then exported as a tabular data file. The net result was a single file, named INPUT.TXT, which contained all twenty-two AGNPS input values for each cell, identified by that cell's id number, organized in tabular format.

Converting the ERDAS Output File to an AGNPS Readable Data File

While the INPUT.TXT file contained all the data for the model to run, and even in proper sequence, the AGNPS program further requires that each field be in a rigidly specified format. A DOS executable program, ERD2AGN.EXE (Appendix L), was written to handle this task. This program, written in ANSI-C, simply read the input.txt file and restructured it according to the format specified by the AGNPS model, naming the output OUTPUT.TXT.

In addition to converting the format of the ERDAS file, a proper header also had to be created and attached to the file. This was accomplished by first creating a new dummy data file in the AGNPS program itself, consisting of the proper header information (cell size, number of cells, storm duration, etc.). Then, using a text editor, this header was copied and pasted to the beginning of the OUTPUT.TXT file. The resulting file, containing all the necessary variable information, could then be loaded into AGNPS and run. Most data files, however, still needed some debugging in the AGNPS program; this debugging most frequently consisted of locating sink hole cells on the fringes of the subwatershed boundary and also identifying the outlet cell.

Appendix C: *Generating Land-Use Expansion Scenarios.*

Alternative landscape scenarios were evaluated by replacing the land use layer in the master database with a modified land use layer, and then reprocessing the subwatershed specific databases just as described in Appendices A and B. This section describes the procedures used in creating these modified landscape layers.

Agricultural Expansion

The expansion of agricultural land, specifically cropland, was simulated by recoding the cells along the perimeter of cropland cells to 210, or the MIRIS Level III value for cropland. Because the cells in the master data layers were 100 m (330 ft) wide, this change represented a radial expansion of 100 m for each clump of agricultural cells. Thus, to represent increased levels of change, more cells along the perimeter would be recoded, each occurring in 100 m intervals for every increment of perimeter cells changed. Expansions of up to 500 m, or five cells away, were used in the simulation event. Water cells, however, were not recoded since it seems unlikely that croplands will expand on top of lakes or ponds.

The cells were recoded using a combination of the ERDAS SEARCH command and a specifically designed GISMO model (AGRILIZER, Appendix M). The SEARCH command was used to create a five-cell buffer around all cropland clumps, and the AGRILIZER model would create a new land use layer by recoding the cells in each successive buffer as cropland, with the exception of cells valued between 500 and 599, which are MIRIS water cells.

Urban Expansion

Urban expansion was simulated just as was agricultural expansion. The SEARCH command was used to create a five-cell buffer of all urban lands (MIRIS levels 110 through 130), followed by a GISMO model (URBANIZER) which recoded all cells in these buffers to urban, with the exception of water cells.

Forest Expanion

Forest expansion again was simulated much like the urban and agricultural expansion scenarios. Buffers were created around all cells with MIRIS level values between 400 and 499, which correspond to forest cover types. These buffers were then recoded into new forest cells.

Appendix D: *ERDAS model (GISMO) scripts contained in AGNPS.MLB library.*

1. Land.dsc->vars

```
-------------------------------------------------------------------
# This model generates separate layers from information contained
# in the land use descriptor files.

DATA
 INPUT landuse FILE ASK "land";      # Asks for land use file name
 OUTPUT ft FILE "var13";             # Surface Condition constant
 OUTPUT cf FILE "var11";             # Cropping factor file created
 OUTPUT ro FILE "var9";              # Manning's roughness file created
 OUTPUT cd FILE "var20";             # Chemical Oxygen Demand file
 INTEGER surf;                       # (Temporary variable)
START
 cf = landuse."cropping factor" * 100;     # Converts decimal to integer
 ro = landuse."Mannings roughness" * 100; # Converts decimal to integer
 cd = landuse."cod";
 surf = landuse."surface condition" *100; # Converts decimal to integer
 ft = CONDITIONAL {
   (landuse >= 500 AND landuse < 600) 0    # Recodes water cells to 0
   (default) surf };                       # Non-water cells = code
END
-------------------------------------------------------------------
```

2. Chslope

```
-------------------------------------------------------------------
# This model generates a channel slope (VAR7)
#   from the slope layer (VAR4) and a buffer file.
# The land use file must also be accessed so that
#   water and marsh cells can be identified and
#   given a value of zero.

DATA
 INPUT land  FILE "land";        # Land use file
 INPUT slope FILE "VAR4.lan";    # Slope layer
 INPUT river FILE "river";       # River file
 OUTPUT csp  FILE "VAR7.lan";    # Channel slope      (% x 10)
 OUTPUT sdsp FILE "VAR8.lan";    # Channel side slope (%)
START
 csp = CONDITIONAL          {
      (land."class code" >= 14) 0  # Water & marsh cells have value = 0
      (river >= 1)  slope          # River & drain cells = land slope
      (default)     slope/2 };     # All other cells = 1/2 slope
 sdsp = EITHER 0 IF land."class code" >= 14 OR 10 OTHERWISE;
END
-------------------------------------------------------------------
```

3. Side Slope

```
---------------------------------------------------------------
# This model generates a channel side slope (VAR8)
#   from the slope layer (VAR4) and a buffer file.
# The land use file must also be accessed so that
#   water and marsh cells can be identified and
#   given a value of zero.

DATA
 INPUT land  FILE "Land";           # Land use file
 INPUT slope FILE "VAR4.lan";       # Slope layer
 INPUT bf    FILE "buffer";         # River buffer
 OUTPUT csp  FILE "VAR8.lan";       # Channel side slope (%)
START
 csp = CONDITIONAL          {
      (bf EQ 1)  slope              # adjacent cells have value = slope
      (bf GT 1)  slope/2            # other cells = 1/2 land slope
      (land."class code" == 14) 0   # Water cells have value = 0
      (land."class code" == 16) 0};# Marsh cells have value = 0
END
---------------------------------------------------------------
```

4. slope->var4

```
---------------------------------------------------------------
#This converts the lrectified slope data into proper variable 4
#format (setting water values to zero, as AGNPS states)

DATA
 INPUT land  FILE "land";
 INPUT slope FILE "slope";
 OUTPUT slp  FILE "var4.lan";
START
 slp = conditional {
   (land."class code" == 14) 0
   (default) slope };
END
---------------------------------------------------------------
```

5. Ch Ind

```
---------------------------------------------------------------------
# Configures the channel layer according to agnps
DATA
 INPUT riv  FILE ASK "riv";
 INPUT land FILE ASK "land";
 OUTPUT ch  FILE "var22.lan";
START
 ch = CONDITIONAL {
  (riv == 2) 7 #River cells take the AGNPS value of perrenial streams
  (riv == 1) 6 #Drain cells take the AGNPS value of intermittent...
  (land."class code" == 14) 0
  (default) 1   };
END
---------------------------------------------------------------------
```

6. Var2 I

```
---------------------------------------------------------------------
DATA
 Input as FILE "var14.lan";
 Input n  FILE "north";
 Input en FILE "neast";
 Input e  FILE "east";
 Input se FILE "seast";
 Input s  FILE "south";
#Input sw FILE "swest";       # No room! Moved to part II
#Input w  FILE "west";        # ...
#Input nw FILE "nwest";       # ...
 Input v1 FILE "var1.lan";
 Output x FILE "x1";
START
 x = conditional {
  (as == 1) n
  (as == 2) en
  (as == 3) e
  (as == 4) se
  (as == 5) s
 #(as == 6) sw
 #(as == 7) w
 #(as == 8) nw
  (default) v1 };
END
---------------------------------------------------------------------
```

7. Var2 II

```
-------------------------------------------------------------------
DATA
 Input as FILE "var14.lan";
#Input n  FILE "north";    # Done in part I
#Input en FILE "neast";    # ...
#Input e  FILE "east";     # ...
#Input se FILE "seast";    # ...
#Input s  FILE "south";    # ...
 Input x1 FILE "x1";
 Input sw FILE "swest";
 Input w  FILE "west";
 Input nw FILE "nwest";
#Input v1 FILE "var1";
 Output x  FILE "var2.lan";
START
 x = conditional {
 #(as == 1) n
 #(as == 2) en
 #(as == 2) e
 #(as == 4) se
 #(as == 5) s
  (as == 6) sw
  (as == 7) w
  (as == 8) nw
  (default) x1 };
END

-------------------------------------------------------------------
```

8. Slope->Var6

```
-------------------------------------------------------------------
# Determines slope length from SEMCOG recode tables
DATA
 INPUT slp FILE ASK "slope class";
 OUTPUT ls FILE "var6";
START
 ls = CONDITIONAL {
 (slp == 1) 400
 (slp == 2) 300
 (slp == 3) 150
 (default)  80   };
END
-------------------------------------------------------------------
```

9. Soil.dsc->vars

```
------------------------------------------------------------------
data
input soils file "soils";
input land file "land";
output erosiv  file "var10";
output texture file "var15";
start
erosiv  = soils."kfactor";
texture = either 0 if land."class code" >= 14 or soils."texture"
otherwise;
end
------------------------------------------------------------------
```

10. RIVASP

```
------------------------------------------------------------------
DATA
 INPUT asp FILE ASK "aspect";
 INPUT riv FILE ASK "river";
 OUTPUT ra FILE "rivasp";
START
 ra = EITHER asp IF riv GT 0 OR 0 OTHERWISE;
END
------------------------------------------------------------------
```

11. ASPfix

```
------------------------------------------------------------------
# Fixes recieving cell/aspect problems in sink hole cells
# {sets aspect to zero and receiving cell to cell id for sink holes}
DATA
 input var2 file "var2.lan";
 input var1 file "var1.lan";
 input asp  file "var14.lan";
 output v2a file "var2a.lan";
 output asb file "var14a.lan";
START
  v2a = either var1 if var2 == 0 or var2 otherwise;
  asb = either 0 if (var2 == 0) or asp otherwise;
END
------------------------------------------------------------------
```

12. Agrilizer

```
-----------------------------------------------------------------
DATA
 input skirt file "agskirt";
 input land  file "landx";
 integer stop;
 output out file ask "out";
START
 stop = 4;
 out = either 210 if (skirt gt 0 and skirt <= stop) or land otherwise;
 out = either land if land gt 500 and land lt 600 or out otherwise;
END
-----------------------------------------------------------------
```

13. Ripariator

```
-----------------------------------------------------------------
DATA
 input skirt file "rpskt";
 input land  file "landx";
 integer stop;
 output out file ask "out";
START
 stop = 5;
 out = either 410 if (skirt >= 0 and skirt <= stop) or land otherwise;
END
-----------------------------------------------------------------
```

Appendix E: *ERDAS Scripts Contained in the* AGNPS.DSL *Descriptor Library*

1. MIRIS->Name

```
-----------------------------------------------------------------
CONDITIONAL {
 (class >=110 and class < 120)   "residential"
 (class >=120 and class < 130)   "commercial"
 (class >=130 and class < 140)   "industrial"
 (class >=140 and class < 150)   "transportation"
 (class >=170 and class < 180)   "extractive"
 (class >=190 and class < 194)   "recreation"
 (class ==194)                   "cemetery"
 (class >=210 and class < 220)   "cropland"
 (class >=220 and class < 230)   "orchard"
 (class >=230 and class < 240)   "feedlot"
 (class >=240 and class < 250)   "pasture"
 (class >=290 and class < 300)   "farmstead"
 (class >=310 and class < 320)   "herbaceous"
 (class >=320 and class < 330)   "shrubland"
 (class >=410 and class < 430)   "deciduous"
 (class >=420 and class < 429)   "conifer"
 (class ==429)                   "xmas trees"
 (class >=500 and class < 600)   "water"
 (class >=610 and class < 620)   "wooded wetland"
 (class >=620 and class < 630)   "wetland"
 (default) "   ---   " };
-----------------------------------------------------------------
```

2. Name->Code

```
-----------------------------------------------------------------
conditional {
('class name' == "residential")        1
('class name' == "industrial")         2
('class name' == "commercial")         2
('class name' == "transportation")     3
('class name' == "extractive")         4
('class name' == "recreation")         5
('class name' == "cemetery")           5
('class name' == "cropland")           6
('class name' == "orchard")            7
('class name' == "feedlot")            8
('class name' == "pasture")            9
('class name' == "farmstead")          10
('class name' == "herbaceous")         11
('class name' == "shrubland")          11
('class name' == "deciduous")          12
('class name' == "conifer")            13
('class name' == "xmas trees")         7
('class name' == "water")              14
('class name' == "wooded wetland")     15
('class name' == "wetland")            16
(default) 0};
-----------------------------------------------------------------
```

3. Name->Surface

```
----------------------------------------------------------------
# Written 14 Sept 93; modified 15 sept 94
conditional {
('class name' == "residential")      0.01    # AGNPS Table 23.
('class name' == "commercial")       0.01    # AGNPS Table 23.\ Urban Non-
('class name' == "industrial")       0.01    # AGNPS Table 23./ residential
('class name' == "transportation")   0.01    # AGNPS Table 23.
('class name' == "extractive")       0.80    # AGNPS Table 23.
('class name' == "recreation")       0.22    # AGNPS Table 2.(good pasture)
('class name' == "cemetery")         0.22    # AGNPS Table 2.(good pasture)
('class name' == "cropland")         0.17    # Big Darby Table 2-5
('class name' == "orchard")          0.17    # Big Darby Table 2-5
('class name' == "feedlot")          0.01    # AGNPS Table 2.(poor pasture)
('class name' == "pasture")          0.15    # AGNPS Table 2.(fair pasture)
('class name' == "farmstead")        0.01    # AGNPS Table 2.
('class name' == "herbaceous")       0.59    # AGNPS Table 2.(perm.meadow)
('class name' == "shrubland")        0.59    # AGNPS Table 2.(perm.meadow)
('class name' == "deciduous")        0.59    # AGNPS Table 2.
('class name' == "confifer")         0.29    # AGNPS Table 2.
('class name' == "xmas trees")       0.29    # AGNPS Table 2.
('class name' == "water")            0.01    # AGNPS Table 2.
('class name' == "wooded wetland")   0.01    # AGNPS Table 2.(marsh)
('class name' == "wetland")          0.01    # AGNPS Table 2.(marsh)
(default) 0.01};
----------------------------------------------------------------
```

4. Name->Roughness

```
---------------------------------------------------------------
#Written 14 Sept 93, modified 15 Sept 94
conditional {
('class name' == "residential")       0.02   # AGNPS Table 23.
('class name' == "commercial")        0.02   # AGNPS Table 23.\ Urban Non-
('class name' == "industrial")        0.02   # AGNPS Table 23./ residential
('class name' == "transportation")    0.02   # AGNPS Table 23.
('class name' == "extractive")        0.10   # AGNPS Table 23.
('class name' == "open space")        0.13   # AGNPS Table 5.(excel. grass)
('class name' == "cropland")          0.13   # AGNPS Table 5.(excel. grass)
('class name' == "cropland")          0.03   # Big Darby Table 2-5
('class name' == "orchard")           0.03   # Big Darby Table 2-5
('class name' == "feedlot")           0.04   # AGNPS Table 5.(sparse grass)
('class name' == "pasture")           0.15   # AGNPS Table 5.(fair pasture)
('class name' == "farmstead")         0.01   # AGNPS Table 5.(residential)
('class name' == "herbaceous")        0.15   # Nelisher Table 2.2 (prarie)
('class name' == "shrubland")         0.13   # Nelisher Table 2.2 (range)
('class name' == "deciduous")         0.80   # Nelisher Table 2.2 (h.woods)
('class name' == "conifer")           0.40   # Nelisher Table 2.2 (l.woods)
('class name' == "xmas trees")        0.40   # Nelscher Table 2.2 (l.woods)
('class name' == "water")             0.99   # AGNPS Table 5.
('class name' == "wooded wetland")    0.99   # AGNPS Table 5.(marsh)
('class name' == "wetland")           0.99   # AGNPS Table 5.(marsh)
(default) 0.001 };
---------------------------------------------------------------
```

5. Name->Cropping

```
------------------------------------------------------------

conditional {
('class name' == "residential")      0.01  # AGNPS Table 23.
('class name' == "commercial")       0.01  # AGNPS Table 23.\ Urban Non-
('class name' == "industrial")       0.01  # AGNPS Table 23./ residential
('class name' == "transportation")   0.01  # AGNPS Table 23.
('class name' == "extractive")       0.10  # AGNPS Table 23.
('class name' == "recreation")       0.06  # SEMCOG Table 8.
('class name' == "cemetery")         0.003 # SEMCOG TABLE 8.
('class name' == "cropland")         0.39  # AGNPS Table 23.
('class name' == "orchard")          0.43  # AGNPS Table 23.
('class name' == "feedlot")          0.20  # W&S p.33
('class name' == "pasture")          0.03  # AGNPS Table 23.
('class name' == "farmstead")        0.01  # Big Darby Table 4-1.
('class name' == "herbaceous")       0.13  # SEMCOG Table 8.
('class name' == "shrubland")        0.003 # SEMCOG Table 8.
('class name' == "deciduous")        0.02  # AGNPS Table 23.
('class name' == "conifer")          0.02  # AGNPS Table 23.
('class name' == "xmas trees")        0.43 # AGNPS Table 23.(cultiv.)
('class name' == "water")             0.0  # AGNPS Table 23.
('class name' == "wooded wetland")    0.0  # AGNPS Table 23.(marsh)
('class name' == "wetland")           0.0  # AGNPS Table 23.(marsh)
(default) 0};
------------------------------------------------------------
```

6. Name->COD

```
----------------------------------------------------------
conditional {
('class name' == "residential")       110   # AGNPS Table 23.
('class name' == "commercial")         80   # AGNPS Table 23.\ Urban Non-
('class name' == "industrial")         80   # AGNPS Table 23./ residential
('class name' == "transportation")    110   # AGNPS Table 23.
('class name' == "extractive")         80   # AGNPS Table 23.
('class name' == "recreation")         60   # AGNPS Table 8.
('class name' == "cemetery")           60   # AGNPS Table 8.
('class name' == "cropland")          170   # Big Darby Table 2-5
('class name' == "orchard")           170   # Big Darby Table 2-5
('class name' == "feedlot")          4000   # Young,et al. Table 2
('class name' == "pasture")            50   # AGNPS Table 5.(fair pasture)
('class name' == "farmstead")          80   # AGNPS Table 8.
('class name' == "herbaceous")         60   # AGNPS Table 8.(pasture/open)
('class name' == "shrubland")          60   # AGNPS Table 8.(pasture/open)
('class name' == "deciduous")          65   # AGNPS Table 8.
('class name' == "conifer")            65   # AGNPS Table 8.
('class name' == "xmas trees")         65   # AGNPS Table 8.(forested)
('class name' == "water")               0   # AGNPS Table 8.
('class name' == "wooded wetland")     25   # AGNPS Table 8.(marsh)
('class name' == "wetland")            25   # AGNPS Table 8.(marsh)
(default) 0};
----------------------------------------------------------
```

Appendix F: *ASCII file used to insert soils descriptor information to soils map*

```
---------------------------------------------------------------------
Adrian,muck,38,4,1,0
Adrian,muck,Ad,4,1,0
Aquents,muck,31,4,1,0
Arkport-Okee,loamy_fine_sand,35,1,2,17
Barry,loam,17,2,2,28
Barry,sandy_loam,Ba,2,2,28
Barry-Brady-urban,urban,57,4,2,24
Beaches,sand,27,1,9,99
Belleville,loamy_fine_sand,Ba,1,2,17
Belleville,loamy_fine_sand,36,1,2,17
Berrien,loamy_sand,Bb,1,9,99
Berrien,sandy_loam,Bc,1,9,99
Berville,loam,Bd,2,9,99
Blount,loam,Bf,2,3,43
Blount,loam,13,2,3,43
Blount,loam,Bb,2,3,43
Blount-Pewamo,loam,Bg,2,3,43
Blount-Pewamo,loam,Bc,2,3,43
Blount-Pewamo-Metamora,complex,62,2,3,29
Blount-Urban,urban,56,2,3,43
Boyer,loamy_sand,Bn,1,2,17
Boyer-Kidder,complex,Bo,1,2,17
Boyer-Oshtemo,sandy_loam,11,2,2,24
Brady,sandy_loam,16,2,2,20
Brady,sandy_loam,Bh,2,2,20
Brady-Macomb,loam,Bk,2,2,24
Brady-Macomb,sandy_loam,Bm,2,2,24
Bronson,loam,Bn,2,9,99
Brookston,loam,Bo,2,2,28
Brookston,loam,Bp,2,2,28
Brookston,loam,61,2,2,28
Brookston,loam,Br,2,2,28
Cadmus,loam,Ca,2,9,99
Cadmus,sandy_loam,Cb,2,9,99
Cadmus-Blount,loam,Cc,2,9,99
Capac,loam,65,2,2,32
Carlisle,muck,Cd,4,4,0
Ceresco,fine_sandy_loam,46,2,2,20
Channahon,loam,45,2,4,37
Cohoctah,fine_sandy_loam,Cc,2,2,28
Cohoctoh,fine_sandy_loam,22,2,2,28
Colwood,sandy_loam,Ce,2,2,28
Colwood,loam,29,2,2,28
Colwood-Wauseon,sandy_loam,Cf,2,2,24
Conover,loam,Cg,2,2,28
Conover,loam,Co,2,2,28
Conover-Brookston,loam,Cp,2,2,28
Corunna,sandy_loam,24,2,2,20
Corunna,fine_sandy_loam,Co,2,2,20
Covover,loam,60,2,2,24
```

```
cut_land,,Cu,0,4,0
Del_Rey,silt_loam,62,2,3,43
Del_Rey,silt_loam,14,2,3,43
Dixboro,fine_sandy_loam,43,2,2,20
Dixboro-Kibbie,fine_sandy_loam,Do,2,2,20
Dumps,,32,0,4,0
Edwards,muck,30,4,2,0
Edwards,muck,Ea,4,2,0
Edwards,muck,Ed,4,2,0
Edwards,muck,Ee,4,2,0
Eleva,sandy_loam,55,2,2,24
Eleva,fine_sandy_loam,66,2,2,17
Fill_land,,Fd,0,4,0
Fox,sand,Fa,1,2,24
Fox,loam,Fb,2,2,24
Fox,sandy_loam,Fc,2,2,24
Fox,eroded,Fd,2,2,24
Fox,sandy_loam,Fo,2,2,24
Fox,cobbly_sandy_loam,Fp,2,2,24
Fulton,silty_clay_loam,15,2,4,43
Genesee,loam,Ga,2,9,99
Genesee,sandy_loam,Gb,2,9,99
Genesee-Eel,loam,Gc,2,9,99
Gilford,sandy_loam,55,2,2,20
Gilford,sandy_loam,Gf,2,2,20
Gilford-Colwood,complex,18,2,2,24
Granby,loamy_sand,Gd,1,1,17
Granby,sandy_loam,Ge,2,1,17
Granby,loamy_sand,18,1,1,17
Granby,fine_sand,Gr,1,1,15
Griffin-Genesee,sandy_loam,Gf,2,9,99
Griffin-Sloan,loam,Gg,2,9,99
Griffin-Sloan,sandy_loam,Gh,2,9,99
Henrietta,muck,63,4,4,0
Hillsdale,sandy_loam,Ha,2,2,24
Hillsdale-Riddles,sandy_loam,49,2,2,24
Histosols-Aquentis,muck,47,4,4,0
Houghton,muck,Hb,4,1,0
Houghton,muck,Hn,4,1,0
Houghton,muck,20,4,1,0
Hoytville,clay_loam,Hc,2,4,28
Hoytville,mucky_clay_loam,Hd,2,4,28
Hoytville,clay_loam,He,2,4,28
Hoytville,clay_loam,42,2,4,28
Hoytville,clay,Ho,3,4,28
Hoytville-Wauseon,complex,Hf,3,4,24
Ionia,loam,Ia,2,4,0
Kendalville,loam,Ka,2,2,37
Kendalville,sandy_loam,Kb,2,2,37
Kendalville,loam,Kc,2,2,37
Kendalville,loam,Ke,2,2,37
Kerston,loam,Kd,2,9,99
Kibbie,fine_sandy_loam,29,2,2,20
Kibbie,sandy_loam,Ke,2,2,20
Kibbie,sandy_loam,28,2,2,20
```

```
Kibbie,fine_sandy_loam,Kn,2,2,20
Kidder,sandy_loam,Kr,2,2,24
Kokomo-Barry,loam,Kf,2,9,99
Kokomo-Barry-Wallkill,loam,Kg,2,9,99
Lake,,La,0,4,0
Lamson-Colwood,fine_sandy_loam,Ln,2,4,28
Lenawee,silt_loam,40,2,2,28
Lenawee,silty_clay_loam,Lb,2,2,28
Lenawee,silty_clay_loam,10,2,2,28
Lenawee,silty_clay_loam,21,2,2,28
Lenawee-Urban,urban,57,0,2,28
Leoni,gravelly_sandy_loam,44,2,2,10
Linwood,muck,Lc,4,2,0
Macomb,sandy_loam,Ma,2,2,28
Macomb,loam,Mc,2,2,28
Macomb-Hoytville,sandy_clay_loam,Mb,2,2,28
Made_land,,Mb,0,4,0
Marlette-Owosso,complex,64,2,2,28
Martisco,muck,45,2,4,0
Matherton,sandy_loam,Md,2,2,20
Maumee,loamy_sand,Mc,1,9,99
Metamora,sandy_loam,23,2,2,20
Metamora,sandy_loam,Me,2,2,20
Metamora-Corunna,sandy_loam,17,2,2,20
Metamora-Pewamo,sandy_loam,Mf,2,2,24
Metea,sand,41,1,2,17
Metea,loamy_sand,Mh,1,2,17
Miami,loam,Md,2,2,37
Miami,loam,Mf,2,2,37
Miami,loam,Mm,1,2,37
Miami-Boyer,sandy_loam,Me,1,2,27
Miami-Boyer,sandy_loam,Mg,2,2,27
Millsdale,clay_loam,47,2,2,32
Milton,clay_loam,26,2,3,37
Morley,loam,Mh,2,1,37
Morley,loam,Mk,2,1,37
Morley,loam,Mo,2,1,37
Napoleon,muck,48,4,1,0
Nappanee,silt_loam,Na,2,4,43
Nappanee,clay,Na,3,4,43
Nappanee,loam,Nb,2,4,43
Nappanee,loam,43,2,4,43
Oakville,fine_sand,11,1,1,15
Oakville,fine_sand,49,1,1,15
Oakville,fine_sand,Oa,1,1,15
Oakville-Urban,urban,58,0,1,15
Ogden,muck,Oa,4,4,0
Ormas-Spinks,complex,14,1,1,17
Oshtemo,loamy_sand,Ob,1,2,24
Oshtemo,loamy_sand,Os,1,2,24
Oshtemo-Leoni,complex,68,1,2,17
Oshtemo-urban,urban,58,0,2,24
Ottawa,loamy_sand,Oc,1,9,99
Ottokee,fine_sand,37,1,1,15
Ottokee,fine_sand,50,1,1,17
```

```
Palms,muck,37,4,4,0
Palms,muck,Pa,4,4,0
Palms,muck,Pa,4,4,0
Pella,loam,Pc,2,4,28
Pewamo,clay_loam,Pb,2,3,24
Pewamo,clay_loam,22,2,3,24
Pewamo,clay,Pe,3,3,24
Pits,gravel,52,1,4,0
Pits,quarries,53,0,4,0
Pits-Aquents,,33,0,4,0
Pits-Quarries,,51,0,4,0
Plainfield-Berrien,loamy_sand,Pd,1,9,99
Plainfield-Ottawa,loamy_sand,Pe,1,9,99
Randolf,clay_loam,25,2,4,37
Riddles,sandy_loam,42,2,2,24
Riddles,sandy_loam,Rd,2,2,24
Riddles-Leoni,complex,56,2,2,17
Riddles-urban,urban,59,0,2,24
Rifle,peat,Ra,4,4,0
Rollin,muck,Rb,4,4,0
Saylesville,silt_loam,61,2,3,37
Sebewa,loam,46,2,2,24
Selfridge,loamy_sand,19,1,3,17
Selfridge,loamy_sand,Se,1,3,17
Selfridge-Pewamo,complex,20,2,3,20
Selfridge-Pewamo,complex,59,2,3,20
Selfridge-Pewamo,complex,Sf,2,3,17
Seward,loamy_fine_sand,Se,1,2,17
Seward,loam,Sf,2,2,17
Seweba,loam,Sa,2,2,24
Seweba,sandy_loam,Sb,2,2,24
Seweba,loam,Sb,2,2,24
Shoals,clay,Sh,3,2,37
Sisson,fine_sandy_loam,Sn,2,2,24
Sloan,loam,30,2,2,37
Sloan,loam,So,2,4,28
Spinks,loamy_sand,12,1,1,17
Spinks,loamy_sand,Sp,1,1,17
Spinks-Boyer--Plainfield-Hillsd,complex,Sc,1,1,17
Spinks-Oshtemo,loamy_sand,Sr,1,1,17
StClair,loam,Sd,2,4,37
StClair,loam,Se,2,4,37
StClaire,clay,St,3,4,37
Tawas,muck,Ta,4,4,0
Teasdale,fine_sandy_loam,15,2,2,24
Tedrow,loamy_sand,16,1,2,17
Tedrow,loamy_fine_sand,Te,1,2,17
Tedrow,loamy_fine_sand,Tf,1,2,17
Thetford,loamy_sand,40,1,1,17
Thetford,loamy_sand,Th,1,1,17
Toledo,silty_clay_loam,48,2,4,28
Udorthentis,,51,0,4,0
Udorthents-urban,urban,60,0,4,0
Urban,urban,63,0,4,0
Wallkill,loam,Wa,2,9,99
```

```
Warners,muck,Wb,4,4,0
Warners,silt_loam,52,2,4,43
Wasepi,sandy_loam,44,2,2,20
Wasepi,sandy_loam,Wa,2,2,20
Wasepi,loamy_sand,We,1,2,17
Wauseon,loam,Wc,2,2,20
Wauseon,fine_sandy_loam,Ws,2,2,20
Whalan,loam,67,2,2,32
Willette,muck,Wd,4,4,0
Ypsi,sandy_loam,Yp,2,3,24
Ypsi-Wauseon,complex,39,2,3,24
Owosso-Miami,complex,Ow,2,2,24
Water,water,W,0,0,0
-------------------------------------------------------------------
```

Appendix G: *The MASTER.AUD batch file*

```
---------------------------------------------------------------------
>ERDAS|NOMENU
 ERD>
>del v*.gis

 press any key to continue
?
 ERD>
>del v*.trl

 press any key to continue
?
 ERD>
>del v*.sta

 press any key to continue
?
 ERD>
>gismo
 GISMO -- GIS Modeling
 Version 7.4.03.447
# 1
? 111   0 Land.dsc->vars
 Enter Model Library filename:
?agnps
# 1
? 129   0 slope->var4
? 129   0 Slope->Var6
? 130   0 LAND->CODE
?  13   0 LAND->CODE
 Enter Land filename:
?land
# 1
# 1
# 0
# 1
# 4

 Enter maximum output file value for clipping
?17
# 0
# 1
? 130   0 SOIL->HYDROCON
?  13   0 SOIL->HYDROCON
 Enter Soil filename:
?soils
# 1
# 1
# 0
# 1
# 4

 Enter maximum output file value for clipping
```

```
?4
# 0
# 1
? 120   0 SOIL->HYDROCON
\
 ERD>
>matrix
 MATRIX -- GIS Class Matrix
 Version 7.4.02.434
 Enter Input GIS filename:
?lcode
# 1
# 1
 Is this the variable you wanted ?
?Yes
 Enter Input GIS filename:
?hydcon
# 1
# 1
 Is this the variable you wanted ?
?Yes
 Enter output matrix size (columns, rows)
?17,4
 Enter range of values to recode (-1 to recode as is)
?1,17
 Enter recode option:
  Individual, Block, or Offset
?Individual

?1

?2

?3

?4

?5

?6

?7

?8

?9

?10

?11

?12

?13
```

```
?14

?15

?16
 Press any key to continue
?

?17

 Recode another range of values?
?No
 Enter range of values to recode (-1 to recode as is)
?1,4
 Enter recode option:
  Individual, Block, or Offset
?Individual

?1

?2

?3

?4

 Recode another range of values?
?No
 Recode the matrix output
?Yes
 Enter range of values to recode (-1 to recode as is)
?0,68
 Enter recode option:
  Individual, Block, or Offset
?Individual
     0          0          0

?100
     1          1          1

?77
     2          2          1

?89
     3          3          1

?98
     4          4          1

?30
     5          5          1

?49
     6          6          1
```

```
?72
      7            7           1

?43
      8            8           1

?68
      9            9           1

?49
     10           10           1

?59
     11           11           1

?35
     12           12           1

?35
     13           13           1

?25
     14           14           1

?36
     15           15           1

?100
 Press any key to continue
?
     16           16           1

?85
     17           17           1

?85
     18            1           2

?85
     19            2           2

?92
     20            3           2

?98
     21            4           2

?58
     22            5           2

?69
     23            6           2

?81
     24            7           2
```

```
?65
     25            8            2

?79
     26            9            2

?69
     27           10            2

?74
     28           11            2

?56
     29           12            2

?56
     30           13            2

?55
     31           14            2

?60
 Press any key to continue
?
     32           15            2

?100
     33           16            2

?85
     34           17            2

?85
     35            1            3

?90
     36            2            3

?94
     37            3            3

?98
     38            4            3

?71
     39            5            3

?79
     40            6            3

?88
     41            7            3

?76
```

```
     42            8            3

?86
     43            9            3

?79
     44           10            3

?82
     45           11            3

?70
     46           12            3

?70
     47           13            3

?70
  Press any key to continue
?
     48           14            3

?73
     49           15            3

?100
     50           16            3

?85
     51           17            3

?85
     52            1            4

?92
     53            2            4

?92
     54            3            4

?98
     55            4            4

?78
     56            5            4

?84
     57            6            4

?91
     58            7            4

?82
     59            8            4
```

```
?89
    60         9         4

?84
    61        10         4

?86
    62        11         4

?77
    63        12         4

?77
 Press any key to continue
?
    64        13         4

?77
    65        14         4

?79
    66        15         4

?100
    67        16         4

?85
    68        17         4

?85

 Do you want to recode another range of values?
?No
 Enter Output GIS filename:
?VAR3
# 0
# 0

 Please enter a description for the new GIS variable
 :
?SCS Curve Numbers

 Do you want to enter class names for the output variable
?No
 Use the whole image?
?Yes
\
 ERD>
>del lcode.*
>del hydcon.*
 ERD>
>gismo
 GISMO -- GIS Modeling
 Version 7.4.03.447
# 1
```

```
? 111   0 Land.dsc->vars
 Enter Model Library filename:
?agnps
# 1
?  13   0 Land.dsc->vars
 Enter land filename:
?land
# 1
# 1
# 0
# 0
# 0
# 0
# 0
# 1
# 4

 Enter maximum output file value for clipping
?100
# 0
# 4

 Enter maximum output file value for clipping
?100
# 0
# 4

 Enter maximum output file value for clipping
?100
# 0
# 4

 Enter maximum output file value for clipping
?250
# 0
# 4

 Enter maximum output file value for clipping
?4
# 0
# 1
? 129   0 slope->var4
? 129   0 Slope->Var6
?  13   0 Slope->Var6
 Enter slope class filename:
?slope
# 1
# 0
# 1
# 4

 Enter maximum output file value for clipping
?400
# 0
# 1
```

```
? 130   0 LAND->CODE
? 130   0 SOIL->HYDROCON
? 130   0 Soil.dsc->vars
?  13   0 Soil.dsc->vars
# 1
# 1
# 1
# 1
# 0
# 0
# 1
# 1
# 4

 Enter maximum output file value for clipping
?100
# 0
# 4

 Enter maximum output file value for clipping
?4
# 0
# 1
? 120   0 Soil.dsc->vars
\
 ERD>
>noaud
-------------------------------------------------------------------
```

Appendix H: *The SUB1.AUD batch file*

```
--------------------------------------------------------------------
>ERDAS|NOMENU
 ERD>
>GRDPOL
 GRDPOL -- Grid Polygons
 Version 7.4.02.445
 Enter Output GIS filename:
?SUB
# 0
 Get Input Polygon file names from the Keyboard, Name file or
   Directory selection
?Keyboard
 Enter Input Polygon filename:
?SUB
# 1

?No

 Enter pixel size (x,y) for output
?1320,1320

 Enter upper left map X coordinate
?
 Enter upper left map Y coordinate
?
 Enter lower right map X coordinate
?
 Enter lower right map Y coordinate
?
 Enter the number of classes
?1900

 Is this correct?
?Yes
 Enter initialization value
?0
# 1
\
 ERD>
>ERDAS|NOMENU
 ERD>
>copy sub.GIS var1.lan
 ERD>
>copy sub.GIS var3.lan
 ERD>
>copy sub.GIS var5.lan
 ERD>
>copy sub.GIS var6.lan
 ERD>
>copy sub.GIS var9.lan
 ERD>
>copy sub.GIS var10.lan
 ERD>
```

```
>copy sub.GIS var11.lan
 ERD>
>copy sub.GIS var12.lan
 ERD>
>copy sub.GIS var13.lan
 ERD>
>copy sub.GIS var15.lan
 ERD>
>copy sub.GIS var16.lan
 ERD>
>copy sub.GIS var17.lan
 ERD>
>copy sub.GIS var18.lan
 ERD>
>copy sub.GIS var19.lan
 ERD>
>copy sub.GIS var20.lan
 ERD>
>copy sub.GIS var21.lan
 ERD>
>copy sub.GIS land.gis
 ERD>
>copy ..\land.dsc
 ERD>
>copy sub.GIS river.gis
 ERD>
>copy sub.GIS elev.lan
 ERD>
>copy sub.GIS elevx.lan
 ERD>
>copy sub.gis hydro.gis
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR3.GIS
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\hires
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR3
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)
```

```
?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR6.GIS
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR6
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
```

```
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR9.GIS
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR9
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
        Nearest Neighbor
        Bilinear Interpolation
        Cubic Convolution
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR10.GIS
# 1
 Enter Option :
```

```
?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR10
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR11.GIS
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR11
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)
```

```
?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
        Nearest Neighbor
        Bilinear Interpolation
        Cubic Convolution
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR13.GIS
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR13
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
        Nearest Neighbor
        Bilinear Interpolation
        Cubic Convolution
 Use which technique?
```

```
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR15.GIS
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR15
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR16.GIS
# 1
 Enter Option :

?G - Read .CFN File
```

```
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR16
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\VAR20.GIS
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?VAR20
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
```

```
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
 Use which technique?
?Bilinear Interpolation
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\ELEV
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?ELEV
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?No

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
 Use which technique?
?Cubic Convolution
```

```
\
 ERD>
>LRECTIFY
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?Image
 Enter Input Image filename:
?..\ELEVX
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\LORES
# 1
 Enter Option :

?J - Proceed
 Enter Output Image filename:
?ELEVx
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?No

 Available techniques for data resampling:
       Nearest Neighbor
       Bilinear Interpolation
       Cubic Convolution
 Use which technique?
?Cubic Convolution
\
 ERD>
>SLOPE
 SLOPE -- Slope and Aspect
 Version 7.5.00.447
 Enter Input TOPO filename:
?ELEVX
# 1
 Topo is in units of Feet, Meters, Other?
?Feet
 Enter Output GIS filename:
?ASPECT
# 0
# 0
```

```
 Use the whole image?
?Yes
 Compute Slope or Aspect?
?Aspect
 Output 8-directional aspect or Degrees
?8-directional
\
>ERDAS|MENU
 ERD>
>recode
 RECODE -- Recode GIS Classes
 Version 7.4.02.434
 Enter Input GIS filename:
?aspect
# 1
# 1

 Is this the variable you wanted?
?Yes
 Enter range of values to recode (-1 to recode as is)
?0,9
 Enter recode option:
  Individual, Block, or Offset
?Individual
 Background

?0
 East

?3
 North East

?2
 North

?1
 North West

?8
 West

?7
 South West

?6
 South

?5
 South East

?4
 Flat

?0
```

```
 Do you want to recode another range of values?
?No
 Enter Output GIS filename:
?var14.lan
# 0
# 0

 Please enter a description for the new GIS variable
 :
?

 Do you want to enter class names for the output variable
?No
 Use the whole image?
?Yes
\
 ERD>
>slope
 SLOPE -- Slope and Aspect
 Version 7.5.00.447
 Enter Input TOPO filename:
?elev
# 1
 Topo is in units of Feet, Meters, Other?
?Other
 Enter conversion factor (topo units / map units)
?.1
 Enter Output GIS filename:
?var4.lan
# 0
# 0
 Use the whole image?
?Yes
 Compute Slope or Aspect?
?Slope
 Output slope as Percent or Degrees?
?Percent
\
ERD>
>lrectify
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?GIS
 Enter Input GIS filename:
?..\land
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\HIRES
# 1
 Enter Option :
```

```
?J - Proceed
 Enter Output GIS filename:
?land
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?Yes
# 1
# 0
\
 ERD>
>grdpol
 GRDPOL -- Grid Polygons
 Version 7.4.02.445
 Enter Output GIS filename:
?hydro
# 1
 Get Input Polygon file names from the Keyboard, Name file or
   Directory selection
?Keyboard
 Enter Input Polygon filename:
?..\river
# 1

?No
\
 ERD>
>gismo
 GISMO -- GIS Modeling
 Version 7.4.03.447
# 1
? 111   0 Land.dsc->vars
 Enter Model Library filename:
?..\agnps
# 1
? 130   0 CHslope
?  13   0 CHslope
# 1
# 1
# 1
# 1
# 0
# 0
# 1
# 1
# 1
```

```
# 4

 Enter maximum output file value for clipping
?1900
# 0
# 4

 Enter maximum output file value for clipping
?15
# 0
# 1
? 129   0 Ch Ind
?  13   0 Ch Ind
 Enter riv filename:
?hydro
# 1
 Enter land filename:
?land
# 1
# 1
# 0
# 1
# 1
# 4

 Enter maximum output file value for clipping
?10
# 0
# 1
? 120   0 Ch Ind
\
 ERD>
>del aspect.*

 press any key to continue
?
 ERD>
>del land.*

 press any key to continue
?
 ERD>
>del elev.*

 press any key to continue
?
 ERD>
>del buffer.*

 press any key to continue
?
 ERD>
>del hydro.*

 press any key to continue
```

```
?
 ERD>
>del elevx.*

 press any key to continue
?
 ERD>
>del river.*

 press any key to continue
?
 ERD>
>lrectify
 LRECTIFY -- Linear Rectification
 Version 7.4.04.445
 Rectify a GIS or Image file?
?GIS
 Enter Input GIS filename:
?..\rivasp
# 1
 Enter Option :

?G - Read .CFN File
 Enter Coefficient filename:
?..\rivasp
# 1
 Enter Option :

?J - Proceed
 Enter Output GIS filename:
?var14.lan
# 1
 Overwrite the file?
?Yes
 Map coordinates of upper left corner (X,Y)

?
 Map coordinates of lower right corner (X,Y)

?

 Should zeroes from the input file overwrite values
 in the output file ?
?No
# 1
# 1
\
 ERD>
>tabdata
 TABDATA - Import from ASCII Data Tabular Format
 Version 7.5.01.449
 Enter ASCII Input filename:
?cellid.csv
# 1
```

```
 Is the input file referenced to map coordinates?
?No
 Number of columns in the output file
?
 Number of rows    in the output file
?
 Enter starting X position of upper left corner
?1
 Enter starting Y position of upper left corner
?1
 Create a 4-bit, 8-bit, or 16-bit output file?
?1
# 0

 Press any key to continue
?
 Enter LAN filename:
?var1
# 1
 Overwrite the file?
?Yes
\
 ERD>
>copy var14.trl var1.trl
 ERD>
>noaud
------------------------------------------------------------------------
```

Appendix I: *The SUB2.AUD batch file*

```
----------------------------------------------------------------------
>ERDAS|NOMENU
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No

 Use gis file as mask for scan
?No

 Enter option
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication

 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)

?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  48   0
?  49   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
? 120   0

 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
```

```
 Enter Output GIS filename:
?north
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No

 Use gis file as mask for scan
?No

 Enter option
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication

 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)

?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  48   0
?  48   0
?  49   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
? 120   0
```

```
 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
 Enter Output GIS filename:
?neast
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No

 Use gis file as mask for scan
?No

 Enter option
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication

 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)

?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  49   0
```

```
?  48   0
?  48   0
?  48   0
? 120   0

 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
 Enter Output GIS filename:
?east
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No

 Use gis file as mask for scan
?No

 Enter option
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication

 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)

?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  48   0
```

```
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  49   0
? 120   0

 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
 Enter Output GIS filename:
?seast
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No

 Use gis file as mask for scan
?No

 Enter option
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication

 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)
```

```
?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  49   0
?  48   0
? 120   0

 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
 Enter Output GIS filename:
?south
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No

 Use gis file as mask for scan
?No

 Enter option
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication
```

```
 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)

?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  49   0
?  48   0
?  48   0
? 120   0

 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
 Enter Output GIS filename:
?swest
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No

 Use gis file as mask for scan
?No

 Enter option
```

```
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication

 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)

?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  48   0
?  48   0
?  48   0
?  49   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
? 120   0

 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
 Enter Output GIS filename:
?west
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>scan
 SCAN -- GIS Filtering
 Version 7.4.02.449
 Enter Input GIS filename:
?var1.lan
# 1
# 1
 Is this the variable you wanted?
?Yes
 Enter range of values to change (-1 to use as is)
?-1
 Use the whole image?
?Yes

 Use polygon file to restrict scan area
?No
```

```
 Use gis file as mask for scan
?No

 Enter option
?A = Total

 Select Border option (Duplication or Initialization)

?Duplication

 Enter scan window option (Rectangle, Circle, Donut, or Arbitrary
window)

?Arbitrary window

 Enter box dimensions (X,Y)
?3,3
?  49   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
?  48   0
? 120   0

 Is this window correct?
?Yes

 Exclude zero input values from analysis
?No
 Enter Output GIS filename:
?nwest
# 0
# 0

 Please enter a description for the new GIS variable
 :
?
\
 ERD>
>noaud
-------------------------------------------------------------------
```

Appendix J: *The SUB3.AUD batch file*

```
---------------------------------------------------------------------
>ERDAS|NOMENU
 ERD>
>..\del2
 ERD>
>fixhed
 FIXHED -- Fix Header
 Version 7.4.02.434

 Is this an Image file or a GIS file?
?Image
 Enter Image filename:
?a
# 1
 Number of columns in this data set
?
 Number of rows    in this data set
?
 Number of bands   in this data set
?22

 Enter starting X position of upper left corner
?1
 Enter starting Y position of upper left corner
?1

 Is data packed as 4-bit, 8-bit, or 16-bit?
?16 bit

 Is data base associated with any type of map?
    (i.e., georeferenced or rectified)
?Yes
 Available Coordinate Types:
   1 = UTM                       99 = Other Map
   2 = State Plane              100 = Geographic (Lat/Lon)
   3 = Albers Conical Equal Area
   4 = Lambert Conformal Conic
   5 = Mercator
   6 = Polar Stereographic
   7 = Polyconic
   8 = Equidistant Conic
   9 = Transverse Mercator
  10 = Stereographic
  11 = Lambert Azimuthal Equal Area
  12 = Azimuthal Equidistant
  13 = Gnomonic
  14 = Orthographic
  15 = General Vertical Near-Side Perspective
  16 = Sinusoidal
  17 = Equirectangular
  18 = Miller Cylindrical
  19 = Van der Grinten
  20 = Oblique Mercator
```

```
 Specify coordinate type
?2

 Enter X map coordinate of upper left cell
?
 Enter Y map coordinate of upper left cell
?
 Enter X cell size
?
 Enter Y cell size
?

 What are the units of area?
    (Acres, Hectares, Other Units, or None)
?Acres
 Enter no. of Acres per cell
?
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var1
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?Yes
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var2
```

```
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?2
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var3
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?4
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434
```

```
 Image or GIS file?
?Image
 Enter Input Image filename:
?var4
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?5
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var5
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?6
```

```
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var6
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?7
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var7
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes
```

```
 Copy all bands in order?
?No
 For input band 1, enter output band
?21
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var8
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?22
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var9
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
```

```
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?8
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var10
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?9
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var11
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
```

```
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?10
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var12
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?11
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var13
```

```
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?12
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var14
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?3
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434
```

```
 Image or GIS file?
?Image
 Enter Input Image filename:
?var15
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?13
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var16
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?14
```

```
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var17
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?15
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var18
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes
```

```
 Copy all bands in order?
?No
 For input band 1, enter output band
?16
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var19
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?17
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var20
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
```

```
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?18
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var21
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?19
\
 ERD>
>subset
 SUBSET -- Subset/Mosaic Files
 Version 7.4.01.434

 Image or GIS file?
?Image
 Enter Input Image filename:
?var22
# 1
 Use the whole image?
?Yes
 Enter Output Image filename:
?a
```

```
# 1
 Overwrite the file?
?Yes

 Enter output file coordinates at which to place
    upper left corner of input subset
?1,1

 Should input zero values overwrite data in the output file?
?Yes

 Copy all bands in order?
?No
 For input band 1, enter output band
?20
\
 ERD>
>datatab
 DATATAB -- ASCII Data Tabular Format
 Version 7.4.04.449
 Dump an Image or GIS file
?Image
 Enter Image filename:
?a
# 1
 Include any other files?
?No

 Select option:
?Data file
 Enter upper left file coordinates
?1,1
 Enter lower right file coordinates
?
 Enter x skip factor
?1
 Enter y skip factor
?1
 Enter Ascii Output filename:
?output.xls
# 0
\
 ERD>
>noaud
---------------------------------------------------------------------
```

Appendix K: *ANSI-C Source Code for CELLID.EXE*

```
------------------------------------------------------------------
/*
 * This program converts the output generated by the ERDAS SUB1.AUD batch file
 * into a cell identification file (AGNPS variable 1).
 *
 */

#include <stdio.h>
#include <stdlib.h>

/* file constants */
#define inputFile  "input.txt"
#define inputFile  "output.txt"

/* constant definitions */
#define kMaxLine  150
#define kFirstRow 4

int main()
{
   FILE   *input,
      *output;
   char   inbfr[kMaxLine];
   int tempInt,
      row,
      col,
      stop,
      n,
      lineIndex;


   /* open the input file */
   if (!(input = fopen(inputFile, "r"))) {
      fprintf(stderr, "Can't open the input file\n");
      exit(-1);
   }

   /* open the output file */
   if (!(output = fopen(outputFile, "w"))) {
      fprintf(stderr, "Can't open the output file\n");
      exit(-1);
   }

   /* read input file */
   for (row = 0; fgets(inbfr, kMaxLine, input); row++)
   {

      /* ignore the first kFirstRow rows */
      if (row < kFirstRow) continue;

      for (lineIndex = 0, col = 1; col <= kMaxCol; col++, lineIndex += n) {

         /*read in the next integer */
```

```
            sscanf(&inbfr[lineIndex], " %d%n", &tempInt, &n);

            /*read the column value */
            switch (col) {
                case kFirstCol:
                case kSecondCol:
                    fprintf(output, "%07d" kColBreak, tempInt);
                    break;

                case kThirdCol:
                    if (tempInt == 0) fprintf(output, "%07d" kColBreak, tempInt);
                    else {
                        fprintf(output, "%07d" kColBreak, newInt);
                        newInt++;
                    }
                    break;

                default:
                    break;
            }
        }
    }

    /* close the files */
    fclose(input);
    fclose(output);

    return(0);
}
```

Appendix L: *ANSI-C Source Code for ERD2AGN.EXE*

```
-------------------------------------------------------------------
/*
 * This program converts the output generated by the ERDAS SUB3.AUD batch file
 * into AGNPS format.
 *
 */

#include <stdio.h>
#include <stdlib.h>

/* file constants */
#define kInputFileName       "input.txt"
#define kOutputFileName      "output.txt"
#define kRead            "r"
#define kOverWrite           "w"

/* constant definitions */
#define kFirstRow        4
#define kMaxLine         150
#define kMaxCol              kTwentysecondCol + 1

enum columns   {
    kFirstCol = 2,
    kSecondCol,
    kThirdCol,
    kFourthCol,
    kFifthCol,
    kSixthCol,
    kSeventhCol,
    kEighthCol,
    kNinthCol,
    kTenthCol,
    kEleventhCol,
    kTwelfthCol,
    kThirteenthCol,
    kFourteenthCol,
    kFifteenthCol,
    kSixteenthCol,
    kSeventeenthCol,
    kEighteenthCol,
    kNineteenthCol,
    kTwentiethCol,
    kTwentyfirstCol,
    kTwentysecondCol
};

/* multipliers */
#define kFirstColMult       1000
#define kSecondColMult      1000
#define kFifthColMult       0.1
#define kEighthColMult      0.01
#define kNinthColMult       0.01
#define kTwentyfirstColMult  0.1
```

```
/* column constants */
#define kSixthColVal         1
#define kEleventhColVal      1
#define kFifteenthColVal     10
#define kSixteenthColVal     0
#define kSeventeenthColVal   0
#define kNineteenthColVal    0

/* debugging macros */
/*#define DEBUG*/

#ifdef  DEBUG
    #define kColBreak       "|"
    #define DBGMSG(m)     fprintf(stderr, m"\n")
    #define DBGPAR(m,p)       fprintf(stderr, m"\n", p)
    #define PRT_DBG_HDR(f)    fprintf(f, "      1|       2|14|    3|     4| 5|    6|     9|
10|  11|    12|  13|15|16|  17|\n");
#else
    #define kColBreak
    #define DBGMSG(m)
    #define DBGPAR(m,p)
    #define PRT_DBG_HDR(f)
#endif

int main()
{
    FILE    *input,
            *output;
    char    inbfr[kMaxLine];
    int     tempInt,
            row,
            col,
            stop,
            n,
            lineIndex;

    /* open the files */
    if (!(input = fopen(kInputFileName, kRead)))    {
        fprintf(stderr, "Can't open the input file\n");
        exit(-1);
    }

    if (!(output = fopen(kOutputFileName, kOverWrite)))    {
        fprintf(stderr, "Can't open the output file\n");
        exit(-1);
    }

    /* debugg file header */
    PRT_DBG_HDR(output);

    /* reset row and begin reformatting the text - exit: fgets returns NULL when EOF
*/
    for (row = 0; fgets(inbfr, kMaxLine, input); row++)    {
```

```
        /* ignore the first kFirstRow rows */
        if (row < kFirstRow)
            continue;

        for (lineIndex = 0, stop = 0, col = 0; col < kMaxCol && !stop; col++, lineIndex
+= n)   {
            /* read in the next integer */
            sscanf(&inbfr[lineIndex], " %d%n", &tempInt, &n);

            /* read the column value */
            switch (col)   {
                case kFirstCol:
                    /* if column one is zero, delete the line */
                    if (!tempInt)      {
                        stop = 1;
                        break;
                    }
                    fprintf(output, "%07d" kColBreak, tempInt * kFirstColMult);
                    break;

                case kSecondCol:
                    fprintf(output, "%07d" kColBreak, tempInt * kSecondColMult);
                    break;

                case kThirdCol:
                case kThirteenthCol:
                    fprintf(output, "%02d"kColBreak, tempInt);
                    break;

                case kFourthCol:
                case kSeventhCol:
                case kEighteenthCol:
                    fprintf(output, "%04d"kColBreak, tempInt);
                    break;

                case kFifthCol:
                    fprintf(output, "%05.1f" kColBreak, (float)tempInt * kFifthColMult);
                    break;

                case kSixthCol:
                    fprintf(output, "%02d" kColBreak, kSixthColVal);
                    break;

                case kEighthCol:
                    fprintf(output, "%05.3f"kColBreak, (float)tempInt * kEighthColMult);
                    break;

                case kNinthCol:
                case kTenthCol:
                case kTwelfthCol:
                    fprintf(output, "%04.2f"kColBreak, (float)tempInt * kNinthColMult);
                    break;

                case kEleventhCol:
                    fprintf(output, "%05.2f"kColBreak, (float)kEleventhColVal);
```

```
                    break;

                case kFourteenthCol:
                    fprintf(output, "%02d"kColBreak, tempInt);
                    break;

                case kFifteenthCol:
                    fprintf(output, "%04d"kColBreak, kFifteenthColVal);
                    break;

                case kSixteenthCol:
                    fprintf(output, "%02d"kColBreak, kSixteenthColVal);
                    break;

                case kSeventeenthCol:
                    fprintf(output, "%04d"kColBreak, kSeventeenthColVal);
                    break;

                case kNineteenthCol:
                    fprintf(output, "%03d"kColBreak, kNineteenthColVal);
                    break;

                case kTwentiethCol:
                    if (tempInt <= 1)
                        stop = 1;
                    fprintf(output, "%02d\n", tempInt);
                    break;

                case kTwentyfirstCol:
                    fprintf(output, "%07.1f"kColBreak, (float)tempInt *
kTwentyfirstColMult);
                    break;

                case kTwentysecondCol:
                    fprintf(output, "%07.1f\n", (float)tempInt);
                    break;
                default:
                    /* delete columns not specified */
                    break;
            }
        }
    }

    /* close the files */
    fclose(input);
    fclose(output);

    /* bye bye */
    return(0);
}
```