ALTERNATIVE FUTURES FOR THE NORTHERN FLINT HILLS: SCENARIOS PROVIDED BY HYDROLOGIC MODELING

by

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Abstract

Environmental degradation is a major concern in agricultural landscapes. Innovative tools and methods will be necessary to identify and deal with the ongoing environmental impacts of past and present agricultural practices. The use of scenarios in environmental modeling is one way to address these concerns. Recently a group of researchers devised a framework for creating future land cover scenarios for two physiographic regions in Iowa. Based on that work, a suite of scenarios were created for Antelope Creek watershed in the Northern Flint Hills of Kansas. The Antelope Creek scenarios represent conditions pre Euro-American settlement, present day, increased intensification of agricultural production, enhancement of water quality, and enhancement of biodiversity. These scenarios were then modeled using the Soil and Water Assessment Tool (SWAT). Additional model runs were completed to compare SSURGO and STATSGO soil datasets. Results indicated that reductions in discharge, total suspended sediment and various nitrogen and phosphorus loads could be achieved by implementing modest changes to agricultural management practices. Results also indicated that a higher detail soil dataset such as SSURGO lead to slightly higher loads than with STATSGO data.

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CHAPTER 1 - Global change, scenario development, and the Flint Hills

Global Change and Agriculture

The nature of the Earth makes it a challenging system to study. Dynamism inherent in the flows of energy and matter adds to the complexity of system components interacting over space, scale, and time. A major challenge in designing tools for ecosystem assessment and management is this dynamic nature and the need to couple interacting subsystems (Gillison and Willis 2004). Our understanding of the physical processes of the Earth continues to improve but will never be complete. Uncertainty can be problematic when attempting to manage ecosystems, and communicate those management objectives to local stakeholders.

Adding humans and their behavior further complicates the study of the Earth system processes and interactions. Humans more than any other species have achieved the ability to alter the environment to suit there own needs for survival. In this respect, perhaps one of the biggest impacts humanity has accomplished is the conversion of roughly 1/3 of the terrestrial planetary surface to cultivated agriculture systems (DeFries *et al.* 2004, Millennium Ecosystem Assessment 2005). Disturbances of this magnitude can lead to unintended feedback effects as the system adjusts to either maintain the status quo or move into a new state of equilibrium. In many cases, the expression of these changes and feedbacks are often not fully understood until they are already evident in a landscape.

Agriculture and Environmental change in the United States

The United States has been a leader along the path toward a domesticated planet, converting over 50% of total land area to cropland (USDA 1992). Along with the mass conversion of land use/ land cover (LULC), humans have also found ways to increase the amount of production on a given area of cultivated land. Agricultural intensification has been the result of several factors present in the United States during the 20th century. These include the spread of new agricultural technology (e.g. mechanization, irrigation, new crop varieties, and fossil fuel based fertilizers), the commercialization of agricultural commodity markets increasing demand for agricultural products, and government policies that have favored increased production (Gardner 2002). Unfortunately, progress in agricultural expansion and production came with serious costs for the environment.

The need for methods and tools to assess long term system change resulting from human impact on the environment has never been more prevalent. There is a strong body of evidence indicating that changes in the scale and intensity of agriculture have had damaging impacts on Earth's ecosystems (Pimentel *et al.* 1995). These impacts include loss of biodiversity that accompanies conversion of natural ecosystems to agriculture, pollution of water sources (ground and surface) from nutrients and pesticides applied to croplands, and soil degradation from over use (DeFries *et al.* 2004, Tilman *et al.* 2002). To understand the complexity of these system changes, and their impediment to long term sustainability, will require innovative tools and strategies for scientists, managers, policy makers, and stakeholders.

One suite of tools for coupling human and natural systems to address the relative impact of potential change is environmental modeling. The research performed for this Master's thesis uses the Soil and Water Assessment Tool (SWAT) to compare and contrast a number of scenarios for change in the Antelope Creek watershed in the Flint Hills of Kansas.

The Dynamics of Grasslands and the Flint Hills

As humans continue to influence more of the earth and its processes, we increasingly disturb that which is considered wild, untouched, or natural. Grasslands are believed to be a natural vegetative response to a number of environmental drivers. The tallgrass prairie of the interior United States is considered one of the most widely transformed ecosystems in the world. Grasslands once occupied a considerable part of the central North American continent. Settlement by Native American's and burning to encourage grazing was probably the first know management of tallgrass prairie. The influence of European settlement and expansion played a large role in the expansion of human settlement in the plains. Possibly the single largest influence on the prairies has been the proliferation, and intensification of agriculture across the central Great Plain region (Middendorf *et al.* 2008). This manipulation of the tallgrass prairie saw its peak in the 20th century as agricultural practices were blamed for the onset of the Dust Bowl. The soil conservation service was formed by president Franklin D. Roosevelt in response to the soil erosion problem of the 1930's, and conservation has been a part of farming ever since. While detrimental agricultural practices were at their pinnacle in the early 20th century, foundations for this disturbance were laid in the preceding decades and centuries.

Native American occupancy of the central Plains region is believed to have begun around 12,000 to 11,500 years ago with the Clovis people (Sherow 2007). These people are thought to have been a society that subsisted using hunting and gathering methods. As early as 8,000 years ago, native people may have been employing fire as a management tool in the tallgrass prairie. Later groups of Native Americans are believed to have used fire to burn off old biomass, creating greener, more lush growth to attract buffalo. This legacy of fire is still a major influence in the tallgrass landscape today, as burning is incorporated in rangeland management strategies to increase grass growth and weight gains in production animals.

European settlement in the Americas and subsequently the plains has been arguably the largest influence on the tallgrass prairie. The spread of Euro-borne diseases ravaged indigenous populations, as they were exposed to small pox, measles, chicken pox and other infectious diseases for the first time. The economic systems and associated production practices of Euro-American settlers also changed the patterns present on the landscape. During the mid to late 19th Century the frontier was opened to settlers from the East. During this time waves of pioneers moved onto the prairies of the Flint Hills. The grassland was tilled up and in its place cash crops were planted, and grazing came to dominate the upland areas with shallow soils. By the 1880's barbed wire had put an end to the free range grazing in the uplands in the Flint Hills, and subsequent droughts drove many small farm holders out of the trade. Many of these small farms were bought by ranching operations and subsequently grazing became a major influence on the landscape which, like burning, persists to this day.

Today the Flint Hills are home to the largest tract of tallgrass prairie in the United States. Grazing and hay production are still major agricultural enterprises in the area, and burning is widely practiced to increase biomass for production. Some have argued that the prairie only exists in relation to burning, which is either anthropogenically induced, or ignited by lightning strikes. This makes the tallgrass prairie a fertile ground for study of human impact on environment, and to improve our understanding of how society can influence a socio-ecological system through time.

Ecosystem Management and Nature

Ecosystem management attempts to balance the demands society places on the environment with maintaining the integrity of natural systems (Furuseth and Cocklin 1995). When managing the natural environment there is an emphasis on meeting human needs, but also the understanding that serving human interest occurs only insofar as the ecosystem has the ability to maintain health and function. This means that in order to successfully manage agricultural ecosystems, producers must maintain their natural resources capital as they meet their own economic goals by providing goods and services to society. Given recent concerns over bio-energy and food production, agricultural products will continue to be in demand. Meeting the needs of society will be a daunting task due to the aforementioned complexity of coupled human-environment systems. Nonetheless, facing these challenges is necessary to meet the concerns of recent and on-going environmental degradation. Environmentally keen agricultural management will necessitate innovative and dynamic tools in order to balance the increasing demand for grain with the natural limitations of the environment. Ideas from landscape ecology are helpful in meeting the challenge of ecosystem management and sustainability.

Incorporating landscape ecology principles into sustainability science will be critical as managed lands increase. Managers will need a way to reconcile and evaluate the potential impacts on ecosystems in order to maximize production while avoiding serious impacts to the functionality of the system. Dale *et al.* (2001) proposed a set of guidelines for land use that are helpful to bear in mind when evaluating possible management strategies:

- Examine the impacts of local decisions in a regional context.
- Plan for long-term change and unexpected events.
- Preserve rare landscape elements, critical habitats, and associated species.
- Avoid land uses that deplete natural resources over a broad area.
- Retain large contiguous or connected areas that contain critical habitats.

- Minimize the introduction and spread of nonnative species.
- Avoid or compensate for effects of development on ecological processes.
- Implement land-use and land management practices that are compatible with the natural potential of the area.

The principles outlined by Dale *et al.* fit well with the ideas expressed above about ecosystem management. They take into account both the human and the natural elements of the system, but they also address the issues of time, scale, and space. However these ideas are only a portion of ecosystem management. New tools and strategies will be necessary to manifest these ideas into actual land-use practices (Santelmann *et al.* 2001).

Hydrologic Modeling in Support of Environmental Management

Hydrologic models play a prominent role in water quality monitoring and assessment. There are several models available to a user depending on the type of questions being asked. These models can be either statistical models, employing statistical equations to predict outcomes, or physically based models, which use representations of physical processes to predict outcomes for single events or a continuous simulation. Models such as the Spreadsheet Tool for estimating Pollutant Load (STEPL) uses simple equations in a spreadsheet to estimate pollutant loads, while a model such as the Soil and Water Assessment Tool (SWAT) can be used to simulate years of outcomes based on user supplied inputs pertaining to the study area.

SWAT is a spatially explicit continuous model that can be used to simulate long term hydrologic processes (Arnold 2005). The SWAT model requires certain datasets in order to run. The three major requirements are elevation data, landcover data, and soils data. While SWAT incorporates a weather generating feature that can be used in place of temperature and precipitation data, local data are preferred for hydrologic modeling.

In modeling the alternative future scenarios for Kansas, the question was raised as to whether the SWAT model was sensitive to the manipulations of the scenarios. Hernandez *et al*. (2000) discuss the impact of changing land cover data on pollutant loads generated by SWAT. The authors state that the Curve Number (CN) is the most important factor. They also discuss the factors which determine the CN, which are hydrologic soil group, hydrologic condition, cover type, treatment, and antecedent runoff condition. The scenarios created for Antelope Creek watershed include the switch from one LULC to a different LULC in the future. Inherent in this conversion is the adjustment of the CN in these areas. In addition to the CN being adjusted by shifting land cover, one of major manipulations incorporated in the management practices for the Water Quality and Biodiversity scenarios was the reduction of the CN, the resulting lower loads for nearly all pollutants in these two scenarios would tend to reinforce the work done by Hernandez *et al*. Previous research findings, while not explicitly focused on SWAT sensitivity to land cover, speak to the impact of land cover datasets on sub-watershed delineation (Romanowicz *et al*. 2005, Bosch *et al*. 2004,). However in the case of this work, the same sub-basin delineation was used for all scenarios, thereby negating the impact of sub-basin delineation among scenarios.

An Environmental Modeling Framework from Iowa

Recently a group of scholars addressing Gulf of Mexico hypoxia created a suite of scenarios to model environmental and economic response to changes in agricultural practices (Nassauer *et al.* 2007; Nassauer *et al.* 2002; Nassauer and Corry 2004; Santelmann *et al.* 2004). Three scenarios addressed different emphasis in policy and field scale management practices. The goal of this work on watersheds in Iowa was to provide policymakers with likely outcomes from a suite of alternative futures which could be used for planning and analysis. One potential result of this modeling scenario strategy would be to reduce the risk of unexpected side effects of societal or environmental changes. The scenarios were created to represent plausible manipulations of the current land use land cover in a way which addressed environmental concerns, but did so at a cost manageable to stake holders (i.e. farmers and ranchers). The value of local acceptance of ideals related to conservation cannot be underestimated, but economics tend to drive much of the decision making process on the farm, as the types of conservation practices that can be implemented on farm are directly related to the cost to the producer.

The first scenario is based on continued agricultural intensification. This scenario reflects policy and management decisions that cultivate any ground suitable. Activities include removing forests, pasture, or rangelands from agriculturally productive soils and planting them to corn or soy beans. The second scenario has the goal of improving water quality. Management practices incorporated include converting less suitable crop lands to pasture or hayed lands to reduce erosion. The final scenario deals with enhancing biodiversity. Defragmenting the agricultural landscape by creating corridors throughout the study area is an example of a management practice included in this scenario (Nassauer and Corry 2004).

The three specific scenarios were created to reflect plausible responses of the contemporary socio-political landscape in west central Iowa. As agricultural practices change, scenarios can be created to accommodate these changes. Scenario development allows analysis of possible impacts, but the outcomes of the scenarios are not as important as exploring the possibility of maximizing the potential benefits for both the human and natural aspects of the system and comparing alternative futures. As Nassauer and Corry state in respect to scenarios:

> *Knowing what landscape pattern to aim for may inspire new assumptions about what constitutes a plausible scenario and provoke policy-makers to be more inventive than they might otherwise have been...*

These scenarios should be looked at as tools to give policy makers and stake holders the flexibility to better assess the impacts of their decisions, and possibly alter them in a way that is amenable to competing interests.

This pioneering work in Iowa was carried out over a six year period with collaboration from several institutions and a small army of researchers. Scenarios were created through an iterative process of creation, critique, and refinement until the team was confident that the future created in the scenario was a plausible manipulation of the present land cover and local mindsets (Nassauer and Corry 2004). In determining plausibility, the scenarios were subjected to roundtable critiques by scientists from several disciplines then adjusted accordingly. Another step in the scenario refinement process was submitting the end changes to local stakeholders in the respective watershed to gauge the implementation potential. This was done by manipulating aerial photos to represent the changes in the physical landscape, and offering them up to stakeholders along with a survey for them to record their impressions.

Stakeholder interaction is an important step in creating effective change in the watershed. If people within the ecosystem are incorporated in the process of managing it, there is a much higher likelihood of acceptance among key actors within the system. Creating in-roads and working relationships within these communities fosters more effective communication and availability to a qualitative data source that is too often overlooked, the people living in and interacting with these ecosystems on a daily basis.

This initial work was carried out in the Corn Belt region of Iowa, so the choice to cultivate fields in corn and soybean rotations was a natural fit. Given the nature of petroleum prices, and the corresponding push for ethanol and biofuels in markets today, this choice in crops is fairly eloquent. It embodies the underlying spirit of creating the scenarios, which is not to duplicate reality, but to explore what kind of ends can be achieved, how to go about it, and what the environmental ramifications might be.

Given that this thesis research work is focused primarily on a framework of rapid assessment and development of scenarios for multiple purposes, the Iowa work contained many aspects vital to the process. The Iowa research team published design rules they followed to create their scenarios in the two study watersheds. The authors of the Iowa work were very cautious in the way they wrote the design rules in the hopes of avoiding a direct replication of their work in a different watershed. Their rules were designed for specific Iowa watersheds and to apply these rules directly to other watersheds would seriously undermine the validity of the resulting scenario. For the work in the Flint Hills of Kansas, this meant that it would be very important to understand local practices and management options.

Energy and matter flows of the Earth are difficult to account for when implementing agricultural management practices. The ever changing nature of the earth system, as well as human interactions with planetary processes requires constant innovation in methods and tools. The scenario building process developed in west central Iowa, and in this work applied to the Flint Hills of Kansas, is an example of the types of methods and tools needed to address the growing concerns of agricultural sustainability.

CHAPTER 2 - The Northern Flint Hills and Antelope Creek

The study area(s) selected by Nassauer and Corry for research in the U.S. Corn Belt were chosen for characteristics that allowed for creation of scenarios that could improve the environmental health of agricultural landscapes. Distinct physiographic regions were also identified as a rationale for the areas selected in the Corn Belt study (Nassauer and Corry 2004; Santelmann *et al.* 2004). For this research, the latter criterion was the basis for the selection of a study area. Specifically the aim of this work is to further examine alternative scenarios in the context of a tallgrass prairie ecosystem.

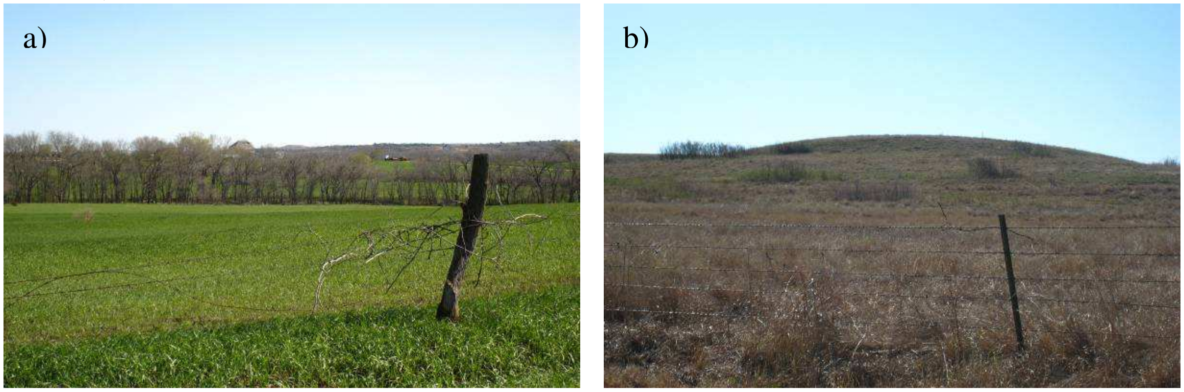
Antelope Creek (5,859 ha; 14,477 acres) is a second order watershed in Wabaunsee County Kansas located in the Flint Hills ecoregion (Omernik *et al.* 1987). The Flint Hills are uplands of cherty limestone containing rocky soils with relatively steep valleys composed of primarily shale (Evans 2004). This upland landscape makes for generally poor areas for crop farming compared to the bottomland areas along streams and rivers. The Flint Hills region is also the western edge of the tallgrass prairie, and home to the largest remaining tract of tallgrass in the North America. Annual precipitation in the Flints Hills is approximately 30–40 inches, and the growing season generally lasts 180 days beginning in April (Gooden *et al.* 2004, Hickman *et al.* 2004). Agricultural activities in the Antelope creek watershed involve a relatively high percentage of pasture and grazing practices and smaller amounts of small grain and row crop production due to the aforementioned shallow, cherty soils on the uplands.

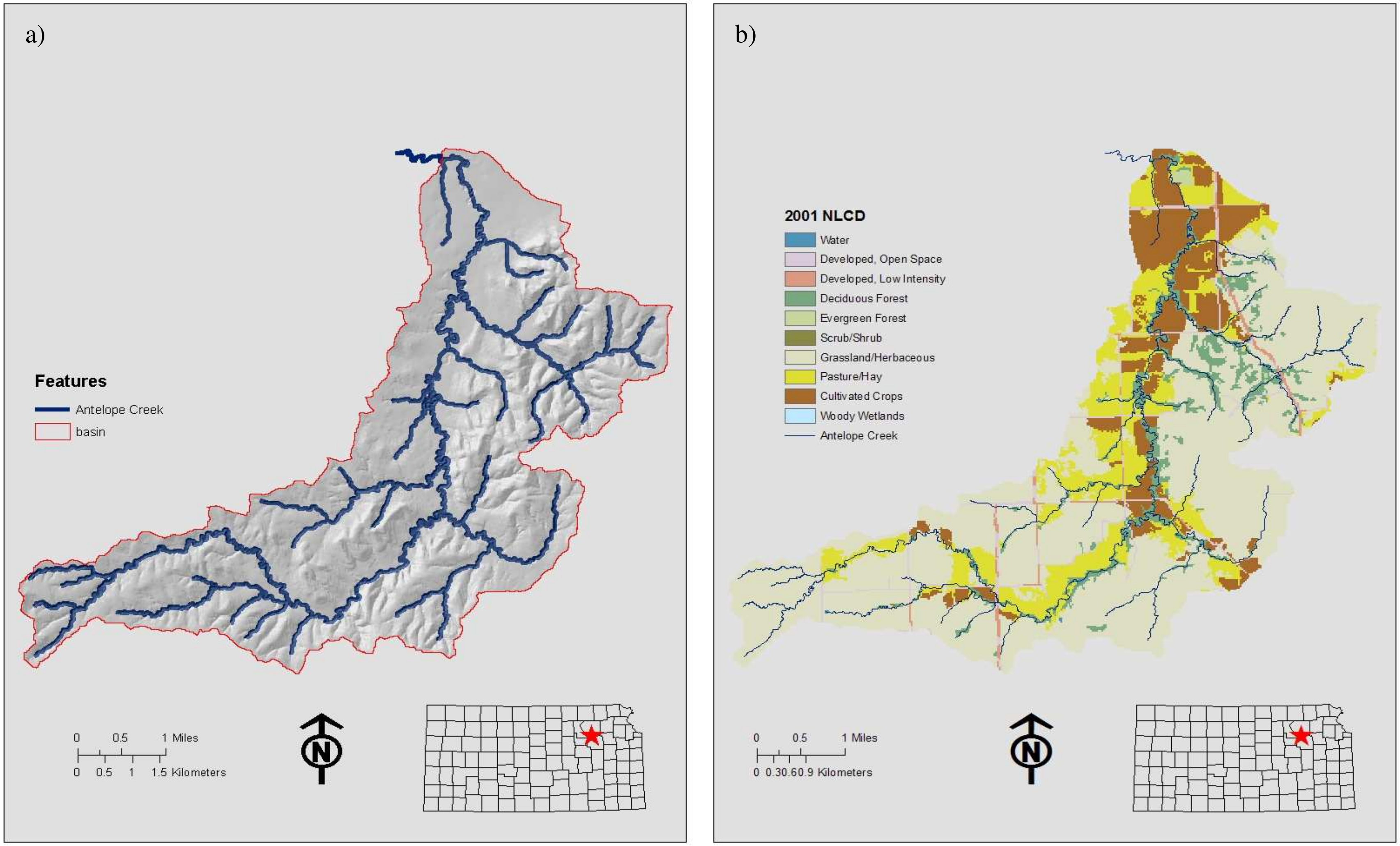
This study area represents a relatively different landscape than in the Corn Belt study, as nearly all agricultural in the Iowa study area(s) were under a row crop rotation of some sort

(Nassauer and Corry 2004). The implications for this application in Kansas are that the scenario rules used in Iowa made sense for a minority of the Antelope creek study area. Rules for landscape change in scenario development would need to be adapted to conform to the practices present in the Flint Hills landscape. The work in Iowa contained rules for which the limiting factor was something other than physical characteristics of the landscape (e.g. combine hopper capacity) and these rules were modified and applied in the Kansas work.

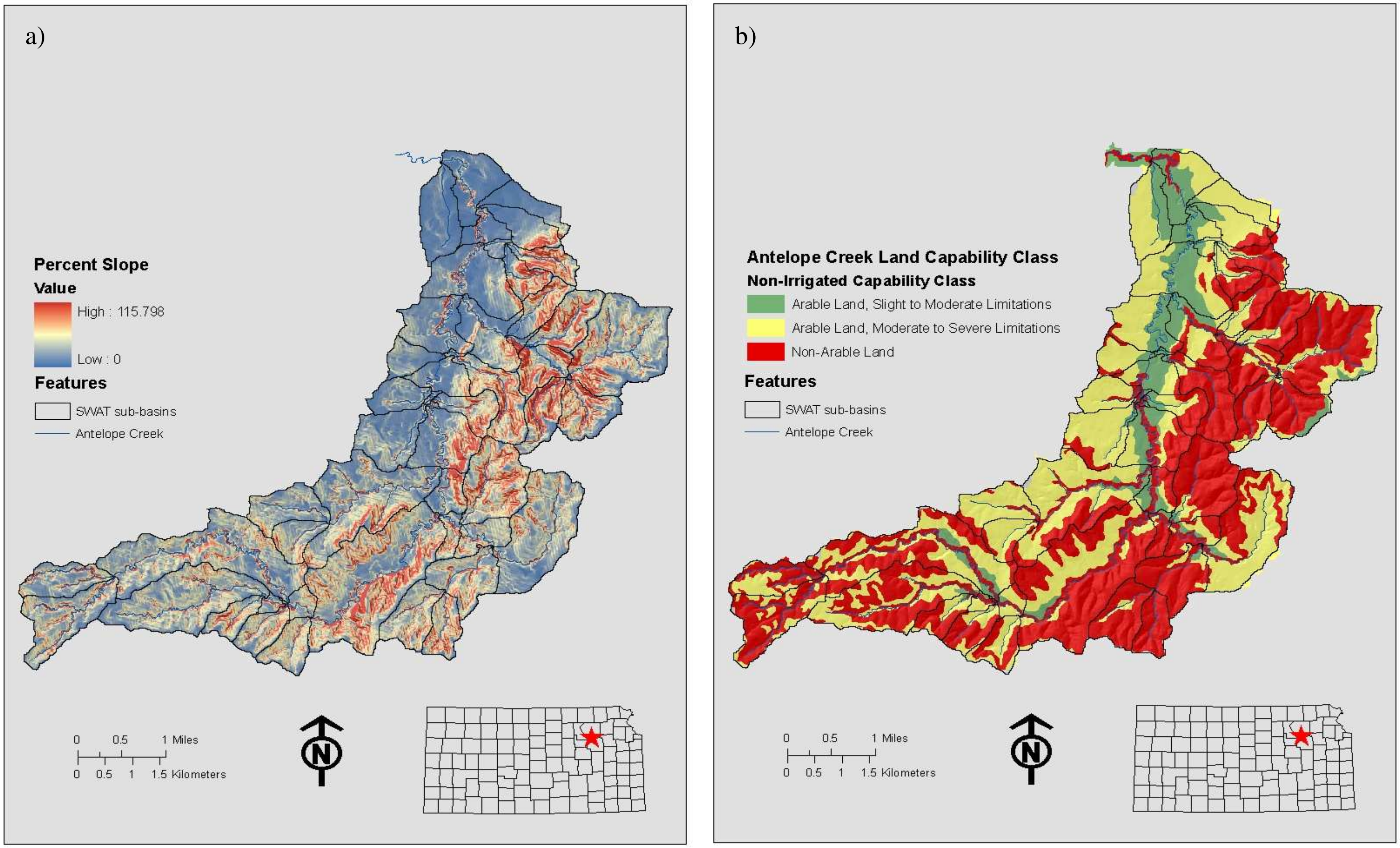
Primary land cover land uses in the Antelope Creek watershed are rangeland, cultivated crops, and pasture or hayed land (fig 2.1a & 2.1b). Pasture and hay make up the majority of agricultural fields while soybeans, wheat, corn, and sorghum are the most common crops grown in cultivated areas (fig 2.2b). Woodlands dominate along riparian corridors as slopes of stream banks are generally too steep and contain unsuitable soils for cultivation (fig 2.3a & 2.3b, 2.5 & table 2.1). The Antelope Creek watershed is sparsely populated and housing is low density farmsteads with grass lawns. A map of digital elevation is given in fig. 2.4.

2.1 Agricultural areas in Antelope Creek watershed: (a) alfalfa, (b) rangeland. (Source: Author)



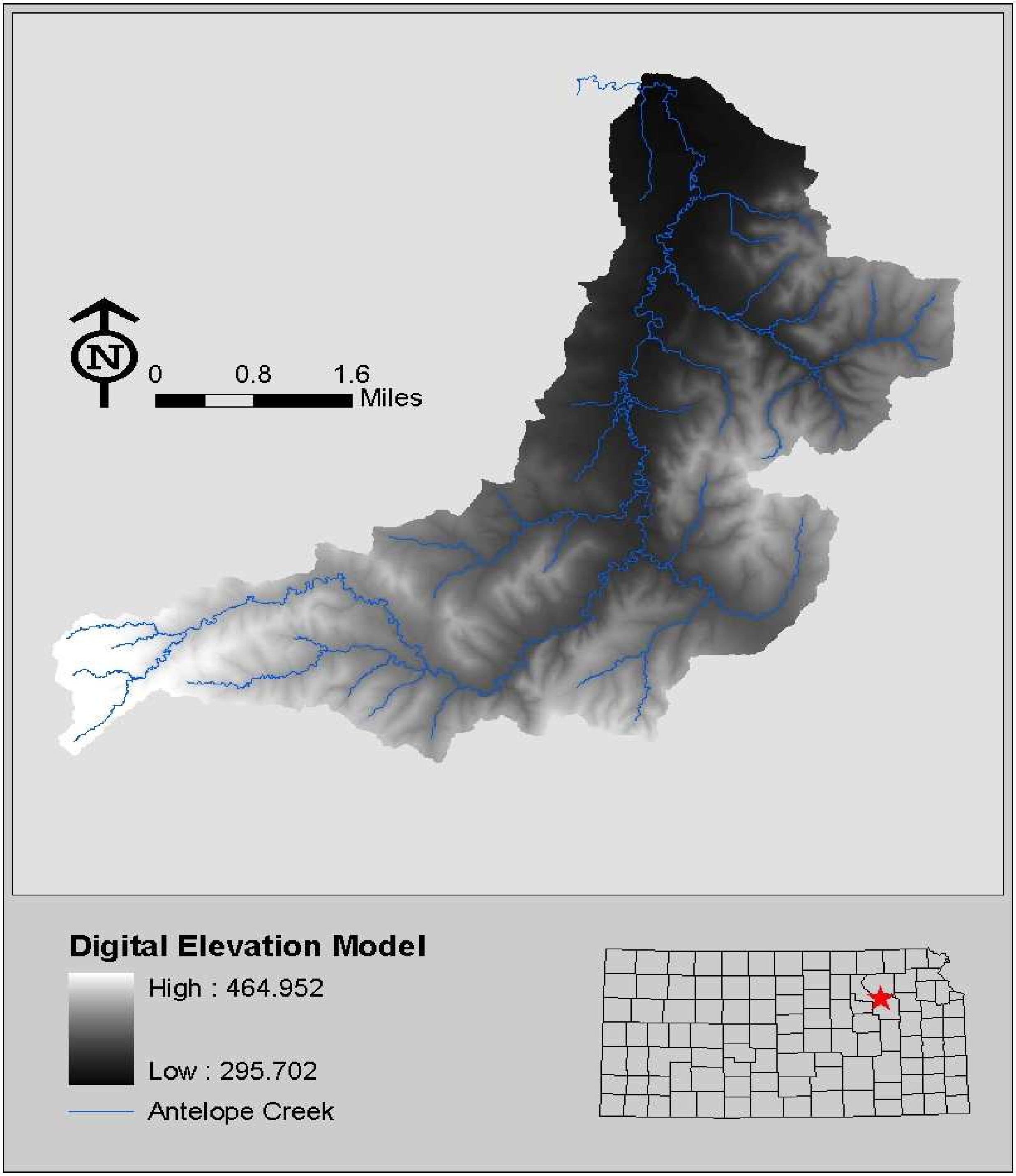


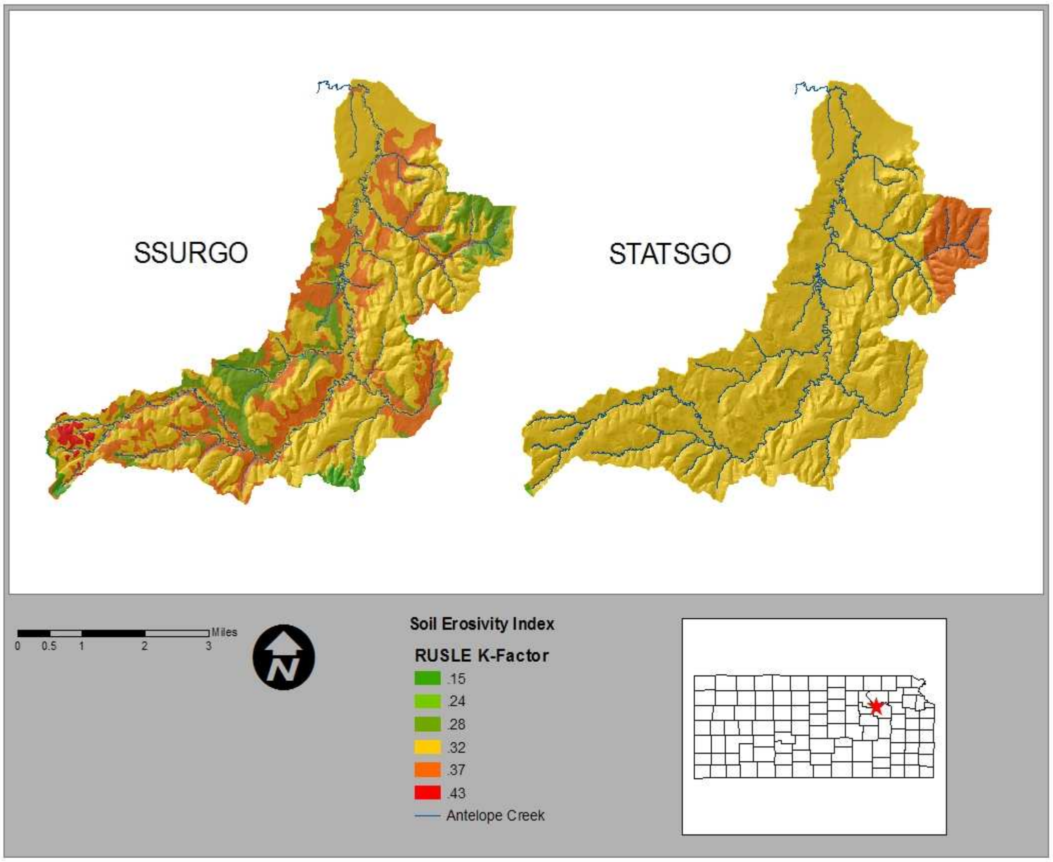
2.2 Antelope Creek in Wabaunsee and Riley counties in Kansas (a) and 2001 National Land Cover Dataset for Antelope Creek (b). (Source: United States Geological Survey)



2.3 Percent Slope (a) and Land Capability Class from NRCS SSURGO dataset for Antelope Creek (b). (Source: Natural Resources Conservation Service; United States Geological Survey

2.4 Ten meter resolution digital elevation model (DEM) of Antelope Creek watershed from the National Elevation Dataset (Source: USGS)





2.5 Map of erosivity (k-factor) for Antelope Creek Watershed (source: NRCS).

Soil Name	Erosivity				
Chase	.37	Irwin	.37	Martin	.37
Ivan	.32	Labette	.37	Martin, eroded	.28
Ivan	.32	Tully	.28	Morrill	.28
Ivan	.32	Wamego	.32	Morrill	.28
Chase	.37	Wamego	.32	Pawnee	.32
Clime	.32	Reading	.32	Pawnee	.32
Clime-Sogn	.32	Reading	.32	Pawnee, eroded	.32
Dwight-Irwin	.43	Eudora	.32	Wymore	.32
Florence-Labettte	.15	Elmont	.32	Wymore-Kennebec	.37
Irwin	.37	Gymer	.32		

Table 2.1 Erosivity values for soil types in Antelope Creek watershed (source: NRCS).

CHAPTER 3 - Designing Scenarios for Global Change: Data and Methods

For the work being presented here, the Iowa research is used as a blueprint. The main goal in this study was to try and apply the scenario design process used in Iowa to a tallgrass prairie ecosystem in Kansas. This work was carried out on a watershed of similar size as the Iowa watersheds, but was carried out over a shorter time period (roughly eighteen months) using the guidelines set forth in the published Iowa work (Nassauer *et al.* 2007).

When attempting to apply ideas or techniques from a previous study, methods transfer becomes the basis of the research. A goal of this work was to study the feasibility of applying the design rules for creating scenarios in the U.S. Corn Belt to the Tallgrass prairie of Kansas. The scenarios created in Iowa (and Kansas in this work) represent 1) a continued intensification of agriculture, 2) enhancing water quality, and 3) enhancing biodiversity. Scenarios were also created to represent a Pre Euro-American settlement tallgrass prairie, and a scenario representing the current conditions in present day Antelope Creek. The framework of the design rules was kept as close to the Corn Belt study (Nassauer *et al.* 2002) as possible while manipulating their application to tailor the rules to a prairie landscape. A number of questions arise in transitioning the design rules:

- Is a three meter buffer along a stream something we would find in Kansas or would it be a thirty meter buffer?
- What types of structural best management practices (BMPs) are suited to this area?
- Are there any BMPs already in use?

These are the types of questions that are asked during the process of transforming and applying the design rules to this particular study area. Inherent in the process of implementing the design rules, is the evaluation of datasets, models, and tools used to create the final scenarios. Throughout the study, an attempt was made to keep as many of the same data types and GIS tools as used with the Iowa Corn Belt work, deviating where necessary to better represent the specific watershed characteristics of Antelope creek.

The scenario development process for the Flint Hills ultimately required two major phases. First, scenario specific design rules are decided upon for the study area. After the rules have been decided on, present day land cover is reclassified according to each scenario's design parameters. This land cover data transformation is done in a GIS environment using modeling tools. After the land cover is converted, information about the landscape is incorporated into a watershed model (in this case the SWAT model), where the data are further manipulated to represent percentages of specific cover in the watershed (e.g. corn, soybean, big bluestem grass, alfalfa, etc.). The SWAT model also has built-in routines for modeling certain management operations such as tillage practices and manure application. In this way the specific management practices for each scenario were implemented in Antelope Creek.

In order to model water quality parameters, one needs to derive the drainage network first. Fortunately SWAT contains routines to automatically delineate a watershed based on a digital elevation model (DEM). The watershed delineation process in SWAT involves the generation of a stream network, the generation of a watershed boundaries, and the generation of sub-basins within the study watershed. These sub-basins are contributing areas of stream reaches that feed into the main reach or channel, and are used as accounting units when calculating the pollutant loads. SWAT sub-basins can be generated by the model, or supplied by the user. In the work done here, the SWAT model was used to generate the sub-basins in Antelope Creek watershed.

The SWAT model defines sub-basins using a minimum area threshold value for each sub-basin. The area threshold is set by the user and defines the minim number of hectares a SWAT sub-basin can be. The smaller the area threshold is set, the higher the number of sub-basins created, as well as the more detail generated in the stream network. In this work, the minimum allowable sub-basin area was 45 hectares (ha), which lead to the generation of 53 sub-basins for Antelope Creek watershed.

The Contemporary Landscape:

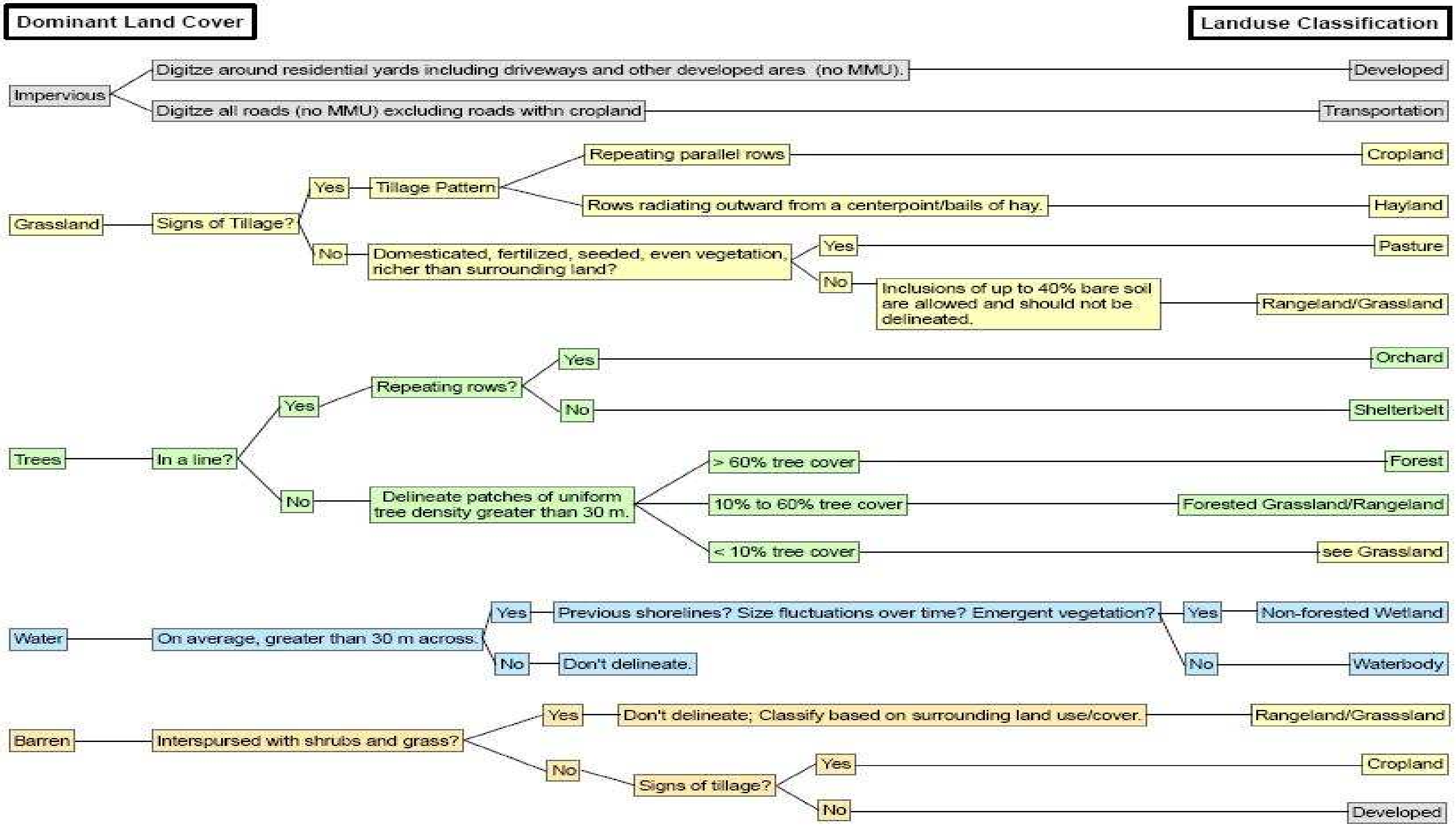
In order to study the impact of changes in land cover, a baseline dataset was needed for comparison. Given the local scale of the research, it was determined that available land cover datasets would not be sufficient to capture the spatial heterogeneity present in the study area. Using 2m aerial photography from the 2006 National Agricultural Aerial Imagery program, study area land cover was digitized and classified. This classification method was developed by the Population and Environment in the United States Great Plains Project for use in classifying aerial imagery. The rules contained in this decision tree (Fig. 3.1) are used as guidelines for heads up digitizing of aerial imagery in a GIS environment. Imagery is digitized in a GIS environment using a heads-up method (i.e. any edge or change in cover type is delineated in the GIS and becomes a new polygon). Once digitizing is complete, the new shapefile is classified using the decision tree. The rules in the tree are used to distinguish among the different land cover classes that each polygon in the shapefile represents. After this processes of delineating and defining different land cover is complete, the shapefile is converted to a 1 meter raster to serve as the Baseline land cover dataset for the contemporary landscape scenario.

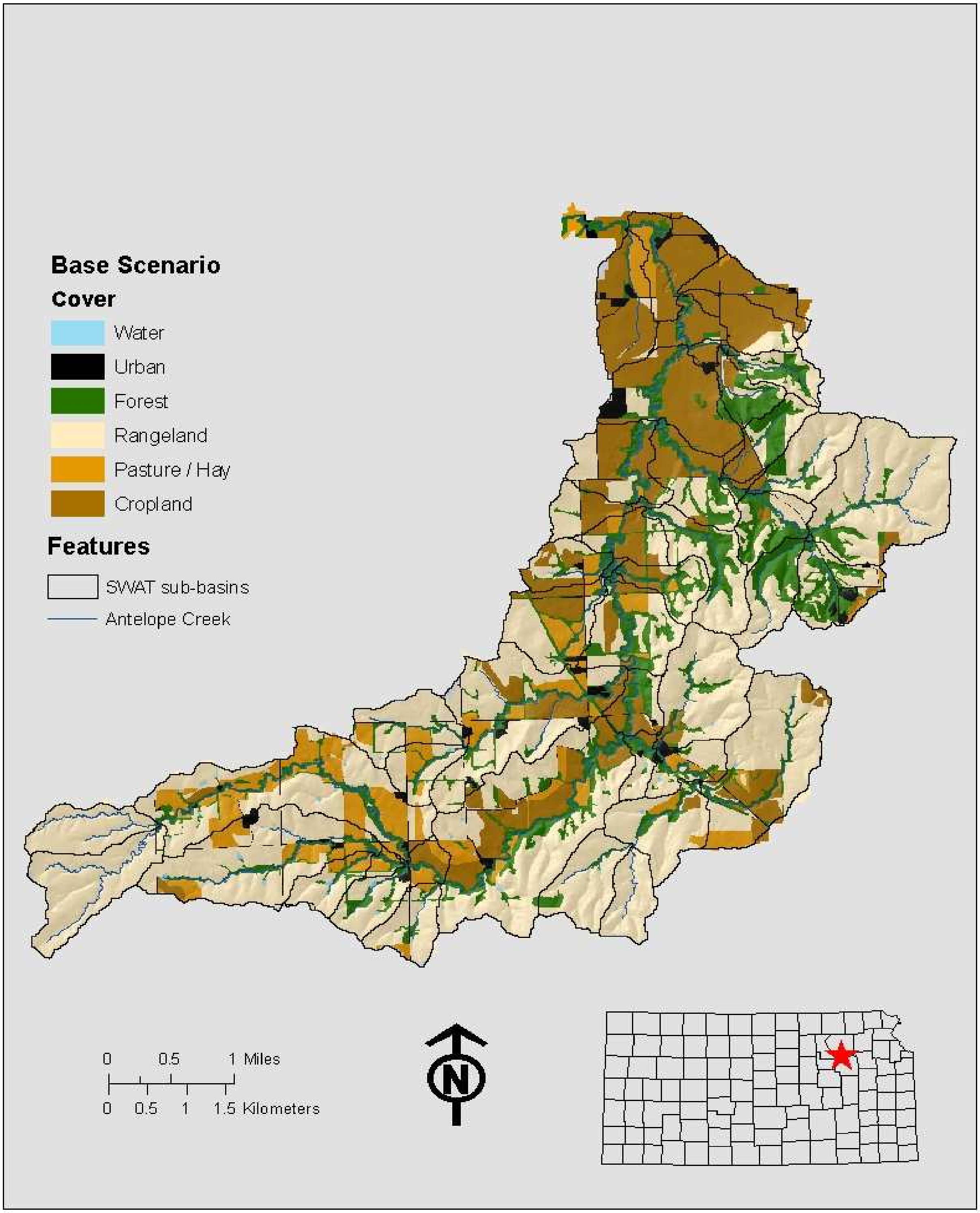
Using 2002 Agricultural census statistics for Wabaunsee County, the Antelope Creek watershed was reclassified into more detailed land cover classes using the plant database contained in the SWAT model (Arnold 2005). Based on the 2002 census data, the area was dominated by Range and Pasture land. In 2002, 65% of the total farmland acreage is in Pasture and Rangeland, and 20% is in harvested cropland (fig. 3.2).

The Base scenario also includes the use of conservation tillage in cultivated areas. This practice is also implemented through the SWAT interface. Using information contained in SWAT's management database, mixing depth and mixing efficiency values for various tillage practices (including conservation and no tillage), are used to change initial values of nutrient and mineral pools in individual soil layers. For conservation tillage this means that nutrients and mineral are mixed to a depth of 100mm at an efficiency of 25%.

All scenarios also include a grazing operation. In terms of grazing management, routines in SWAT were used which simulate the consumption of biomass by livestock as well as the addition of fresh manure (Arnold 2005). SWAT requires several inputs to calculate the impact to the water resources from grazing. The amount of biomass removed daily in kilograms per hectare per day, the amount of manure being introduced from the animals given in kilograms per hectare per day, the starting date of grazing on a given pasture, and the length of time the grazing will occur. In order to estimate the impacts of grazing and management of grazing, estimates for these values from various sources are used to calculate the necessary inputs. The amount of biomass removed per day is calculated using stocking rates given in Hickman *et al.* (2004), which approximate light, moderate, and heavy stocking rates in hectares per Animal Unit (AU). A standard Animal unit equals a one thousand pound cow and is a common measurement unit in grazing management. The stocking rate is then divided by the land area in a range or pasture cover type to determine the number of animal units present in a SWAT sub-basin. Once the number of AUs per sub-basin is determined, this is multiplied by 12 kilograms, an estimation of daily forage intake of a standard animal unit (Ohlenbusch and Watson 1994). Finally this number is divided by the number of hectares in the sub-basin to get the amount of forage consumed in kilograms per hectare. To calculate the amount of manure produced, a rate of 26 kilograms generated per animal unit per day is used (NRCS 1999). This rate is multiplied by the number of animal units per sub-basin and divided by the number of hectares in a given grazing or pasture cover type which gives an estimation of manure generated in kilograms per hectare. SWAT also allows the user to set a minimum amount of biomass present for grazing to occur. For this work the minimum amount required for the stocking rates in each scenario was used as this cutoff. In essence when the amount of biomass in a given sub-basin falls below the minimum amount required for the number of AU present, grazing will not occur until the biomass moves back above this threshold.

3.1 Decision tree used to classify National Agricultural Imagery Program data for Antelope Creek. (Source: U.S. Great Plains Project)





3.2 Map of 2006 Base scenario land cover. (Source: Author)

Preparation of Data for Scenario Development

After the land cover classification process was complete and a 2006 map of current conditions was available, it was necessary to perform several GIS operations to facilitate a querying method during the scenario development stage. A GIS model was created to expedite the GIS functions necessary to create a dataset that can be queried. This model is discussed in further detail in Appendix A.

To develop the three alternative future scenarios, several geospatial datasets were used to represent factors potentially influencing choice of field cultivation. These included soil capability for non-irrigated crop types, the creation of zones along stream corridors to either exclude these areas from production, as in the case of the Agricultural Intensification scenario, or mandating certain management practices are applied, such as strip-cropping in the Biodiversity scenario. Additionally it was necessary to calculate the area of individual, contiguous parcels of land based on the cover type and soil capability. Knowledge of parcel size allows for the implementation of precision farming by excluding small areas of unsuitable soils within cultivated fields, and the implementation of a field size maximum based on combine hopper limits. Designation as a cultivated field is limited to parcels of at least three acres of capable soil for cultivation; a parcel with a size less than three acres remained in 2006 land cover. In the Iowa research (Nassauer and Corry 2004), an upper limit of 320 acres was placed on cultivated field sizes based on combine hopper limits, a technology not likely to see significant improvement in the near future. In Antelope creek, field sizes are limited by local environmental constraints (e.g. soil capability, topography) so that there were no fields that approached this cut-off, and no further limitations were enforced on the upper threshold for field size.

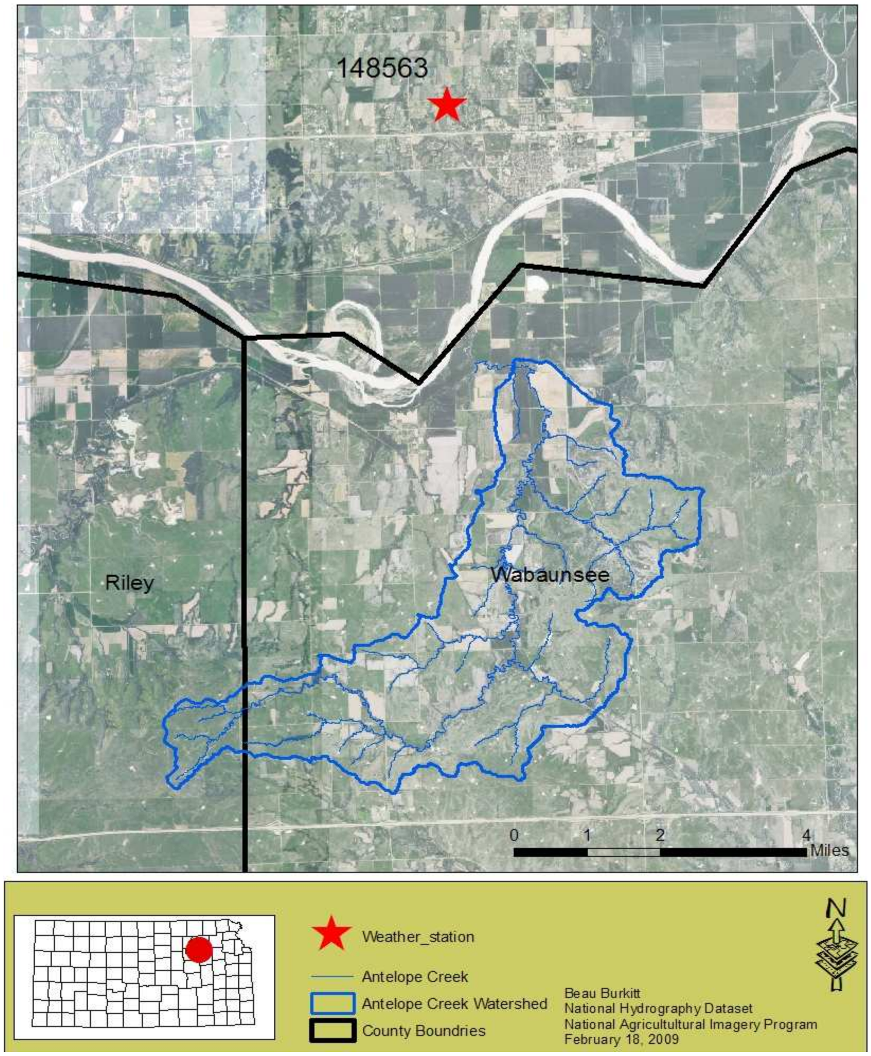
For the modeling project in Antelope Creek ten meter resolution National Digital Elevation Dataset (NED) data were used. The SWAT model requires a DEM in order to delineate the watershed, and calculate the flow direction in. In addition to this, in order to decide how and where certain management practices such as contour farming and strip cropping were to be located and implemented, a dataset for percent slope was created based off the 10 meter resolution NED. A measurement of the percent slope is necessary to adjust values of factors influencing the production of sediment, nutrients, and other pollutants within a field.

For soils data the National Resource Conservation Service SSURGO dataset was used due to a relatively higher level of resolution compared to other products. Model runs were also completed using the STATSGO dataset during this research to determine the need for high level soils dataset in modeling.

In order to determine what soils are suitable for cultivation, the NRCS Land Capability Class (LCC) designation is used to group soils based on their ability to grow common crop types (NRCS 2006). The LCC system includes eight classes ranging from class 1 being the most suited for cultivation and class 8 being the worst. Classes 1 and 2 have slight to moderate limitations for plant choices, but require less intense conservation input. In the Antelope creek watershed most areas in these two classes were already being cultivated. Class 3 soils are classified as having severe limitations for crop production that necessitate special conservation practices, and for the most part are not being cultivated in the 2006 landscape. In the Production scenario, class three soil areas are cultivated.

These scenario development procedures were performed after the classification process was completed, and used to modify the 2006 baseline map so that the final scenario product included attributes that pertained to the ability of a soil to grow non-irrigated crops, the area of a parcel of land containing unique soil capability and cover, the location of restrictive or exclusive areas for production, and finally the slope of an area in percent rise.

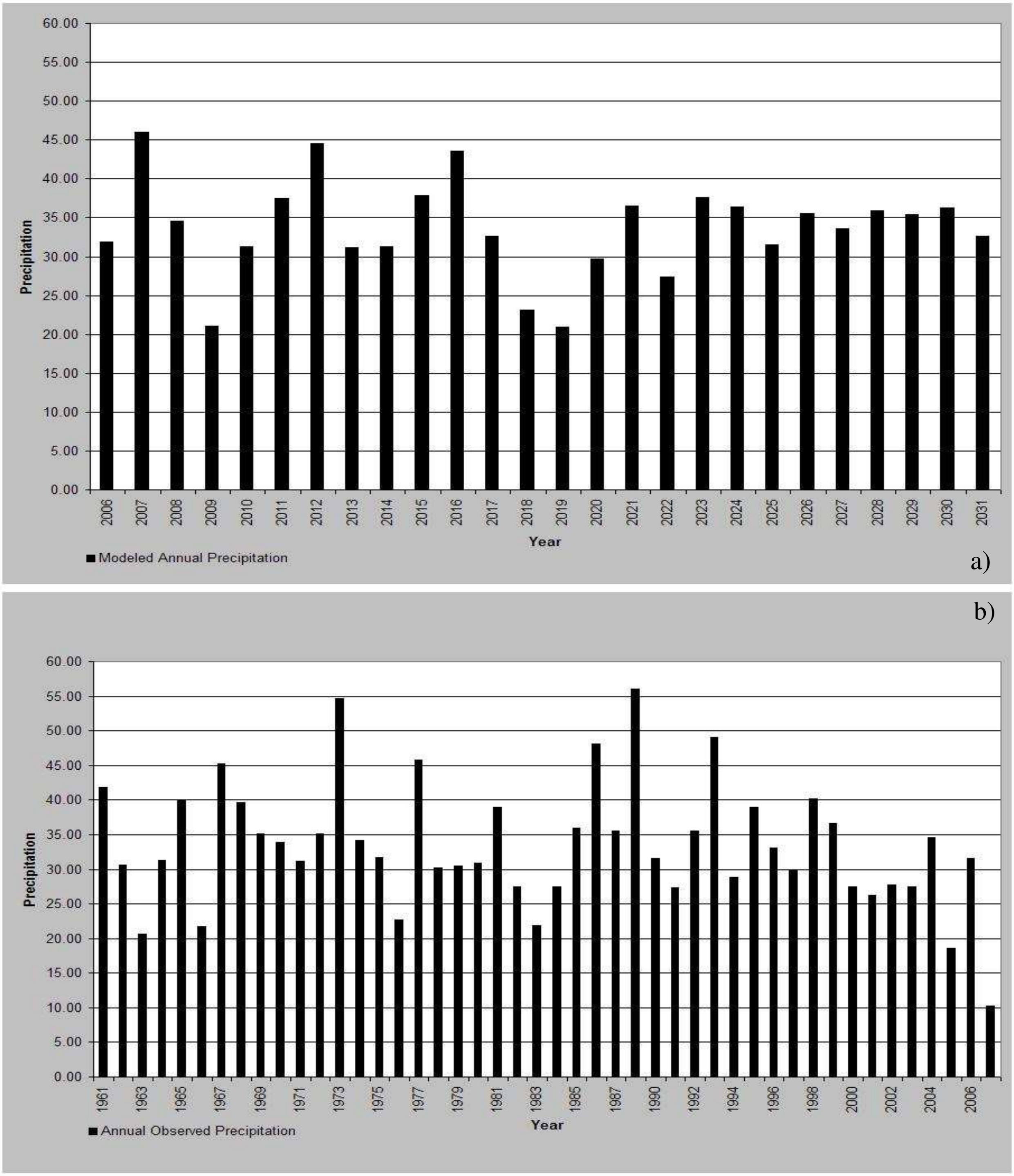
Climate is a key aspect of hydrologic modeling. Precipitation provides the driving force behind many of the physical processes modeled. The accuracy of user supplied weather data becomes important, especially when a modeling effort is attempting to replicate ecosystem function. For Antelope Creek watershed, temperature and precipitation data were derived from a weather station located north of the Watershed (Fig 3.3). The aforementioned station provided continuous data from January 1, 1961 through April 30, 2007. Precipitation and temperature data from the observed dataset, and the modeled climate are presented in table(s) 3.1 & 3.2 and figure(s) 3.4, 3.5 & 3.6. Model precipitation was slightly more wet (annual mean of 33.3 inches to 33.7 inches) as well as having a more narrow range. Modeled temperature tended to run cooler than observed temperatures, with a mean difference of around 2^{o} F for both mean maximum and minimum monthly temperatures. These model numbers are not identical to observed data, but at the same time the patterns of annual heating and precipitation are similar. Even though there is some small discrepancy between the observed and modeled data, for the purpose of this research the impact is considered negligible.



3.3 Location of weather station from which climate data was derived (source: Kansas State University).

Table 3.1 Observed and modeled annual precipitation data.

Annual Precipitation	Observed	Modeled
Mean	33.3	33.7
Std. Deviation	9.0	6.2
Min	10.3	21.0
Max	56.0	46.0

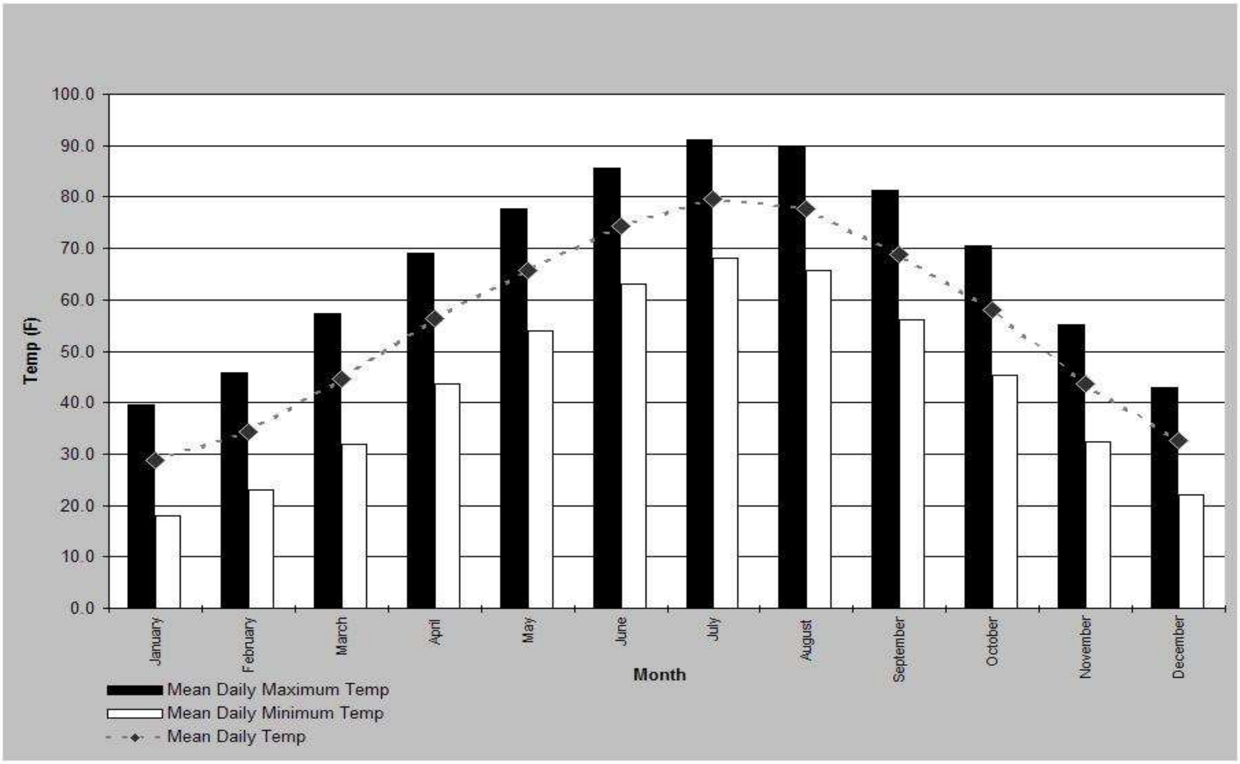


3.4 Observed and modeled annual precipitation. Modeled annual precipitation totals from 2006-2031(a), and observed precipitation from 1961-2007(b) (source: Kansas State University (source: Kansas State University).

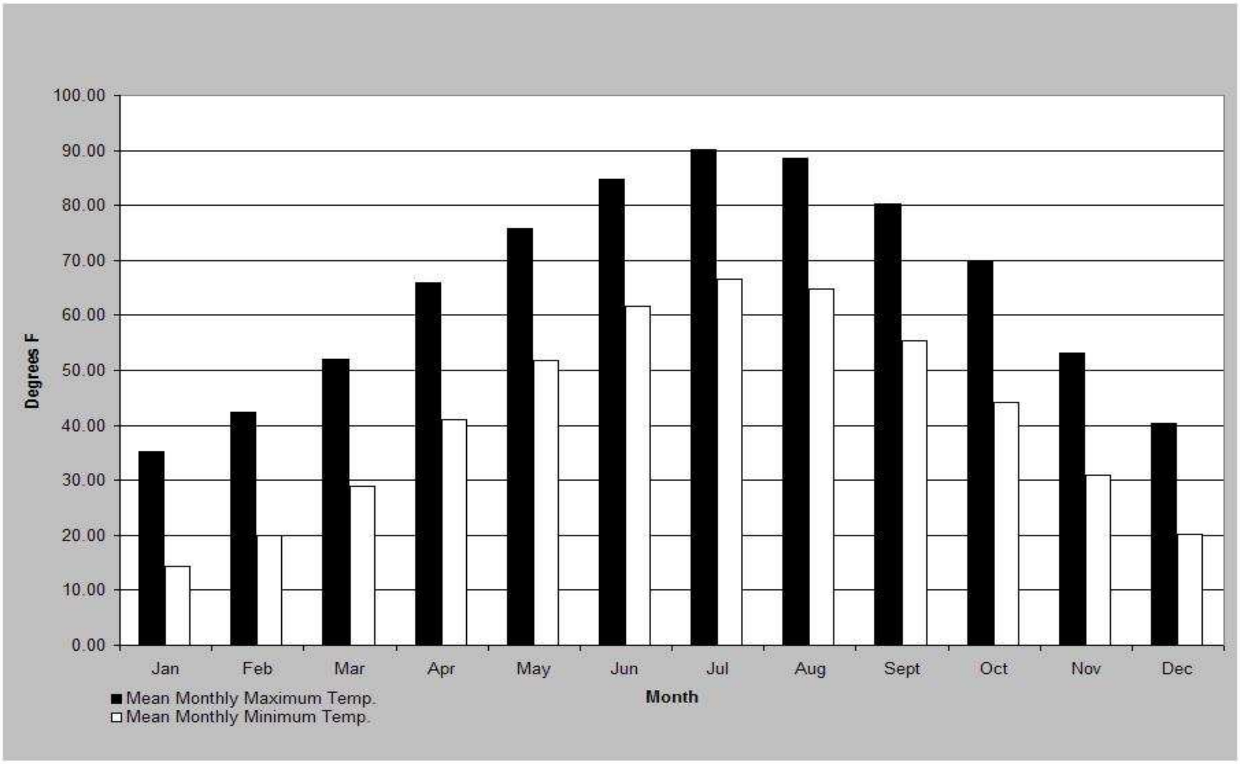
	Observed		Modeled	
Month	Mean Maximum	Mean Minimum	Month	Mean Maximum
Jan	39.7	18.0	Jan	39.7
Feb	45.9	22.9	Feb	45.9
Mar	57.3	31.9	Mar	57.3
Apr	69.1	43.7	Apr	69.1
May	77.6	53.9	May	77.6
Jun	85.6	63.0	Jun	85.6
Jul	91.2	68.0	Jul	91.2
Aug	89.8	65.7	Aug	89.8
Sept	81.4	56.1	Sept	81.4
Oct	70.6	45.3	Oct	70.6
Nov	55.1	32.3	Nov	55.1
Dec	43.0	22.2	Dec	43.0

Table 3.2 Observed and modeled temperature data.

3.5 Observed mean daily maximum and minimum temperature for each month from 1961-2006 (source: Kansas State University).



3.6 Modeled mean daily maximum and minimum temperature for each month from 2006-2031 (source: Kansas State University).



SWAT also necessitates a stream dataset to run. Like weather data, the stream data can be supplied by the user or completely generated by SWAT based on the DEM. There as several stream datasets available for use. The Reach V1 file is the oldest set of stream delineations in the United States, and the Reach V3 dataset is the second generation of V1. The National Hydrography Dataset (NHD) available from the USGS offers several datasets of varying resolution. The NHD is derived from 1:100,000 scale data and is based on the Reach V3 and Digital Line Graph (DLG) hydrography datasets from the USGS. For this study, NHD medium resolution stream data was used to define the Antelope Creek and it's watershed.

In order to use an outside stream dataset in the SWAT model there several steps that must be taken. First the NHD dataset contains more than just streams and rivers in its flowing line classification. It also includes features such as pipelines, canals/ditches, and coastlines. In order to use the NHD data in SWAT many of these features need to be filtered out of the dataset. In the Antelope Creek watershed, all streams are kept, and aforementioned features were removed. The streams features that are left are considered to be flowing bodies of water, including intermittent and ephemeral stream reaches.

The second step in the stream pre-processing procedures is to make sure the stream dataset is a continuous set of flow paths. In essence there can be no gaps or sinks in the stream dataset. One can accomplish the tasks through the SWAT interface by manually drawing connections between gaps in the stream dataset. Alternatively, joining gaps can be completed using the Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) model, which contains and automated function for joining stream lines. For this work the BASINS model was used to generate a continuous stream file.

After the stream dataset has been filtered and connected, it can then be incorporated into the SWAT model. The process of overlaying the stream network on the watershed is known as a burn-in. The model converts the user supplied stream network into a raster file, which is overlayed onto the DEM. Then during the DEM processing step in the SWAT model, the stream generated follows the digitally burnt-in stream network.

Subjectivity in Scenario development

In creating scenarios, the user is in effect, predicting the future. They are deciding on what the future landscape looks like, and in doing so make subjective decisions as to what factors are going to be major influences to create this future (table 3.4). It is vitally important that the person creating the scenarios understand the study area which they work in to avoid unrealistic interpretations.

An example from this work could be the expression of the maximum agricultural production scenario. We chose to increase production of soy beans and corn production in Antelope Creek watershed in what could be a response to increased demand for ethanol. This change, as well as other changes to LULC, is presented in table 4.5. The decision could have been made to favor cellulosic ethanol production, which would have led to large tracts of tallgrass prairie which contains switchgrass (*Panicum virgatum*), a grass commonly referenced in conjunction with cellulosic ethanol production.

Another decision could be the addition of bison to the Grassland scenario. Bison (*Bos Bison*) played a large role in the maintenance of the tallgrass prairie prior to euro-american settlement. Estimates of Bison in the Great Plains range from roughly 30-60 million at their peak. To make the Grassland Scenario a more accurate depiction of the Antelope Creek watershed's recent past, the addition of a grazing operation which included Bison could be added through the SWAT environment.

Methods have been used to estimate Bison population based on free-range cattle numbers the census of agriculture of the latter part of the 19th century (Flores 1991). It may be possible to apply the same type of technique in Antelope Creek, as well as other study areas given reasonably complete census data. Evidence also suggests that removal of significant portions of riparian cover might be removed to better represent conditions present in the 19th century.

Buffer zones along the riparian corridors are a final example. The Iowa research included grassed areas along stream reaches to function as vegetated buffer strips. The widths of these buffers were 3 meters, 6 meters, 9 meters for each of their future scenarios. This work also includes the use of grassed areas along the riparian corridor, but widths have been adjusted to deal with the relatively step slopes along stream banks (table 3.3), and to accommodate grazing in the buffer zones. Introducing these buffer zones should allow for some economic value to remain in these areas while still providing ecosystem services such as water filtration, and shelter for biota.

There are numerous revisions, manipulations and additions that could be applied to these scenarios. In part, this is what makes the use of scenarios so alluring. The flexibility to change past, present or future conditions and get results in an expedient manner could be an asset to planners, managers, and policy makers.

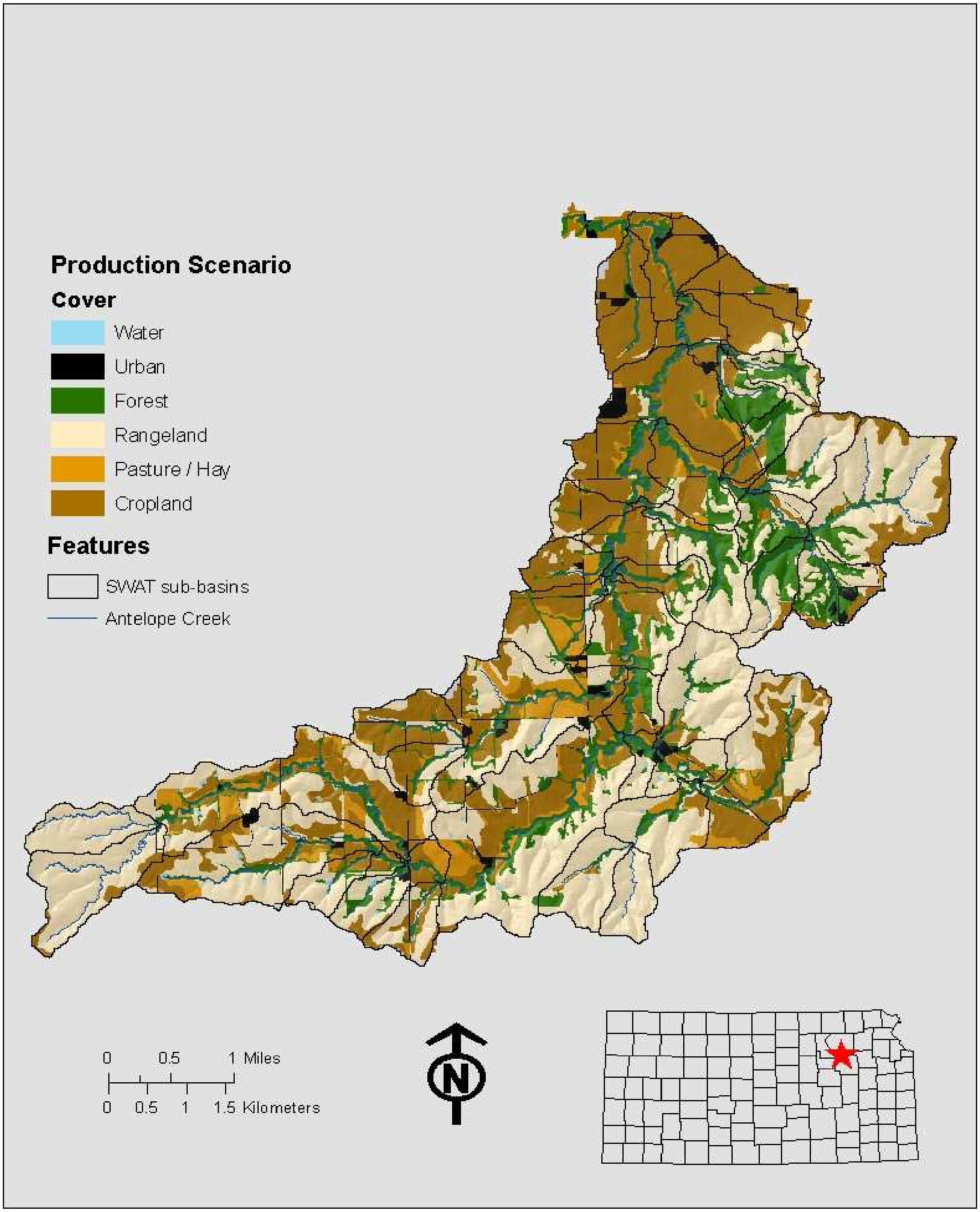
Table 3.3 Statistics for percent rise of slope within each buffer width (m). Calculations performed in each buffer zone separately to avoid overlap.

Buffer Width (m)	Mean percent rise of slope in buffer	Standard deviation of percent rise of slope in buffer
30	9.66	7.26
100	8.24	6.44
130	7.28	5.71

Scenario Design Rules for Antelope Creek watershed

Intensification of Agriculture

The Intensification of Agriculture scenario is the expected result of policy that emphasizes maximum animal production on grazed lands and increased production of cash crops. Several manipulations to the Base 2006 scenario were conducted to represent these changes. Work was done in a GIS environment to accommodate changes to cultivated fields in terms of their size and location as well as adjustments to modeling routines to represent changes in crop management and grazing management. Selection criteria for conversion in this scenario were based on factors that reduce the resistance to production. One example of removing obstacles to production is the planting crops on previously unsuitable soils. There were minimum restrictions placed near streams or riparian corridors for growing crops. A 30 meter restrictive zone around streams was implemented for this scenario. Any parcel not inside this area, containing soils suitable for cultivation, and meeting minimum area constraints (i.e. more than three acres) is converted to a row crop designation in the Production Scenario. Riparian areas along streams that lie outside the buffer are included in this conversion to row crops in 2031 (fig 3.7).



3.7 Map of Production Scenario for Antelope creek. (Source: Author)

Stocking rates and grazing systems were also adjusted relative to the Base 2006 scenario to represent attempts to maximize returns on livestock production from open grazing on native grasses. In this scenario a stocking rate of 2.8 hectares per standard animal unit is used to maximize the number of animals in a given space. A continuous or full season grazing system is also incorporated on range lands. Using the grazing interface within SWAT, grazing is set to occur at a minimum biomass threshold of 4.29 kg, and is given a duration of 153 days. To facilitate the maximum achievement of weight gain during summer months for production animals, but ensures that rangeland is not grazed below a minimum amount of available biomass. A stocking rate of 2.8 hectares per animal unit is considered to be a moderate rate in the Flint Hills, and is also considered to be an optimal rate for production gains in a full season grazing system (Ohlenbusch and Watson 1994).

In agricultural areas, the percentages of cover types were altered to match more closely with the theme of cash crop production. Soy beans, and corn were increased, wheat was decreased. Conservation tillage was applied to all cultivated areas using the SWAT model interface. This is done to represent the a minimal implementation of conservation management applied in the future.

In the Iowa study, areas were identified where there were at least thirty contiguous acres of unsuitable soils using the Corn Suitability Rating (CSR). These areas are planted to alfalfa, and the harvested hay is then sold to confined animal feeding operations. Even in a scenario designed to maximize crop production, the Antelope creek watershed contains relatively large tracts of open prairie and range land along the eastern edge of the watershed, due to the poor suitability of the soils (LCC class six) in these areas. Because of the poor suitability of these soils the areas are left in the 2006 land cover, which is generally rangeland, and a grazing operation is added according the rules outlined above.

Improving Water Quality

The basis for the improving Water Quality scenario was an emphasis on reducing the amount of pollutants reaching the stream. Reductions in sediment, nitrogen, and phosphorus were the target of the management practices being tested here. The Water Quality enhancement scenario incorporates management practices that inhibit overland flow, reduce the energy available for erosion, and increase continuous cover. The scenario design rules should reduce the amount of sediment being transported to the streams, as well as reduce nitrogen and phosphorus loads.

The first change to the land cover in this scenario is the inclusion of a 100m stream buffer. This buffer exists to limit the amount of erosion that is possible along a stream corridor, and impede overland flow which would allow for infiltration before reaching the riparian zone. Within this buffer, the riparian corridor that exists in 2006 is left in tact, but the remainder of the area is converted to a mix of big bluestem (*Andropogon gerardii*) and generic range grasses. The substantial riparian corridor that exists along the bank of the stream in 2006 is likely due to relatively steeper slopes along the stream corridor, causing the areas directly adjacent to the stream to be difficult to plant and/or harvest.

Criteria for conversion to cropland are much the same as in the Production scenario with the biggest difference being the soil capability cutoff for production of row crops. In the Water Quality scenario, row crops are grown only on classes on 1 and 2 while class 3 is reserved for hay land similar to the 2006 scenario. The areas converted over to cropland retain a similar mix to the crop types in 2006, with a slightly higher emphasis on wheat production to create more continuous cover (fig 3.8). Contour farming is also incorporated in the Water Quality scenario. Contour farming is implemented to reduce surface runoff by impounding overland flow and decreasing rill formation, thereby reducing erosion and conserving water through higher rates of infiltration. Arabi *et al.* (2007) describe a method for incorporating contour farming within the SWAT model.

The SWAT model allows users to adjust input values for various factors. For evaluation of management practices on an Indiana watershed, Arabi *et al.* recommend the adjustment of the Soil Conservation Service (SCS) curve number and the Modified Universal Soil Loss Equation (MUSLE) practice or P-factor. The curve number is reduced by three units, and the P-factor is adjusted based on the percent slope. Editing these parameters is done through a GIS environment and the SWAT interface. Using the sub-basins delineated by the model, a maximum slope is calculated for each one. Agricultural crop types are then reclassified using a naming convention that uniquely identifies the maximum slope. This procedure allows the user to specifically alter values for each slope condition per Arabi *et al.*, by editing the SWAT crop database.

A grazing operation is also included in the Water Quality scenario. The emphasis in this scenario is the reduction of pollutants to the stream corridor from agricultural practices. Animals are still grazed on grasslands in the study area, but in order to protect against negative impacts on water resources associated with grazing (e.g. denudation and trampling), grazing is reduced to a partial season system. Stocking rates are kept at the same moderate 2.8 hectares per animal unit as in the Production scenario. The shorter length of the grazing season should also lead to a reduction in nutrients reaching Antelope creek due to lower amount of fresh manure deposition. Grazing is applied to areas of grass buffer along riparian corridors. In implementing a grazing operation within the buffer areas, measures would need to be taken to prohibit cattle direct access to streams. Fencing animals out of the riparian corridors or, applying rotational grazing practices such as moving salt licks, or watering sources could accomplish this (Ohlenbusch and Watson 1994). No till farming is practiced in agricultural areas of Antelope Creek in the Water Quality scenario. No till is incorporated through the SWAT interface by manipulating the management input database. The SWAT model offers several options for the incorporation of a tillage operation. Each type of operation is assigned a mixing depth and mixing efficiency, and based on these factors the amount of nutrients, pesticide, and residue redistributed throughout soil layers from each tillage practice is calculated (Arnold *et al.* 2005).

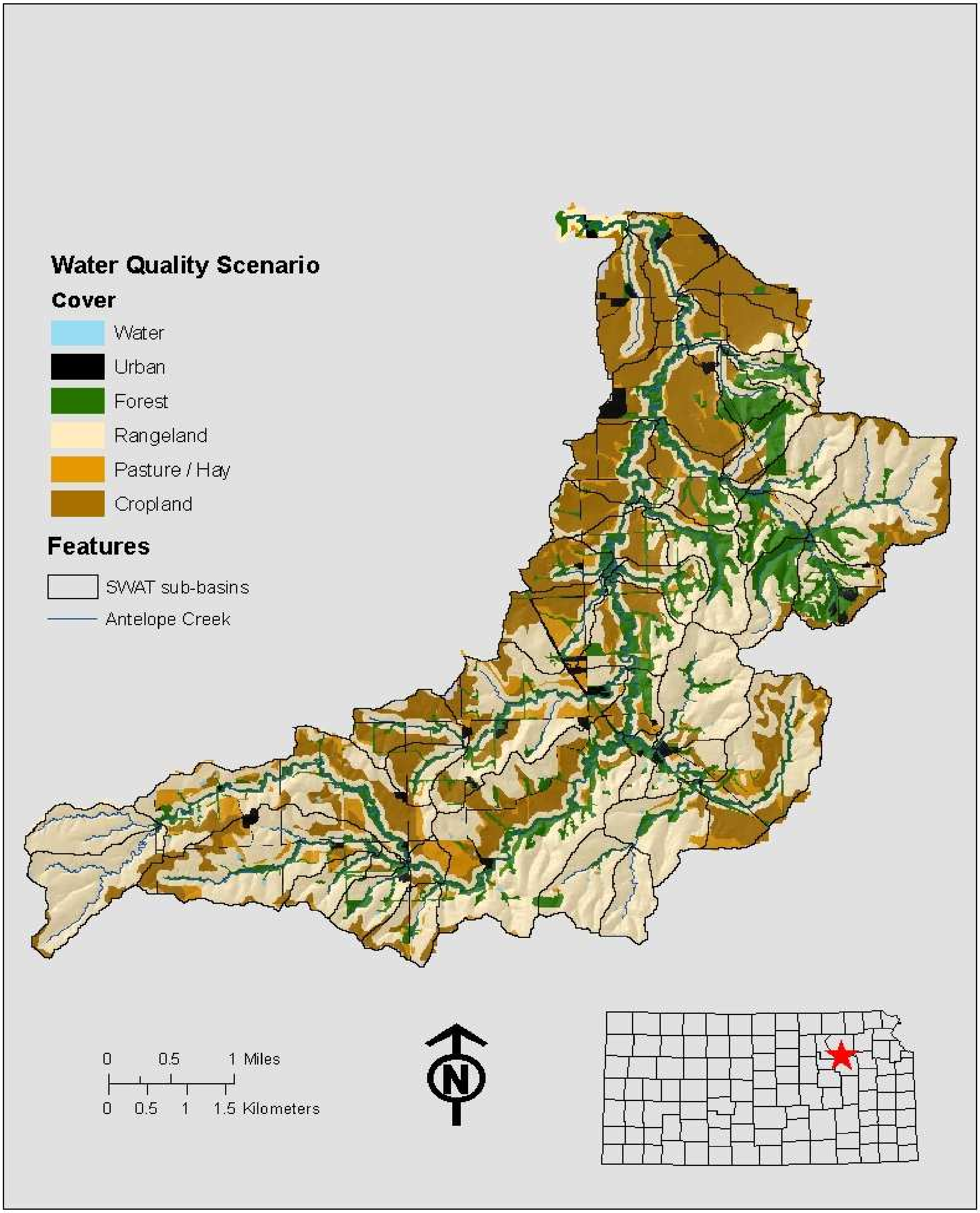
Enhancing Biodiversity

In the Biodiversity scenario the intent is to create a less fragmented landscape to accommodate biota within the watershed. According to the Iowa design rules, the Biodiversity scenario includes putting large tracts of land into reserves and increasing reserve connectivity within the study area, as well as with adjacent watersheds. The specification for a bioreserve core area is taken directly from the Iowa design rules. The reserve areas are at least 259 ha (640 acres), roads and other urban land cover is removed, and no crops are grown in this area. Secondary design specifications include locating a bioreserve core on a boundary of the watershed to facilitate movement between watersheds. Expansion of the bioreserve core area to include adjacent areas where soils are of low capability is also possible. Design rules call for the creation of as many reserves as there are ecosystems in the area. For Antelope Creek, a core reserve for tallgrass prairie was created that lies on the eastern edge of the watershed. A section of road and a farmstead were removed to accommodate the reserve.

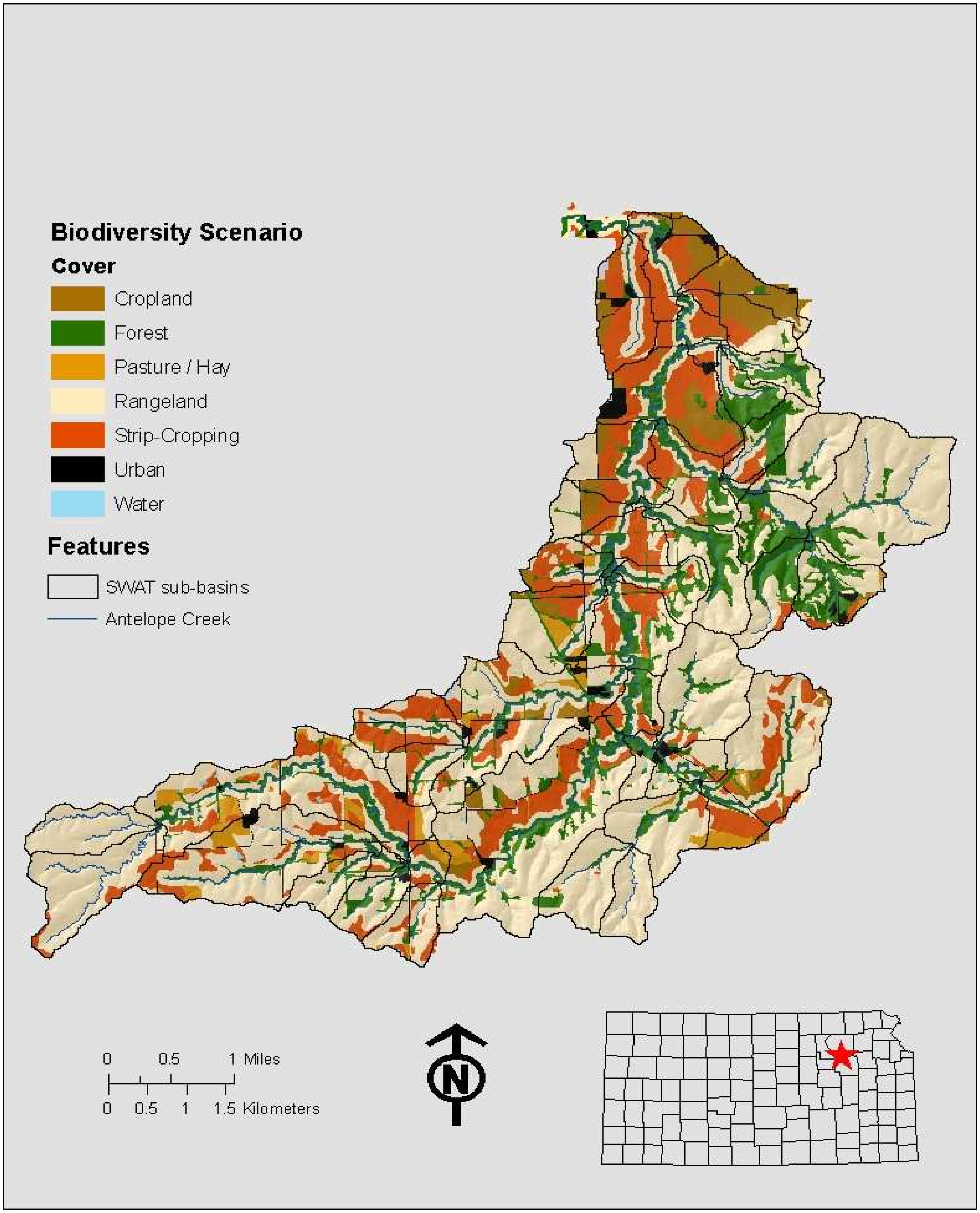
The other major component of the Biodiversity scenario is the change in practices from continuous row crops to strip cropping. This entails intermixing strips of grass and small grain vegetation with row crops. The perennial strip acts as a within field buffer, slowing runoff and capturing sediment as the energy is dissipated from the flow. The loss of energy and decrease in bare soil should also help reduce the amount of channel and gulley formation. In addition to the water quality benefits provided by the grass strip, it may also offer cover to small animals, as well as provide a food source, and act as a transit corridor for biota. To determine areas where strip cropping will be implemented, a zone of 16 ha (40 acres, 1/4 mile, .4 km) surrounding all streams, and reserve areas is used. Any agricultural areas within this zone are converted to a strip cropping classification (fig 3.9). Similar to the process in the Water Quality scenario, areas in the Biodiversity are select. The Curve Number is reduced by three and P-Values are adjusted based on values given in Arabi *et al.* (2007).

In addition to the reserve and strip cropping practices, the riparian corridors are once again buffered from any cultivation. In the Biodiversity scenario, this buffer of trees and range grasses is increased to 130 meters wide. A wider buffer may allow for greater filtration of runoff before it reaches the stream, as well as offer more connective pathways throughout the study area. This wider buffer area may also allow for increased numbers of animals in the grazing scenario, thereby increasing the economic benefit of the Biodiversity scenario.

A light stocking rate of 3.16 acres per AU is applied to Biodiversity scenario in conjunction with a partial grazing season of 76 days. Grazing occurs in the grassed buffer areas along riparian corridors similar to the Water Quality scenario. For cultivated areas not within the strip cropping zone, corn and soybean are reduced, wheat and hayed areas are increased, and no tillage is applied using the SWAT interface.



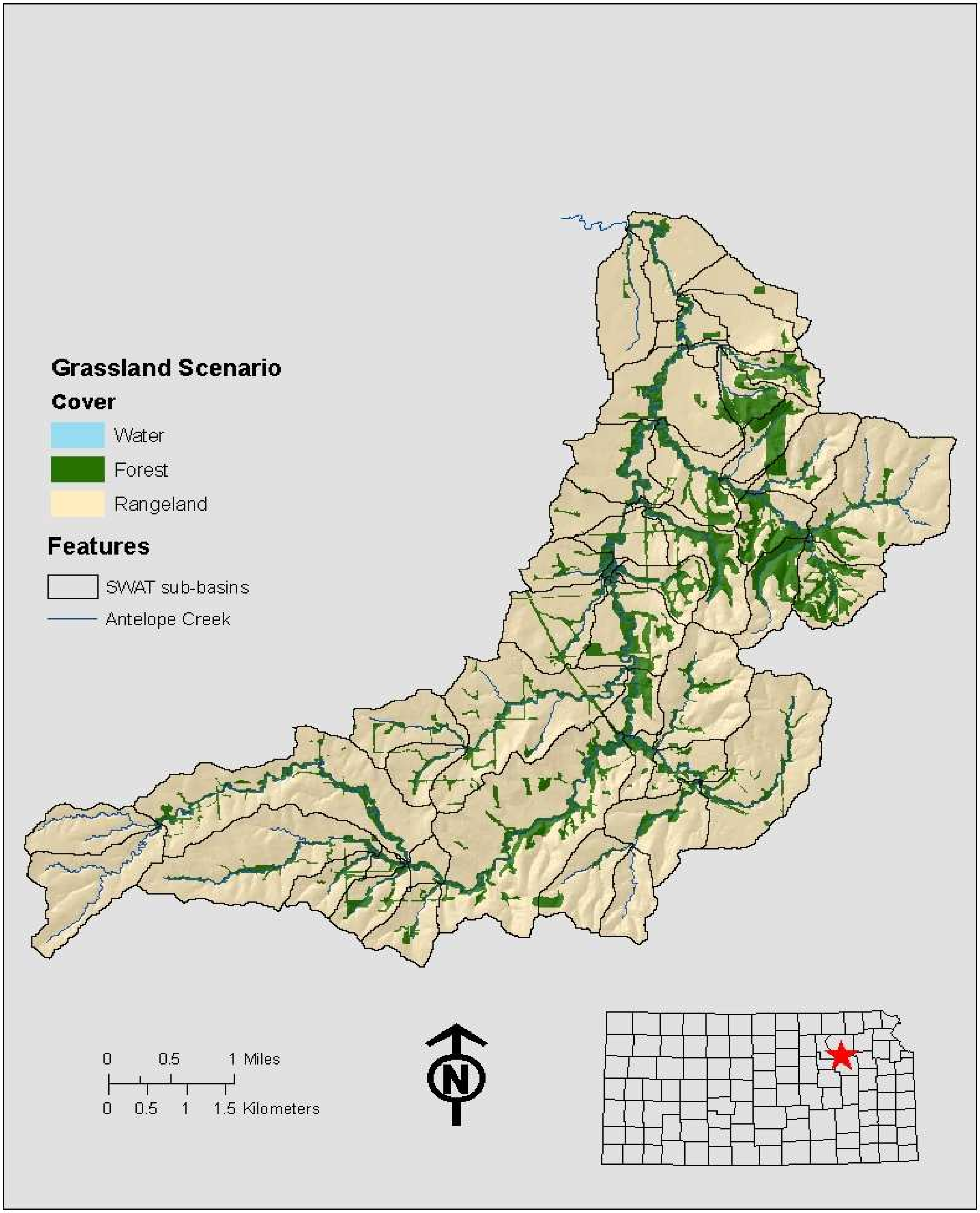
3.8 Map of Water Quality scenario for Antelope Creek. (Source: Author)



3.9 Map of Biodiversity scenario for Antelope Creek. (Source: Author)

Pre Euro-American Settlement Scenario

The final scenario included in this work is a scenario representing the landscape as pre Euro-American settlement grassland. This scenario is based on the work done by Kuchler (1976) and meant to show possible differences in pollutants among present land cover and what may have existed historically. The Fire Sciences Laboratory recently created raster datasets which represented Kuchler's potential natural vegetation (PNV) maps. For Antelope Creek the resolution of the dataset was fairly course. Riparian corridors present in Antelope Creek in 2006 were incorporated with the PNV data to further represent conditions that may have been present before the settlement of the tall grass prairie (fig 3.10). No cropping is added to this scenario to represent a lack of disturbance to the surface layer of soil.



3.10 Map of Grassland scenario for Antelope Creek. (Source: Author)

	Soils Cultivated	**Buffer Width**	**Grazing Parameters**	**Tillage Practice**	**Other Practices Implemented**
Grassland	*N/A*	*N/A*	*N/A*	No Till	*N/A*
Base	LCC Classes 1 & 2	*N/A*	Full season; Moderate Stocking Rate	Generic Tillage	*N/A*
Production	LCC Classes 1-3	30 meters	Full season; Moderate Stocking Rate	Conservation Tillage	*N/A*
Water Quality	LCC Classes 1 & 2	130 meters	Partial Season, Moderate Stocking Rate	No Till	Contour Farming in cropped areas
Biodiversity	LCC Classes 1 & 2	160 meters	Partial Season, Light Stocking Rate	No Till	Creation of a Tallgrass prairie Bioreserve area; Strip Cropping near Riparian corridors and Bioreserve

Table 3.4 Summary of design specifications applied to each of the five scenarios.

Table 3.5 Summary land cover conversion in each scenario (white), total area (light grey), and percent change from the Base scenario (Dark Grey).

Land cover	Base	Grass	Production	Water Quality	Biodiversity
Row Crop	9.7	-	12.0	8.0	7.0
Forest	6.8	6.3	7.6	7.6	7.3
Pasture	2.9	-	2.0	0.9	0.7
Range	27.0	40.0	24.7	29.9	31.3
Total (km2)	46.4	46.4	46.4	46.4	46.4
Acres	11464.2	11463.2	11463.2	11465.9	11460.0
Row Crop	-	-100.0	+24.4	-17.0	-27.5
Forest	-	-6.5	+12.2	+12.5	+7.4
Pasture	-	-100.0	-31.0	-70.3	-74.6
Range	-	+48.3	-8.4	+10.6	+16.0

CHAPTER 4 - Results

Hydrologic modeling provides a means to develop answers to ‘what if’ questions regarding how humans might better manage our planetary landscape. The intent of this work is the transfer of successful global change scenario development methods from physiographic regions in the ‘Corn Belt’ of Iowa, to the tallgrass prairie of the Great Plains. To this end, land use/land cover scenarios were created for hydrologic modeling of Antelope Creek in the tallgrass prairie of Kansas. Five scenarios were created, two of which were intended to be representative of past and present conditions in Antelope creek. The Grassland scenario represents pre-settlement conditions, while the Base scenario represents the present state of land use and land cover in the watershed. The final three scenarios were created to represent plausible futures in Antelope creek. These scenarios were based on changes that might occur in agricultural watersheds if management decisions reflected a preference for different outcomes. A scenario was created to model a preference for Production, a preference for improving Water Quality, and a preference for increasing Biodiversity.

In applying the methods of the Iowa research, part of the results discussion highlights the types of modification to the watershed modeling rules from Iowa that were necessary to adapt the scenarios to the tallgrass prairie of Kansas. The description of rule manipulation from Iowa to Kansas is presented along with the results of the individual scenarios.

Additionally, separate model runs were completed to compare the higher spatial resolution SSURGO and more general STATSGO soil datasets. This modeling was done using the Base scenario and combinations of the two soil datasets and different hydrologic response unit (HRU) delineation methods in the SWAT model. There are two methods available to create

HRU's in the SWAT model. Both were used in conjunction with the two different soil datasets for a total of four model runs. The first HRU delineation method consists of using a single dominant land use and soil type method leading to a single hydrologic response unit per sub-basin. The second option was the multiple HRU method which creates a hydrologic response unit for each unique combination of soil type and land cover in a sub-basin, leading to greater spatial detail and several HRU's per sub-basin. Starting with the comparison runs for soil datasets, results are presented to highlight potential outcomes that were achieved within each model run/scenario.

Results are then presented for individual pollutants. This is done to compare the different scenarios to one another in terms of the modeled pollutant loads. In order to highlight the potential of the management practices implemented in the different scenarios to improve water quality, a percent change from the Base scenario is also included in these results.

Soil Datasets Comparison Runs

SWAT allows the user to incorporate almost any dataset as a model input. These datasets can range from primary data sources collected by the user, such as local land use / land cover data, or national datasets like the NLCD. The ability to use such a wide range of data adds another level of complexity to applying methods from one region / study area to another. Understanding how different datasets impact model routines is especially important when a user is modeling an un-gauged stream, as is the case in this work.

Di Luzio *et al.* (2005) study the impact of varying input data for SWAT. They select several different datasets representing elevation (DEM), soils, and land cover which are modeled in different combinations to determine their respective influence. The elevation datasets consisted of a 30m resolution DEM and a 90m resolution DEM. Soil data consisted of

STATSGO and a county soil survey map, both available from the NRCS. Finally land cover data was a dataset derived from 30m resolution, 1987 Landsat-5 Thematic Mapper imagery, 1992 NLCD data, and a USGS 1:250,000 scale Land Use Land Cover digital map.

For the work being reported here, the impact of different soil maps and land cover data are relevant discussion points. In terms of land cover data, Di Luzio *et al.* found that coarser datasets, with all other inputs held constant, would lead to an overestimation in model results. Considering the scale this study was conducted at, the classification of high resolution becomes an important step.

Selection of a soil dataset tended to have little impact on the results according to Di Luzio *et al*. Results from the Antelope Creek watershed tended to reinforce this finding, as STATSGO and SSURGO datasets are compared for differences.

Part of the work completed in this research was to compare the two widely used NRCS soil datasets, United States General Soil Map (STATSGO) and Soil Survey Geographic (SSURGO) database, to gauge the necessity of incorporating higher resolution (SSURGO) soil data given the relatively small size of the watershed (~ HUC 12-14). SSURGO is the most detailed soil dataset that the National Resource Conservation Service (NRCS) offers. The scale of SSURGO data ranges from approximately 1:12,000 to 1:63,000. The level of detail contained is reflected in its target audience(s), landowners, townships and counties. STATSGO is a much more general map of soils. It is created by sampling more detailed soil maps, and extrapolating a more general dataset. STATSGO is delivered in state/territory or national extents, highlighting the intended scale of use with this dataset. Figure 4.1 and Table 4.1 exemplify the difference in detail of the two soil datasets. The SSURGO dataset contains a relatively smaller amount of class D soils and more of both class B and C soils.

4.1 Differences in soil hydrologic group between STATSGO and SSURGO soil datasets. (Source: Natural Resources Conservation Service)

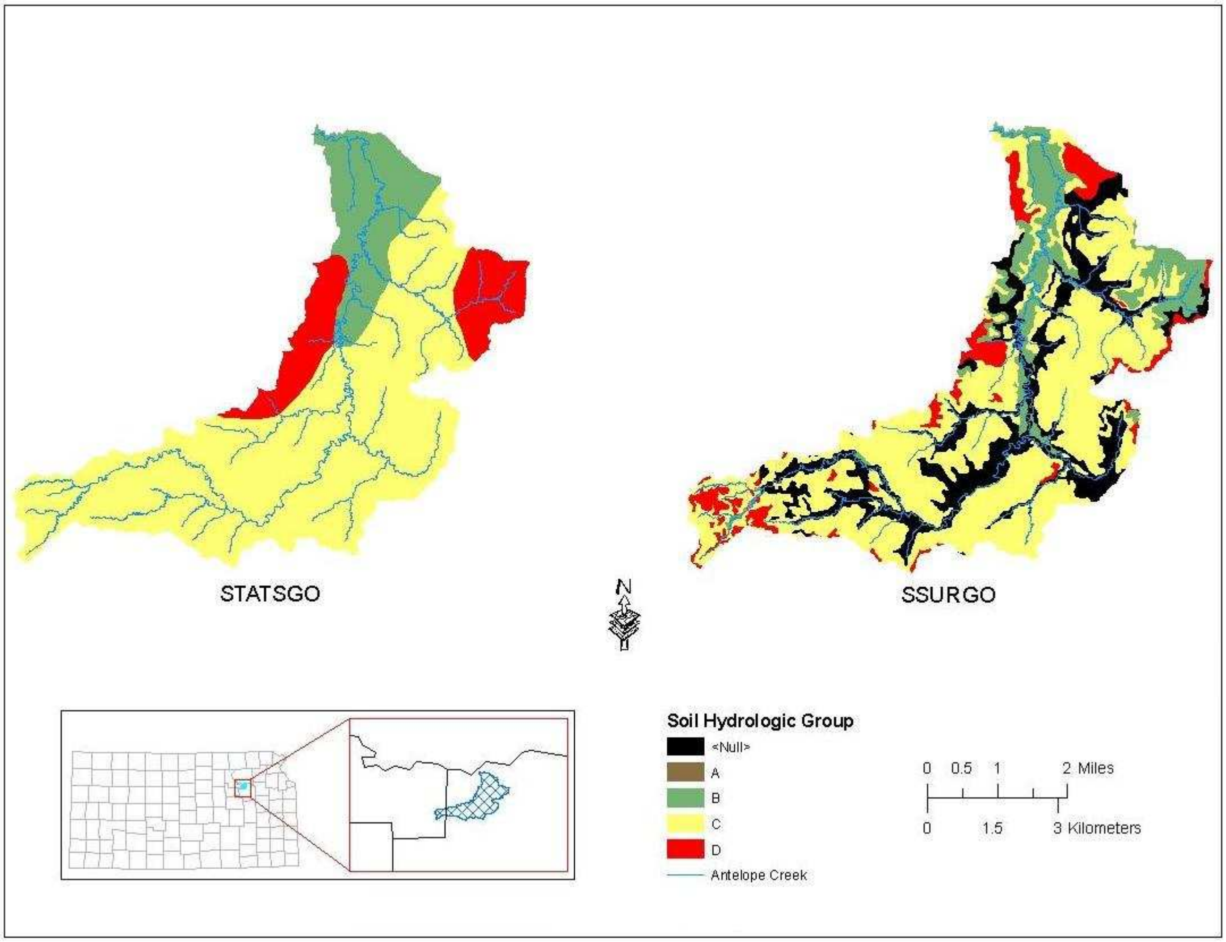


Table 4.1 Differences in the total area of each soil Hydrologic Group between STATSGO and SSURGO datasets.

STATSGO Statistics			SSURGO Statistics		
Hydrologic Group	Area (Km2)	Area (acres)	Hydrologic Group	Area (Km2)	Area (acres)
B	6714.5	1659.19	B	8167.1	2018.1
C	33101.5	8179.56	C	34086.4	8422.9
D	5998.27	1482.2	D	4089.04	1010.4
	45814.3	11320.96	Totals	46342.57	11451.49

Table 4.2 Discharge results and percentage comparisons

	Discharge (mm /sec)	STATSGO[1]	STATSGO[2]	SSURGO[1]	SSURGO[2]
STATSGO[1]	0.0281	-	1.44	1.99	4.92
STATSGO[2]	0.0277		-	0.56	3.53
SSURGO[1]	0.0276			-	2.99
SSURGO[2]	0.0267				-

Table 4.3 TSS results and percentage comparisons

	TSS (tons)	STATSGO[1]	STATSGO[2]	SSURGO[1]	SSURGO[2]
STATSGO[1]	623,523	-	-55.38	-24.9	-67.1
STATSGO[2]	968,802		-	19.6	-7.57
SSURGO[1]	778,775			-	-33.8
SSURGO[2]	1,042,107				-

Table 4.4 Organic nitrogen results and percentage comparison

	Organic N (kg)	STATSGO[1]	STATSGO[2]	SSURGO[1]	SSURGO[2]
STATSGO[1]	691,197	-	-26.5	-4.01	-22.8
STATSGO[2]	874,433		-	17.8	2.91
SSURGO[1]	718,895			-	-18.09
SSURGO[2]	848,960				-

Table 4.5 Organic phosphorus results and percentage comparison

	TSS (tons)	STATSGO[1]	STATSGO[2]	SSURGO[1]	SSURGO[2]
STATSGO[1]	97,473	-	-8.28	1.58	-4.08
STATSGO[2]	105,541		-	9.10	3.88
SSURGO[1]	95,933			-	-5.75
SSURGO[2]	101,450				-

1 Dominant Land Use and Soil type hydrologic response unit option

2 Multiple hydrologic response unit option

In examining surface discharge (Table 4.2), results indicate slightly higher rates associated with the less detailed STATSGO dataset than for the SSURGO dataset. These results also showed a variation among the dominant land use and soil HRU and multiple HRU options, with the multiple HRU leading to slightly higher discharge volumes with both the SSURGO and STATSGO datasets.

Total Suspended Sediment results (Table 4.3) were higher for SSURGO datasets relative to STATSGO. Interestingly, using soil data with a greater spatial resolution leads to model results with less discharge, but creates more sediment leaving the catchment. The multiple HRU option also produced greater sediment loss for the SSURGO dataset relative to the dominant land and soil option. In addition, the STATSGO-based sediment load was greater for the multiple HRU option rather than the dominant land use and soil option.

Nutrient loads varied in their response to the different soils sets and HRU options (Tables 4.4 and 4.5). The loads were higher with the multiple HRU option for both the STATSGO and SSURGO datasets. In both cases, the STATSGO and multiple HRU option led to higher loads than SSURGO with multiple HRU's, but the SSURGO with dominant land use and soil option led to higher loads than the STATSGO.

While these results suggest that there is relatively little difference between the two soil datasets, the lack of a calibrated model doesn't allow for any speculation as to which of these may be the more accurate predictor of pollutant loads in Antelope creek. While there is a difference in the magnitude of pollutant export, the general trends associated with each model run are similar regardless of the soils data used, or hydrologic response unit selected.

Individual Scenario Results

Base Scenario

The Base scenario was created as a proxy for present day conditions in Antelope Creek. It is meant to represent a baseline condition for comparison purposes with the other four scenarios. In order to create this scenario, there was relatively little manipulation of the Iowa framework other than to change the physical attributes, and the inclusion of grazing practice as it is a major enterprise in the Flint Hills physiographic region.

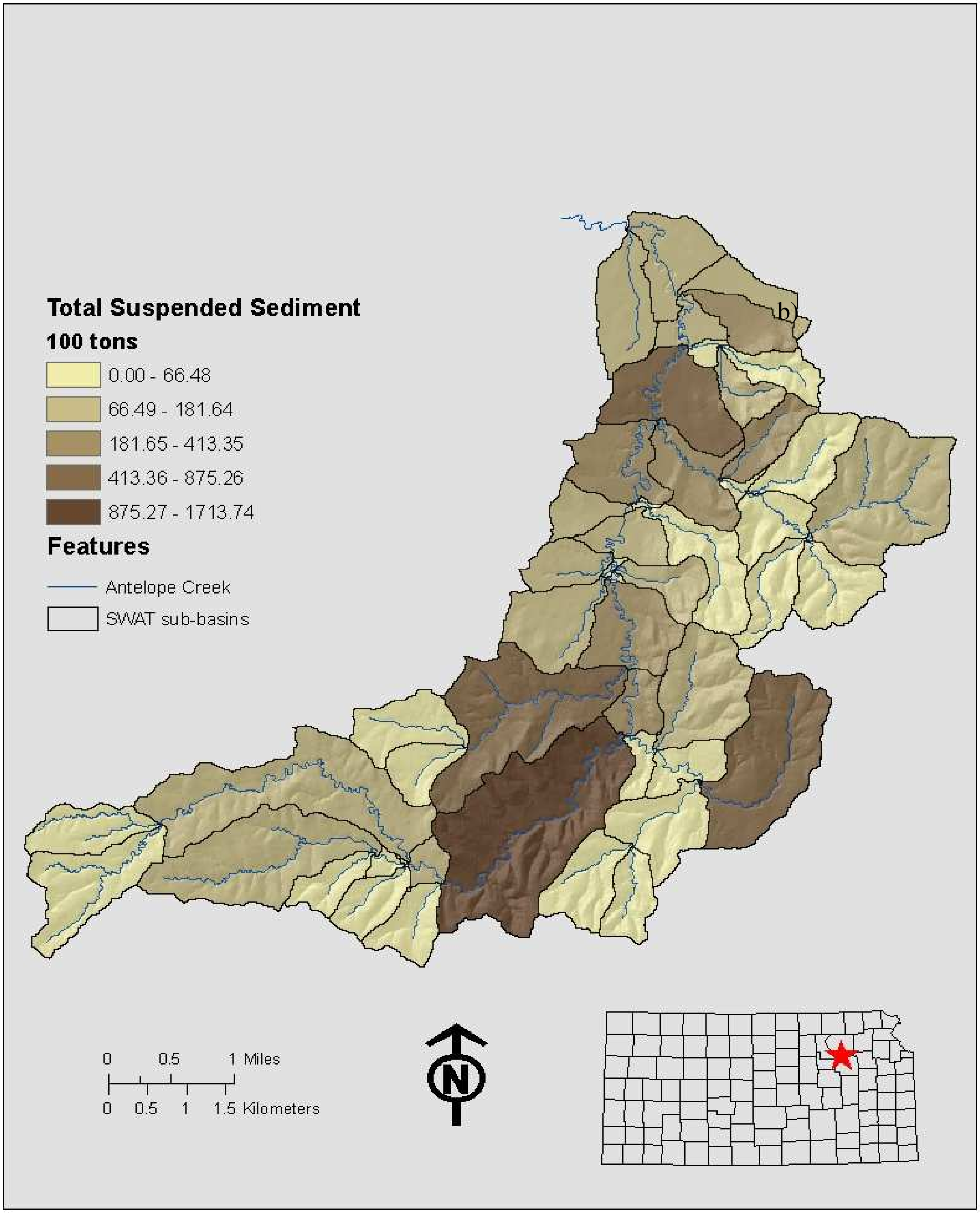
The Base scenario results are presented in table 4.6. Discharge is at a higher rate in areas that contained cropland or hay and also tended to increase in areas with steeper slopes (fig. 4.3). Two of the higher discharging sub-basins for the Base scenario were located in distinct settings. The first was a sub-basin dominated by poor soils for production. This also happened to be an area which had a homestead and cropland adjacent to the stream reach outlet, which may have influenced the results. The second area, located in the northwest corner of the watershed, is an area dominated by cropland that contains good to mediocre soils. The predominance of row cropping in this area is thought to be the main cause of the comparatively high discharge rates.

Total suspended sediment in the watershed tended to be relatively higher in areas where there were high amounts of agricultural land (fig 4.2). When this occurred in sub-basins with moderate or poor soils, some of the highest rates of TSS export were found. Two of the highest exporters of sediment were found in areas which were primarily a row crop cover and at least some poor soil suitability for production.

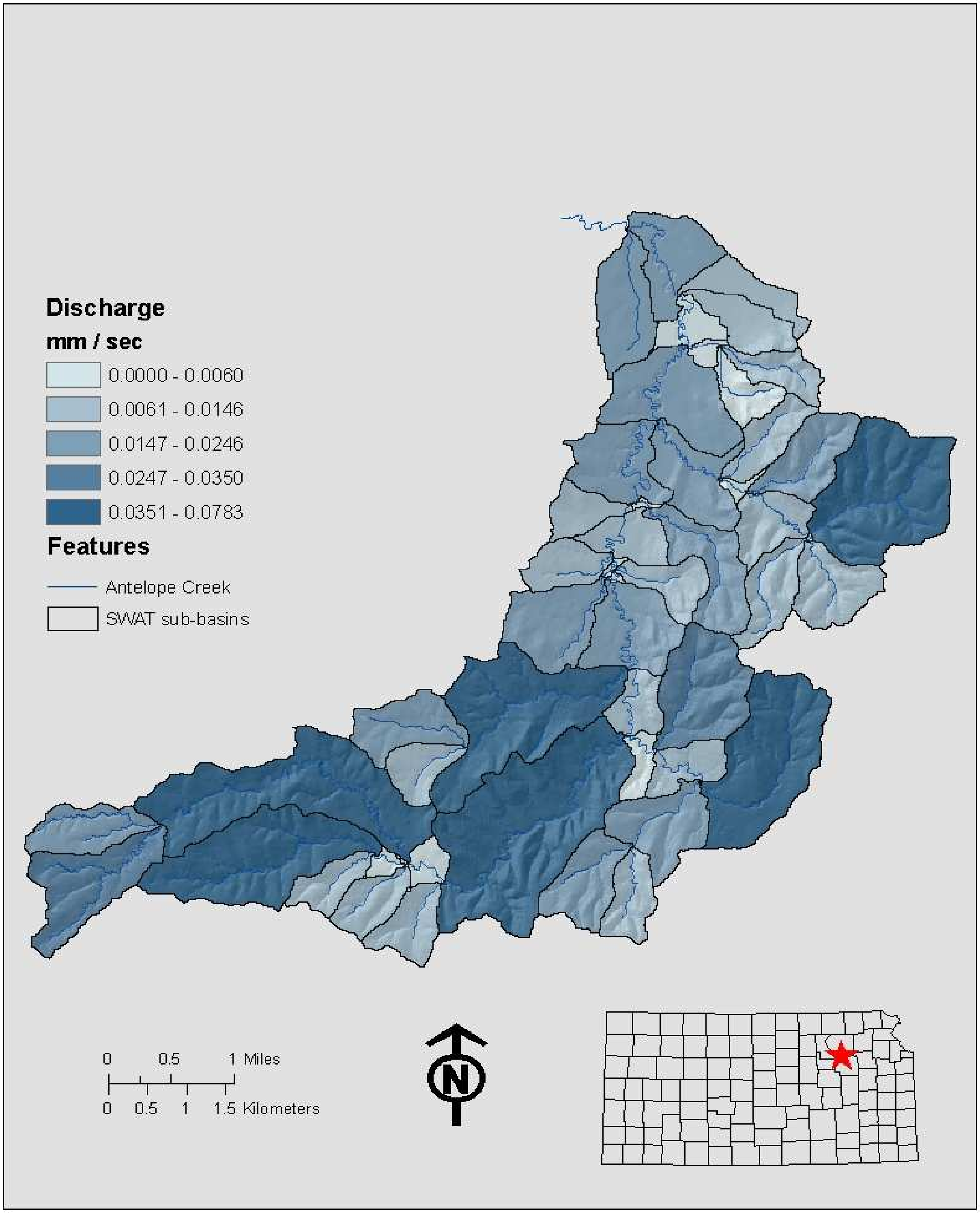
Nutrient loads followed similar patterns as the discharge and sediment, with the different sources of nitrogen and phosphorus following different pathways to the main channel (fig 4.3-4.5). Nitrogen coming from surface runoff and soluble phosphorus followed similar patterns as discharge in the Base scenario. Given the transport mechanisms associated with these two nutrients, this in not surprising. Both organic nutrient pools tended to come from the same areas. Generally where there was cropland, there was a large load of organic nitrogen and phosphorus associated with the area. Phosphorus attached to sediment resembled the same pattern as TSS export. It was generally heavy in areas where cropland was the primary land cover.

Table 4.6 Results from the Base scenario run for selected pollutants

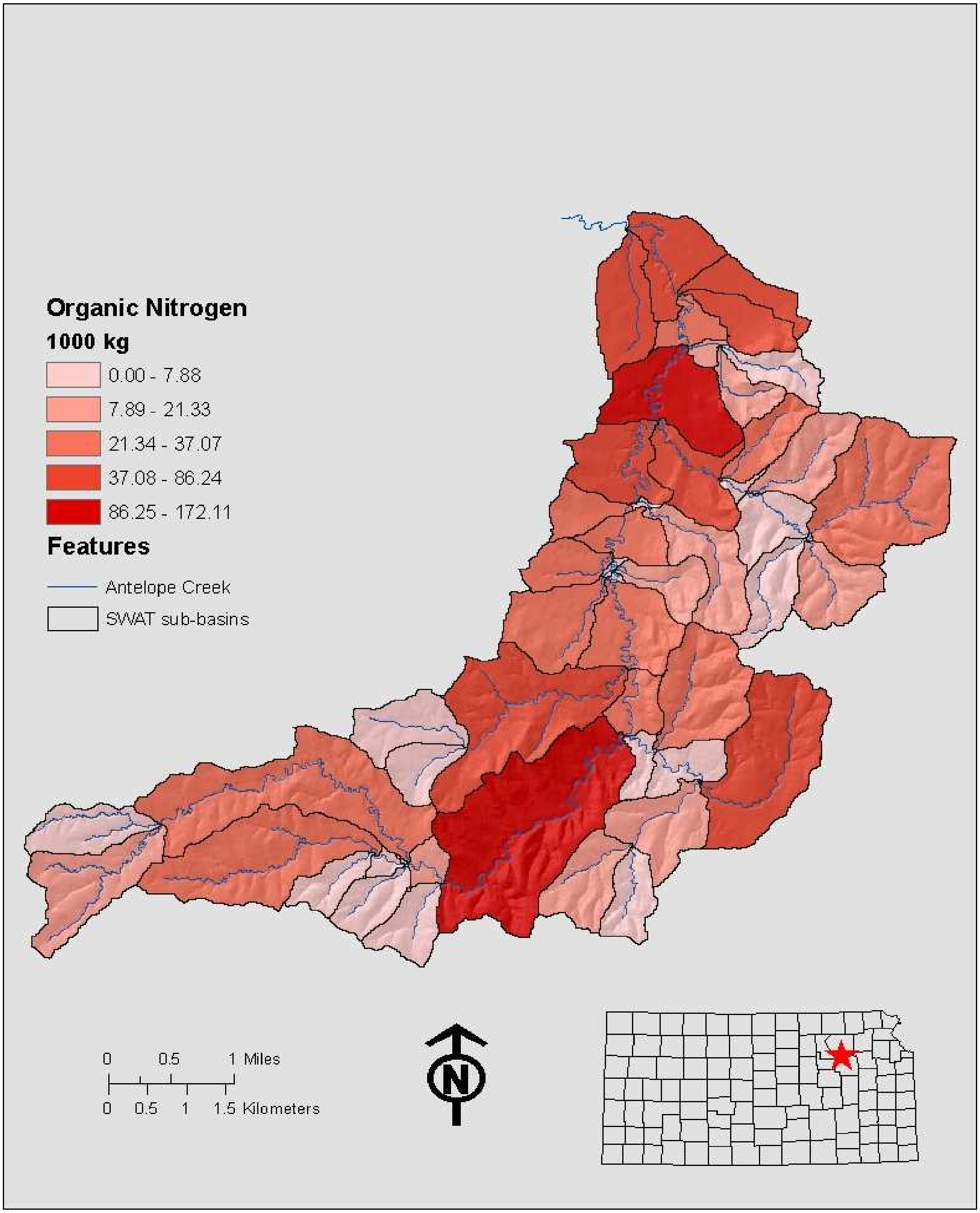
Base Scenario	
Total Sediment (tons)	**10261.4**
Surface Discharge (mm/sec)	**.3243**
Organic nitrogen (kg)	**1,471,665**
Organic phosphorus (kg)	**134,031**
nitrogen In Surface Discharge (kg)	**90,978**
Soluble phosphorus (kg)	**7,684**



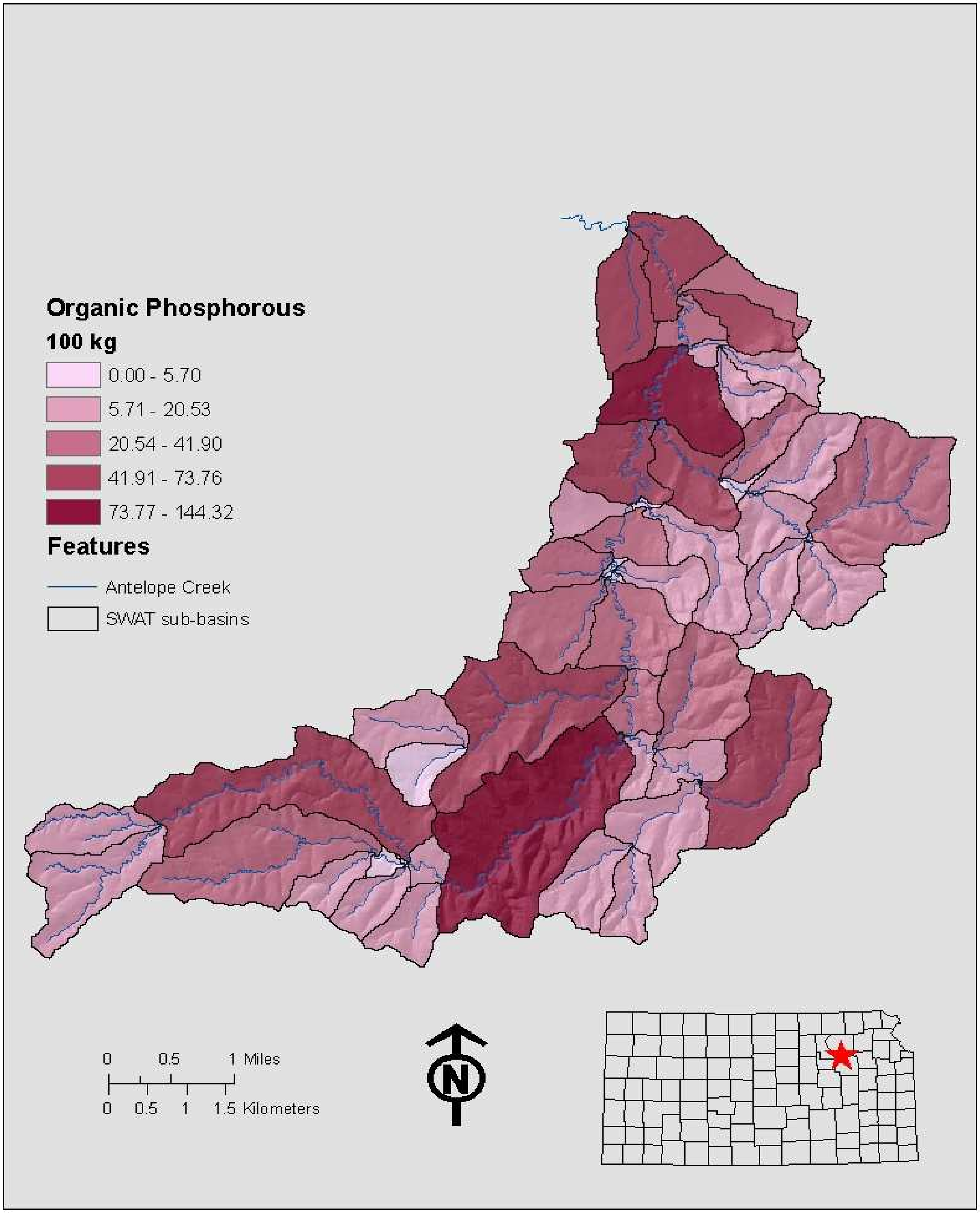
4.2 Total Suspended Sediment results map for Base scenario. (Source: Author)



4.3 Discharge results map for Base scenario. (Source: Author)



4.4 Organic nitrogen results map for Base scenario. (Source: Author)



4.5 Organic phosphorus results map for Base scenario. (Source: Author)

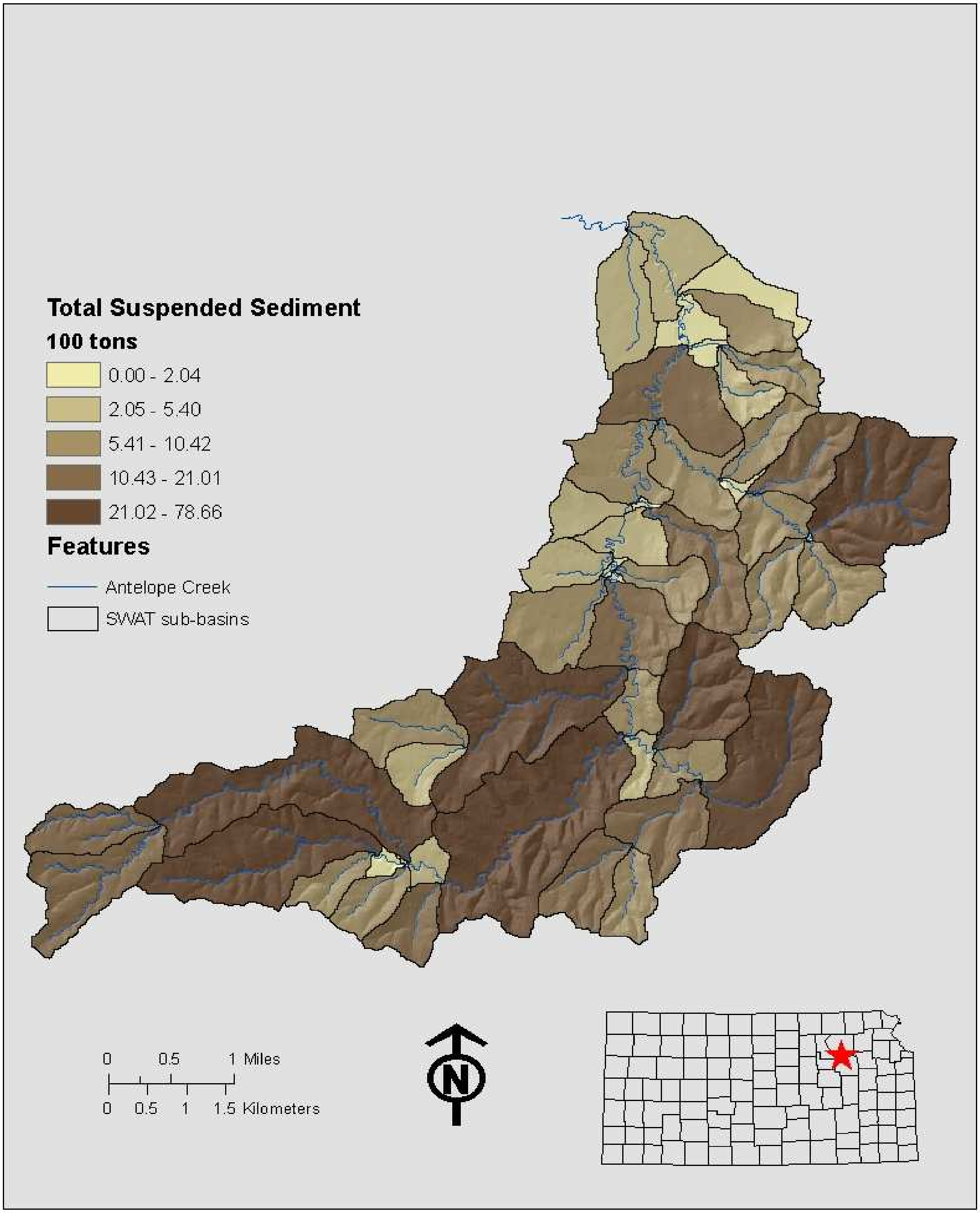
Grassland Scenario

The Grassland scenario was created to represent conditions in Antelope creek pre-Euro-American settlement. The scenario was based on Kuchler's (1976) potential natural vegetation classes for Kansas. For Antelope creek, the Grassland scenario is comprised of big bluestem grass, a generic range grass cover, and forested areas. The Grassland scenario required no application of the Iowa research framework.

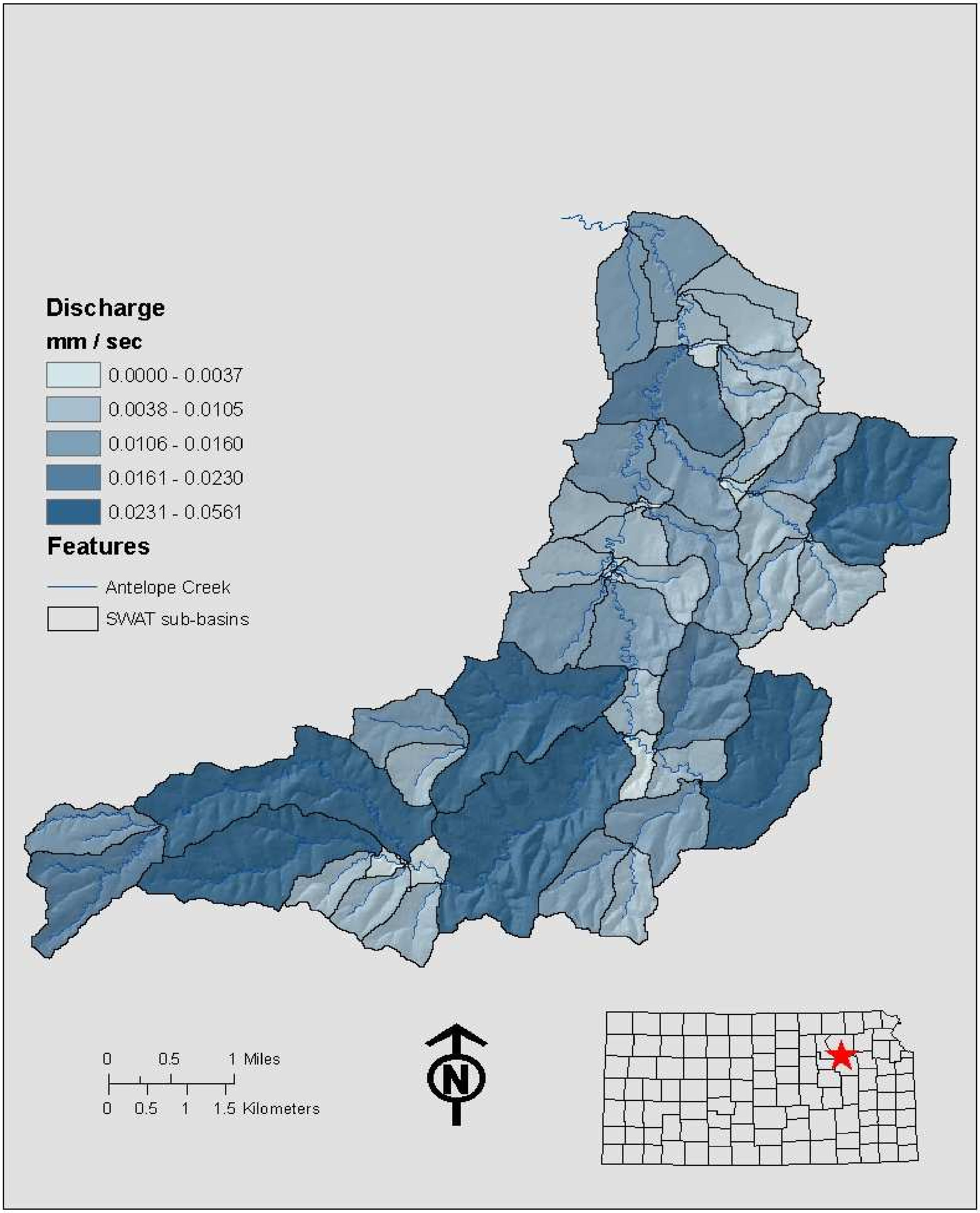
Total suspended sediment, sediment attached phosphorus, organic nitrogen, and organic phosphorus exhibited spatially similar patterns in the Grassland scenario (table 4.7, fig. 4.6-4.9). The highest loading sub-basins were those which contained predominately poor soils. In many cases these areas of poor soils are also areas of moderate to high slopes. This is further evidenced by the relatively low loading in the northern tip of the watershed. This area lies in the floodplain of the Kansas River and exhibits little to no relief. The sub-basins in this area show the lowest loadings in terms of TSS, sedimentary phosphorus and organic nutrients.

Table 4.7 Results from the Grassland scenario for selected pollutants

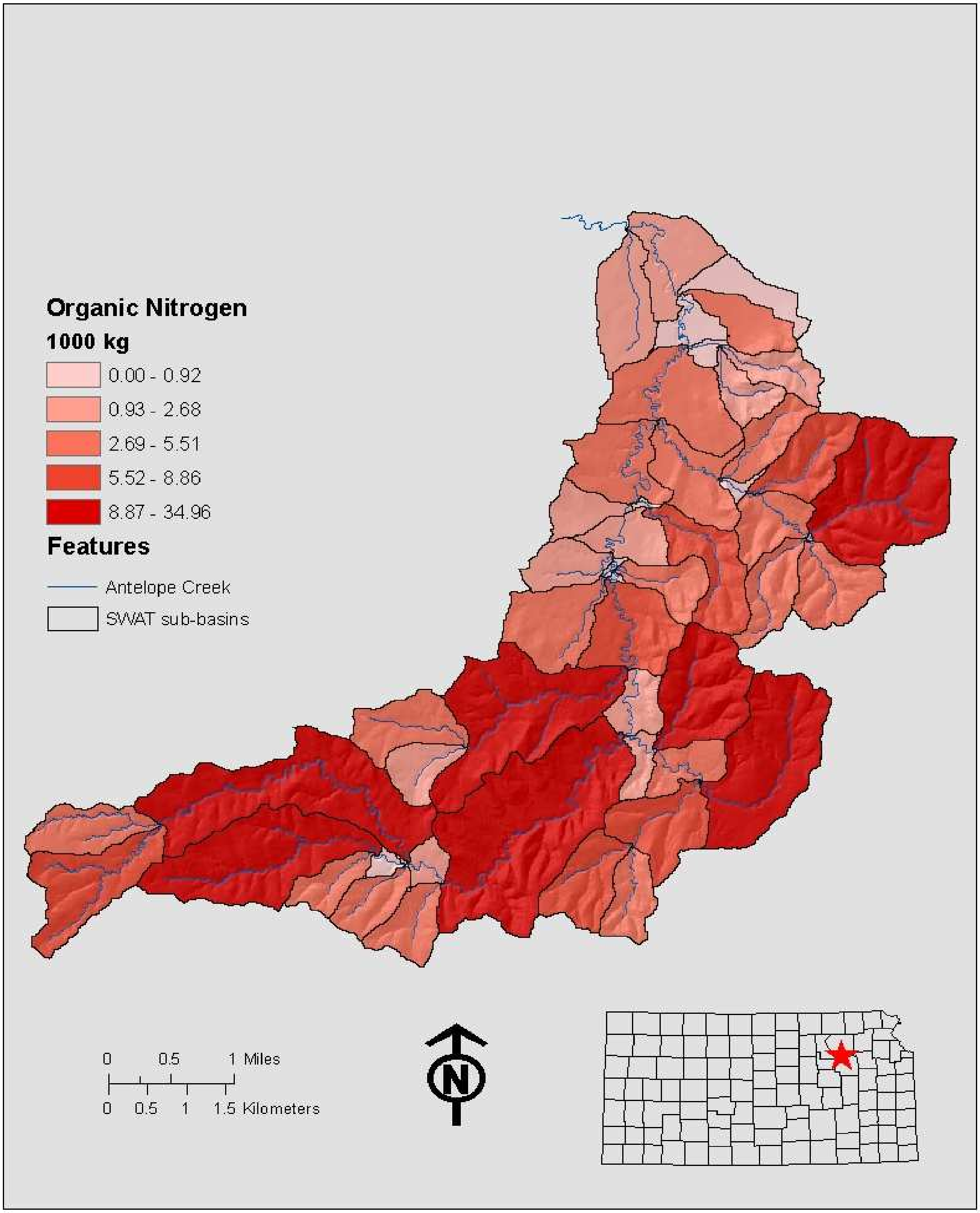
Grassland Scenario	
Total Sediment (tons)	**615.08**
Surface Discharge (mm/sec)	**0.2504**
Organic nitrogen (kg)	**271,355**
Organic phosphorus (kg)	**37,132**
Nitrogen In Surface Discharge (kg)	**54,761**
Soluble phosphorus (kg)	**7,072**



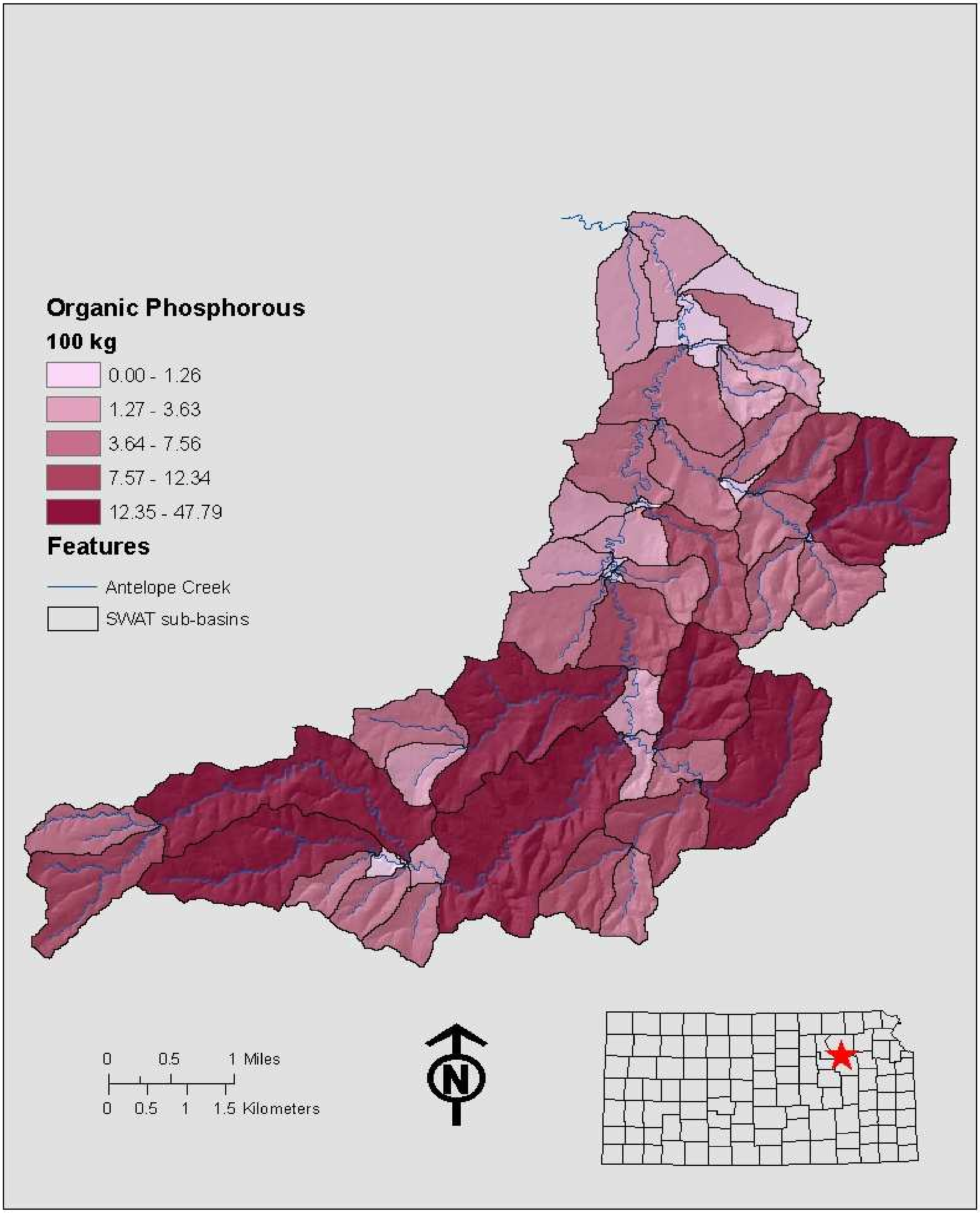
4.6 Total Suspended Sediment results map for the Grassland scenario. (Source: Author)



4.7 Discharge results map for Grassland scenario. (Source: Author)



4.8 Organic nitrogen results map for Grassland scenario. (Source: Author)



4.9 Organic phosphorus results map for Grassland scenario. (Source: Author)

Production Scenario

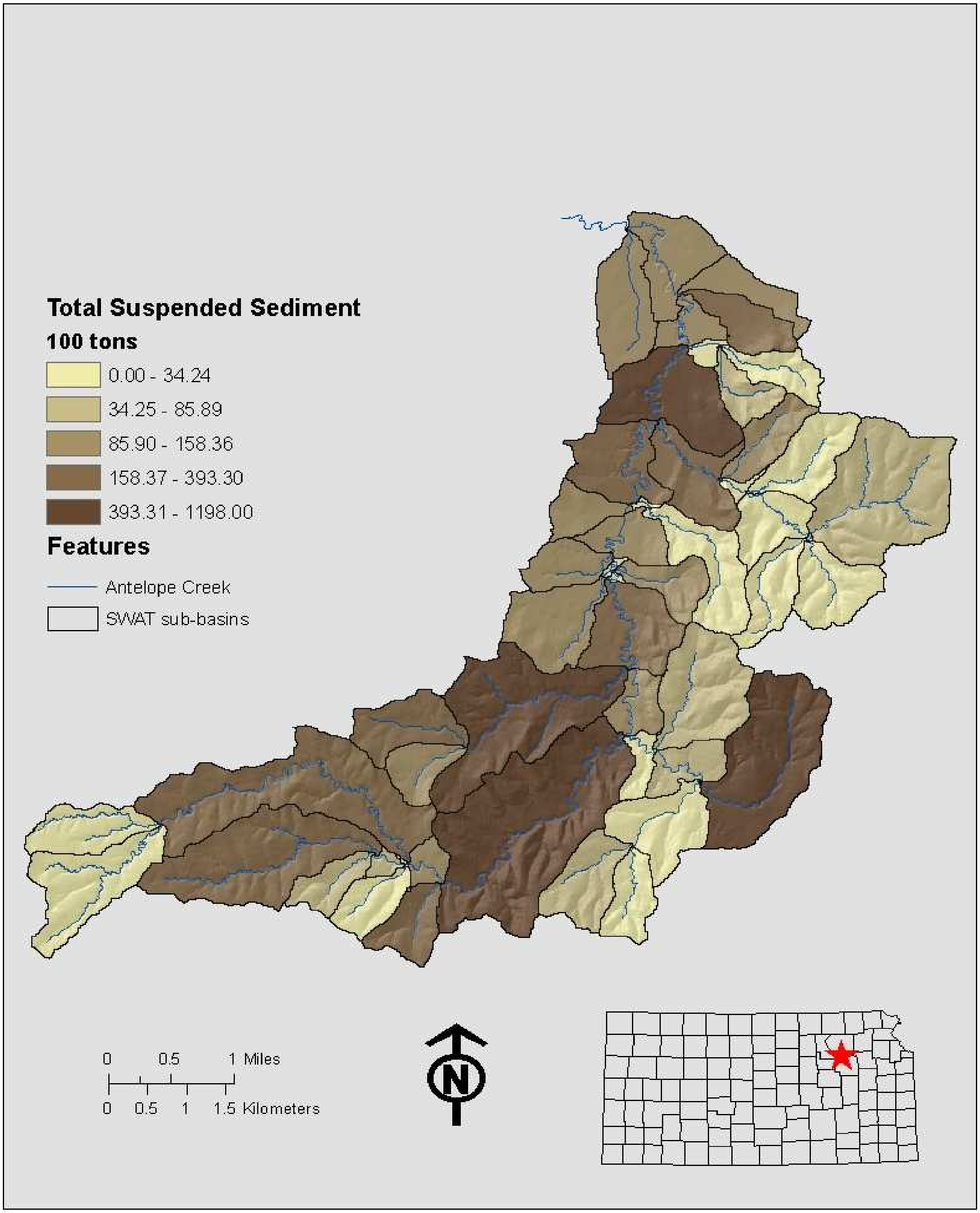
The first of the three future scenarios is one that emphasizes agricultural production. In this scenario the goal is to take any land which could be suitable for producing crops, and shift it to either corn or soybeans. For the purposes of this work, anywhere that contained an LCC rating of three or lower, was considered suitable soil for cultivation.

In adapting the rules from the original work in Iowa, several adjustments were made for Antelope Creek. The biggest adjustment is the addition of grazing for all scenarios. The parameters are kept the same for the Production scenario as in the Base scenario. In the Iowa research, no scenario contains any production animal. Another adjustment of the Iowa framework is the crop choice in agricultural areas. The two Iowa watersheds were located in the Corn Belt region, and as such modeled a mix of primarily corn, with soybean as a secondary crop. In Antelope creek, the most prevalent crop is Soy Bean, and as such is the highest proportion being grown in the Production scenario, with corn as the secondary crop. In Iowa there is a statewide soil suitability classification based on an areas ability to grow corn. No similar rating could be found specifically for Kansas, so we use the non-irrigated land capability class available through the NRCS SSURGO dataset.

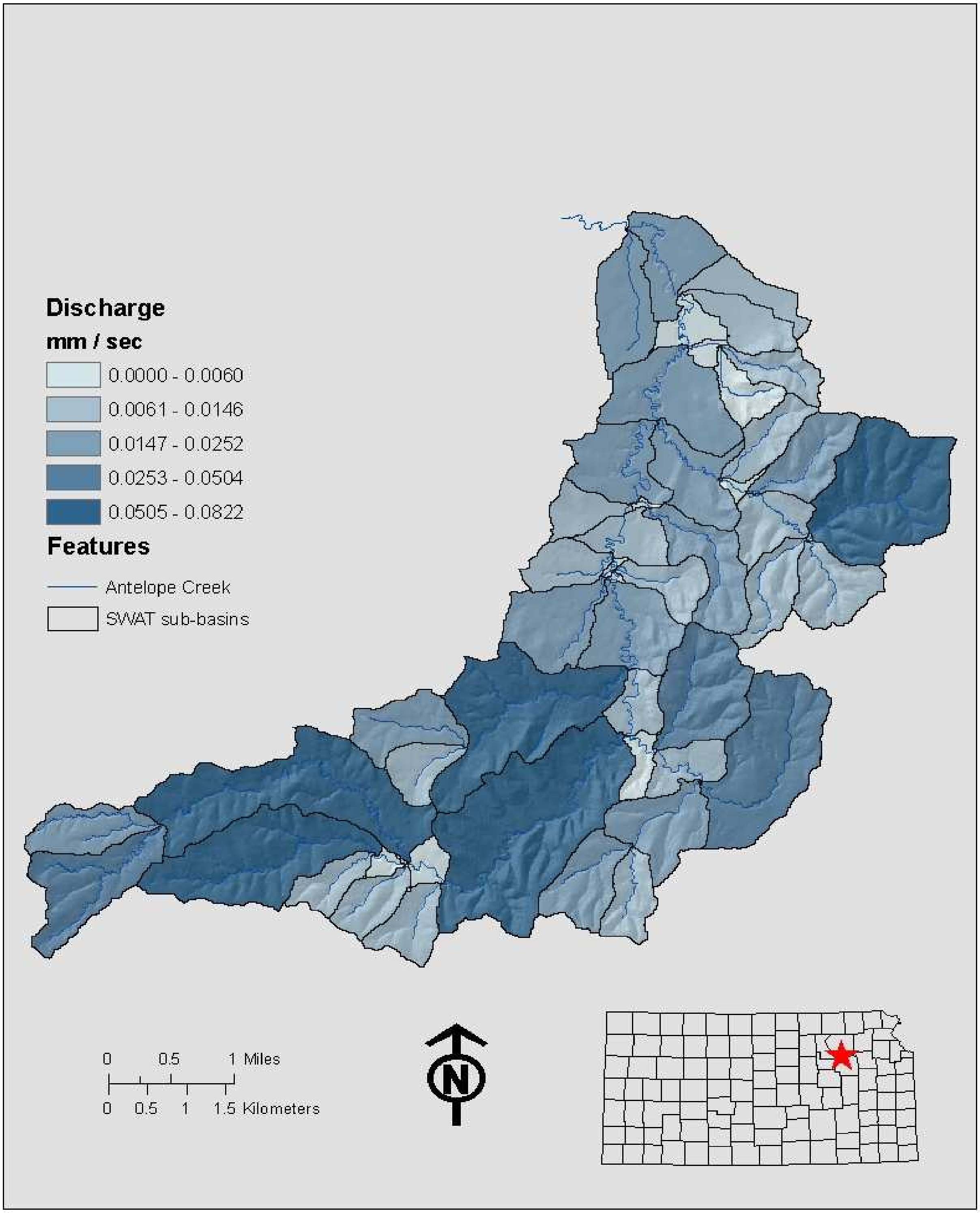
The results in the Production scenario follow similar trends to previous scenarios. Results for TSS, sediment attached phosphorus, organic nitrogen, and organic phosphorus, tended to show higher loading sub-basins are areas where crops being grown on moderate to poorer soils (table 4.8, fig. 4.10- 4.13). The high loading sub-basins in the northern tip of the watershed are dominated by cropland in the Production scenario. These same sub-basins loaded relatively low for pollutants in the Grassland scenario. A sub-basin in the southeastern portion of the watershed exhibited relatively high loadings in the Production scenario when compared with other sub-basins. This area contained areas of cropland which were converted from rangeland under the soil suitability criteria for the Production scenario. While suitable for production according to the LCC rating, these newly converted crop areas would be more susceptible to erosional processes leading to higher rates of export of TSS, sediment attached phosphorus, organic nitrogen, and organic phosphorus.

Table 4.8 Results from the Production scenario for selected pollutants

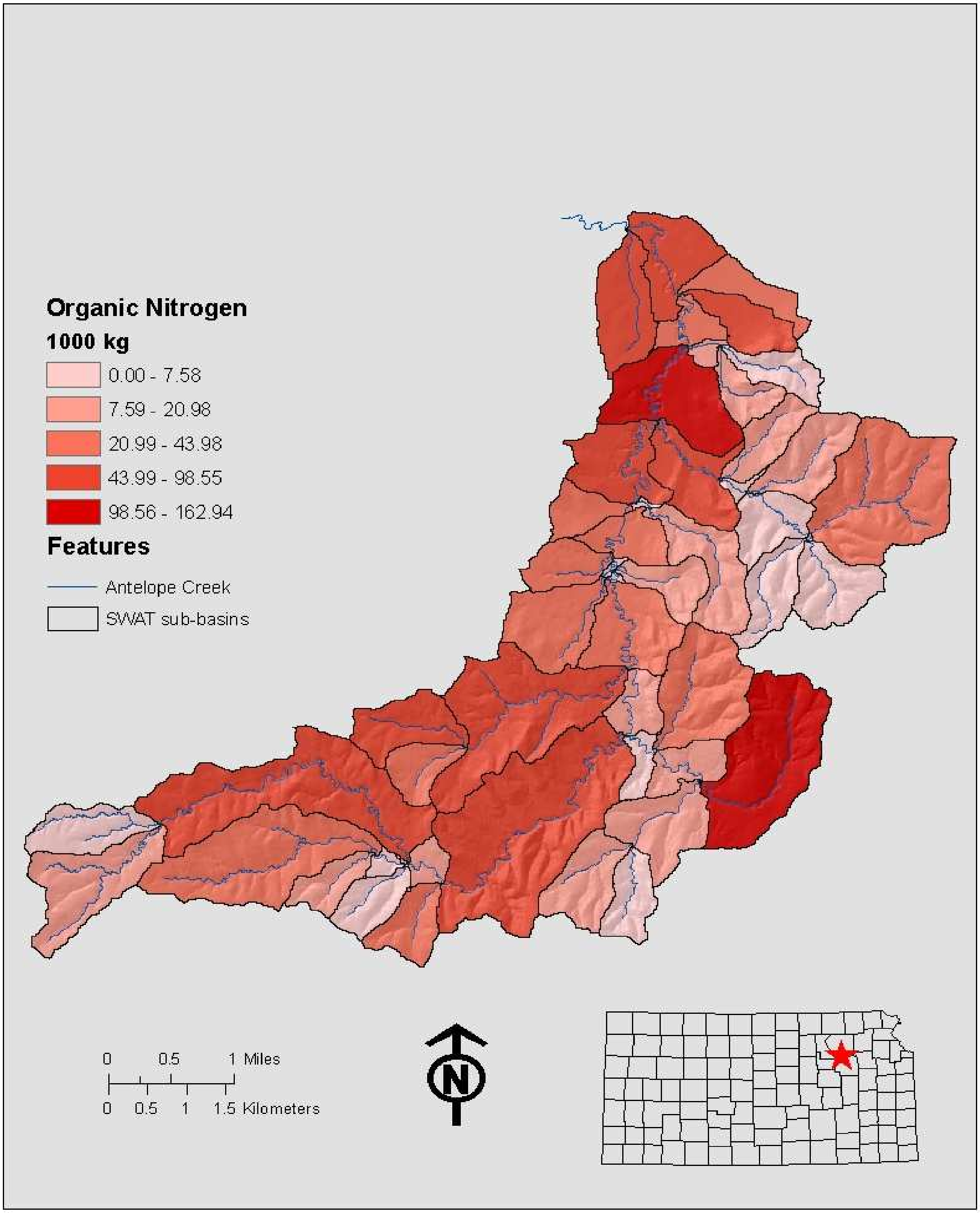
Production Scenario	
Total Sediment (tons)	**9732.3**
Surface Discharge (mm/sec)	**0.3215**
Organic nitrogen (kg)	**1,641,141**
Organic phosphorus (kg)	**150,918**
Nitrogen In Surface Discharge (kg)	**92,656**
Soluble phosphorus (kg)	**8,267**



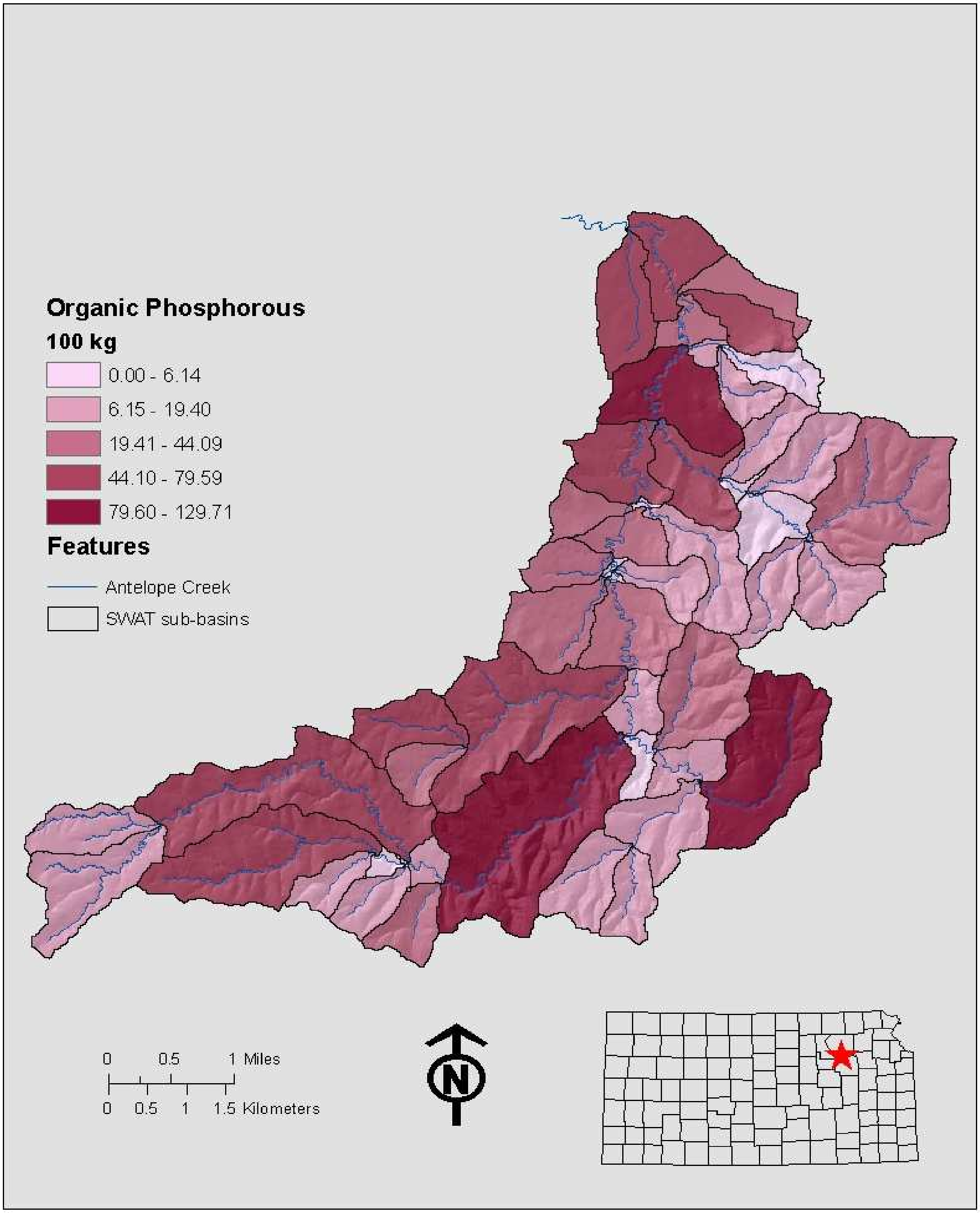
4.10 Total Suspended Sediment results map for Production scenario. (Source: Author)



4.11 Discharge results map for Production scenario. (Source: Author)



4.12 Organic nitrogen results map for Production scenario. (Source: Author)



4.13 Organic phosphorus results map for Production scenario. (Source: Author)

Water Quality

The Water Quality scenario was created to represent a shift in management practices that emphasize the improvement of water quality. Changes in practices for this scenario include the addition of contour farming in the cropped areas, the inclusion of grass buffers along the riparian corridors, the addition of a partial season grazing operation in the grassland areas. The practice of no-till agriculture is added to all the cropped areas to help reduce pollutants reaching the main channel.

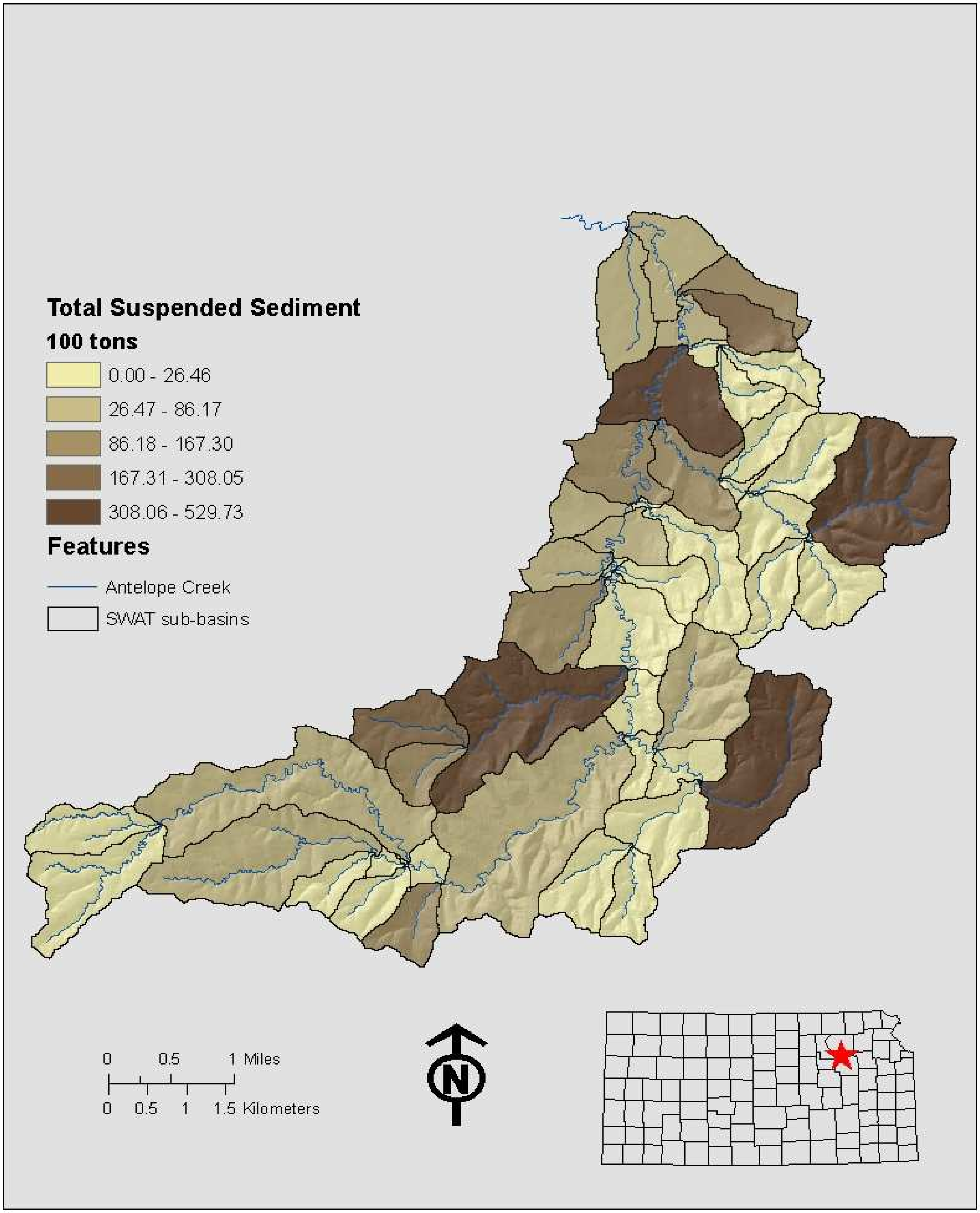
The research in Iowa included many of the same practices in their scenarios for water quality improvements. In the original work a fifteen to thirty meter buffer of perennial vegetation was included to help reduce the amount of pollutants entering the main channel. In the Antelope creek watershed a 130 meter buffer of perennial grass was included along the riparian corridor. This was done to receive the benefit of having perennial grasses along the stream corridors, but increased to incorporate grazing in these areas as well. In order to incorporate grazing so close to the riparian corridor, some measure should be taken to keep animals from entering the stream. This could be accomplished through fencing, or the movement of watering tanks, and salt licks, which would have the added benefit of a more even grazing (Ohlenbusch and Watson 1994).

The Water Quality scenario results for TSS, sediment attached phosphorus, organic nitrogen and organic phosphorus all followed similar spatial patterns (table 4.9, fig. 4.14- 4.17). The higher loading sub-basins were in locations where row crops were being raised on moderate to poor soils. This is evident along the western edge of the watershed where the loadings for these sub-basins area relatively higher than the rest of the watershed.

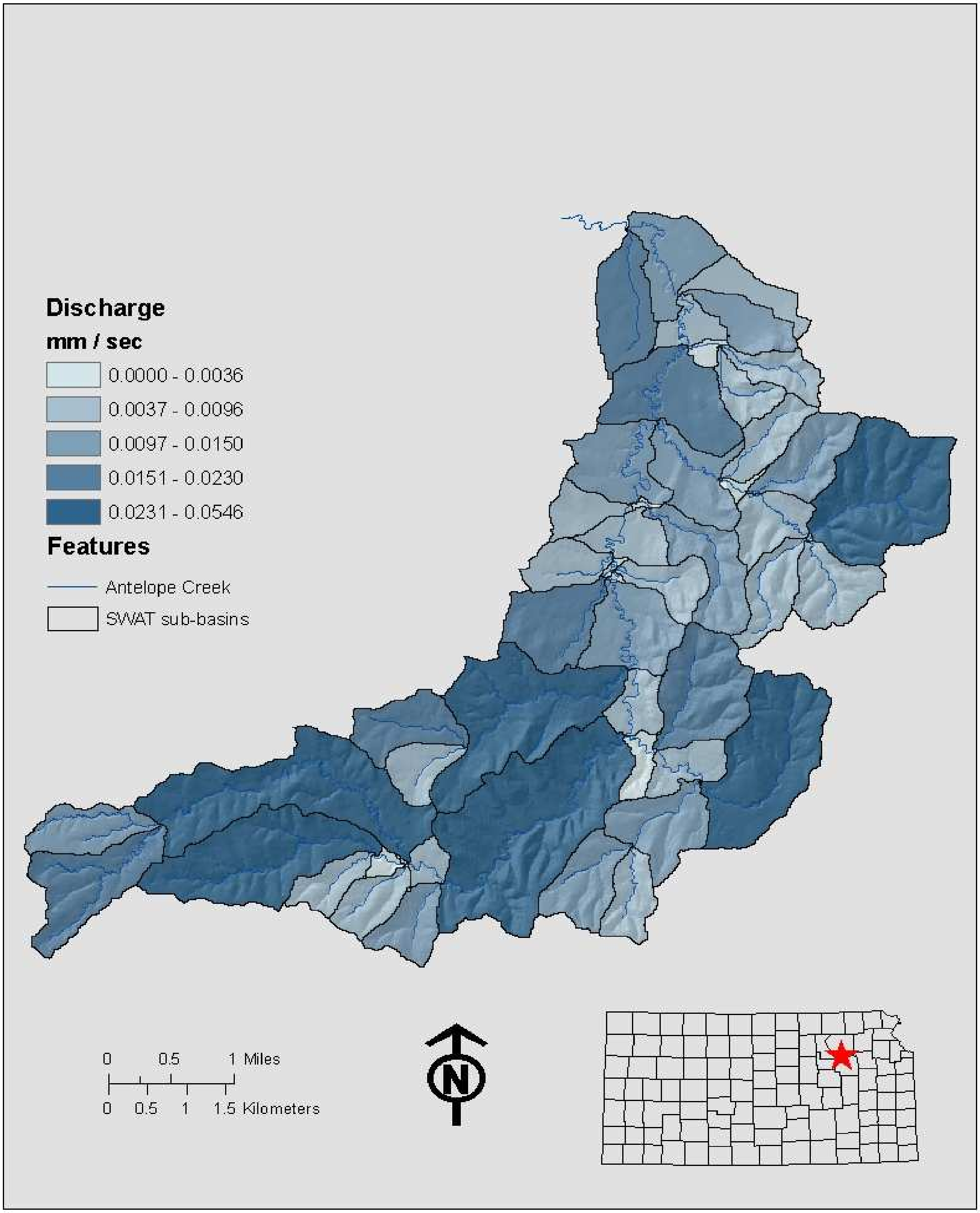
Spatially, results for discharge and nitrogen contained in surface runoff were similar to one another. Soluble phosphorus loads were lower in the floodplain relative to other areas in the watershed. Even in the Water Quality scenario the areas in the Kansas River floodplain are primarily cropped areas. The relatively low loads in soluble phosphorus could be attributed to the practices described above being implemented in this scenario.

Table 4.9 Results from the Water Quality scenario for selected pollutants

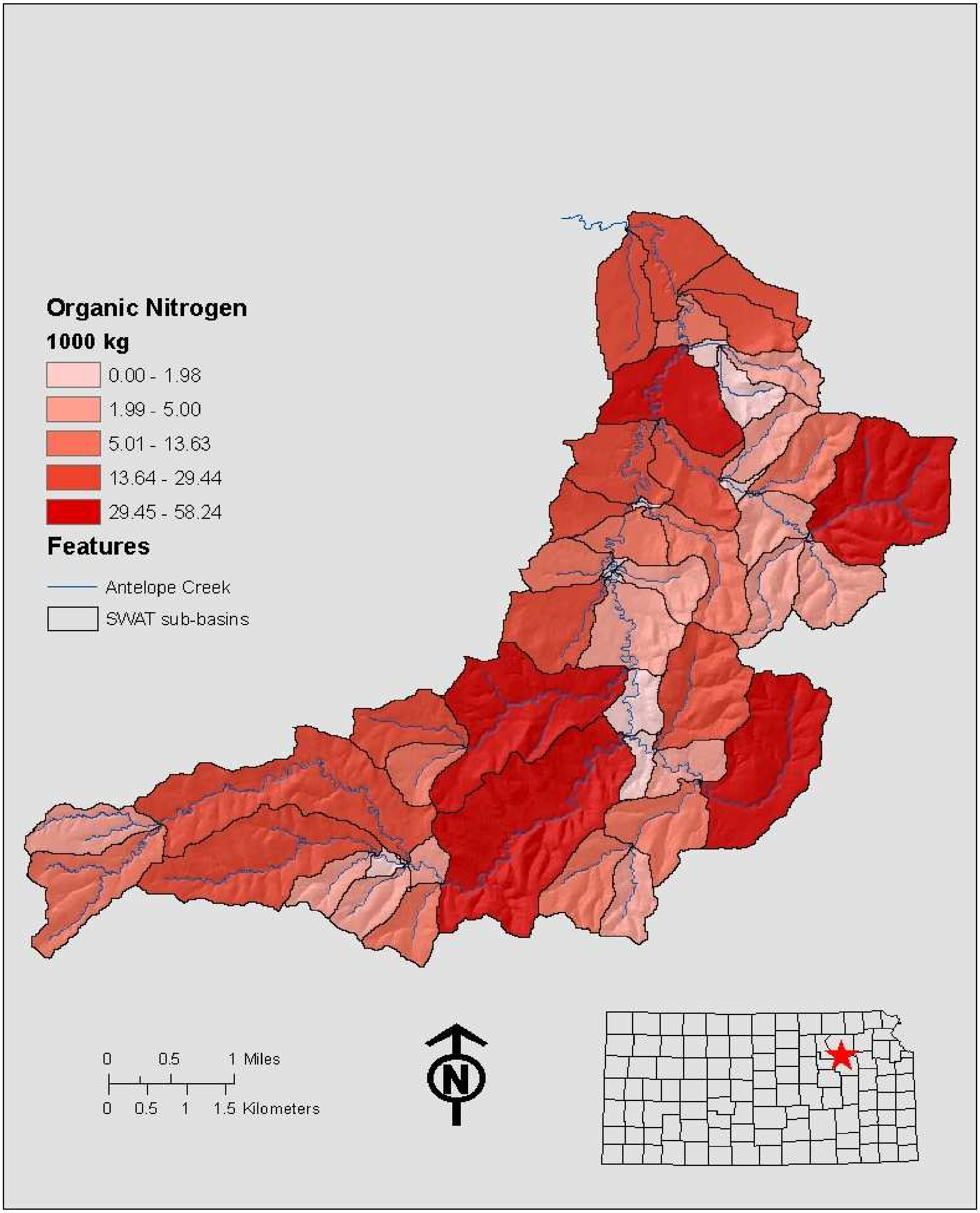
Water Quality Scenario	
Total Sediment (tons)	**4315.5**
Total Surface Discharge (mm/sec)	**0.2483**
Organic Nitrogen (kg)	**597,112**
Organic phosphorus (kg)	**87,642**
Nitrogen In Surface Discharge (kg)	**55,658**
Soluble phosphorus (kg)	**6,089**



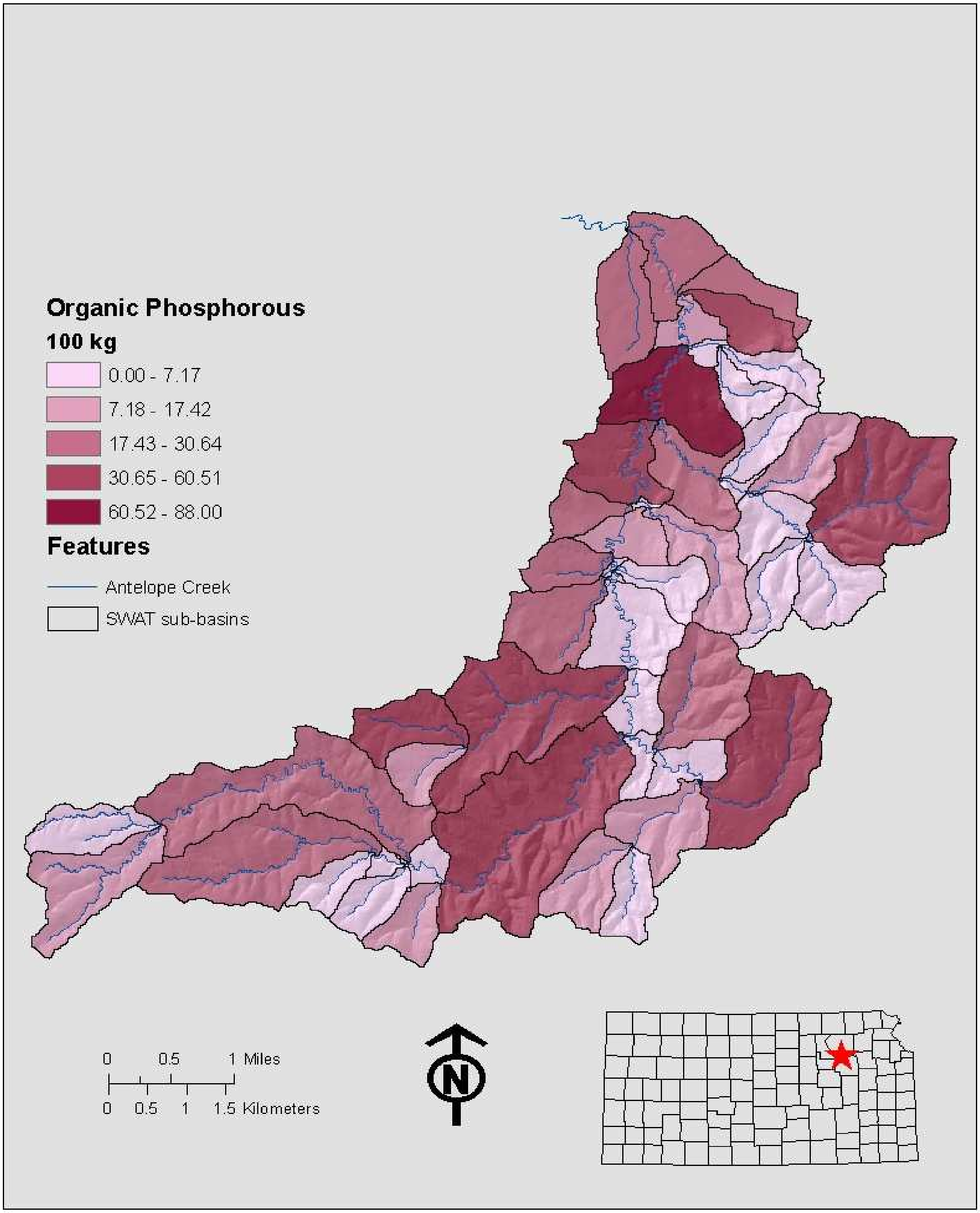
4.14 Total Suspended Sediment results map for Water Quality scenario. (Source: Author)



4.15 Discharge results map for Water Quality scenario. (Source: Author)



4.16 Organic nitrogen results map for Water Quality scenario. (Source: Author)



4.17 Organic phosphorus results map for Water Quality scenario. (Source: Author)

Biodiversity

The Biodiversity scenario is the representation of a shift in agricultural management that emphasizes enhancing biodiversity. To do so involves defragmenting the landscape by creating more connectivity from field to field. To accomplish this goal several steps were taken.

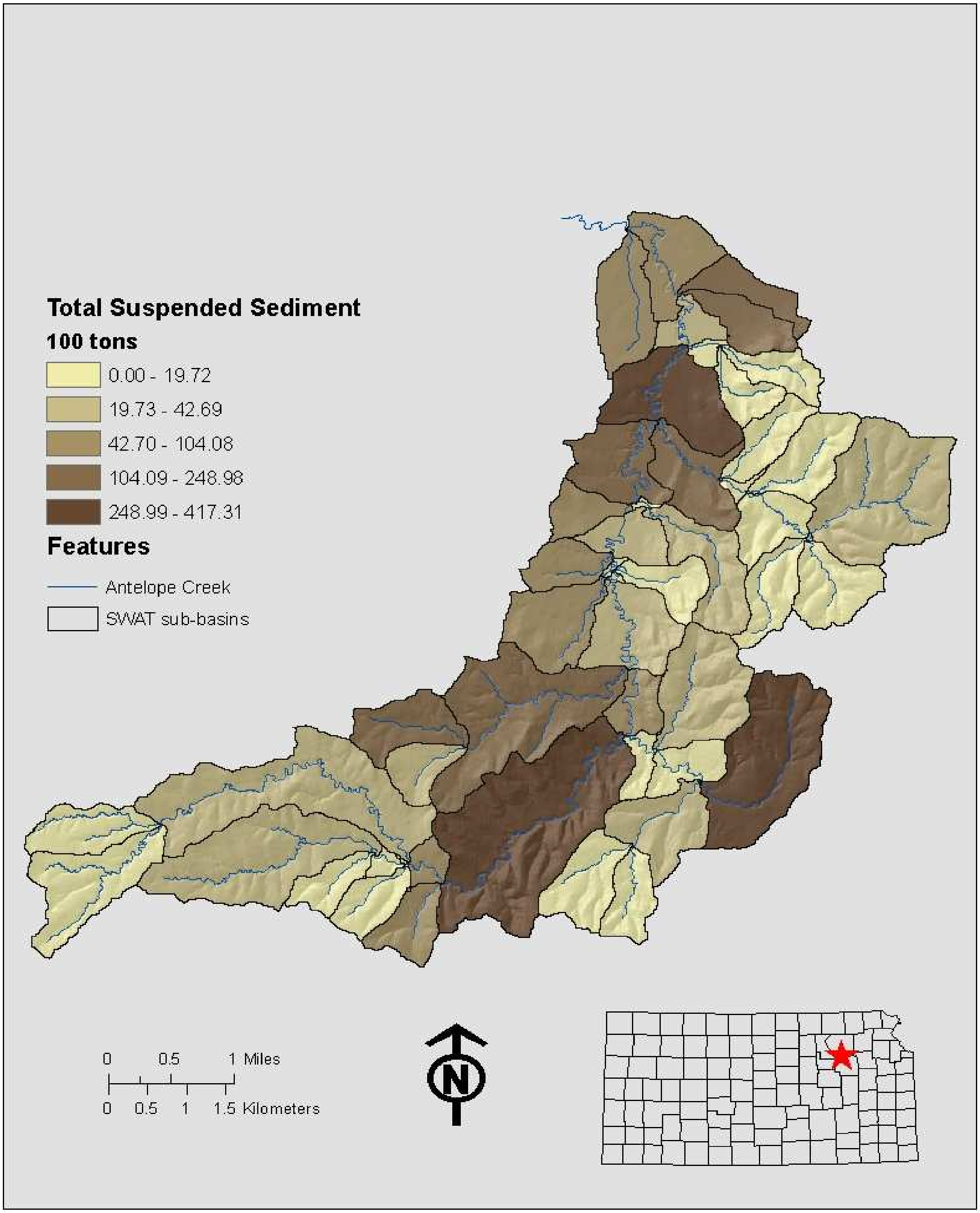
The major aspect of the Biodiversity scenario in the Iowa research was the creation of large preserves of species that are indigenous to the area. In the Antelope creek watershed a tallgrass prairie reserve is created on the northeastern edge of the study area. A quarter mile wide buffer area outside the bioreserve and riparian corridors is designated for strip cropping to be practiced within. This practice allows for the incorporation of perennial strips alternated with row crops and small grain. Strip cropping creates a connective corridor through fields which allows for organisms to move in and out of the bioreserve. In addition to the bioreserve, and the practice of strip cropping, a perennial grass buffer is incorporated along stream corridors. Like the Water Quality scenario this facilitates a partial season grazing operation, and helps reduce the amount of pollutants reaching the main channel. In the Biodiversity scenario it allows for additional connectivity between agricultural areas when not being grazed. No till cropping is again applied in all agricultural areas as in the Water Quality scenario.

Results in the Biodiversity scenario for total suspended sediment, sediment attached phosphorus, organic nitrogen, and organic phosphorus were spatially similar (table 4.10, fig. 4.18- 4.21). There were high loadings along the western edge of the watershed and along the stream corridors. These areas are generally where the cropped lands were located, and even though more conservation minded management practices are being employed, these are still the highest loading sub-basins in the watershed.

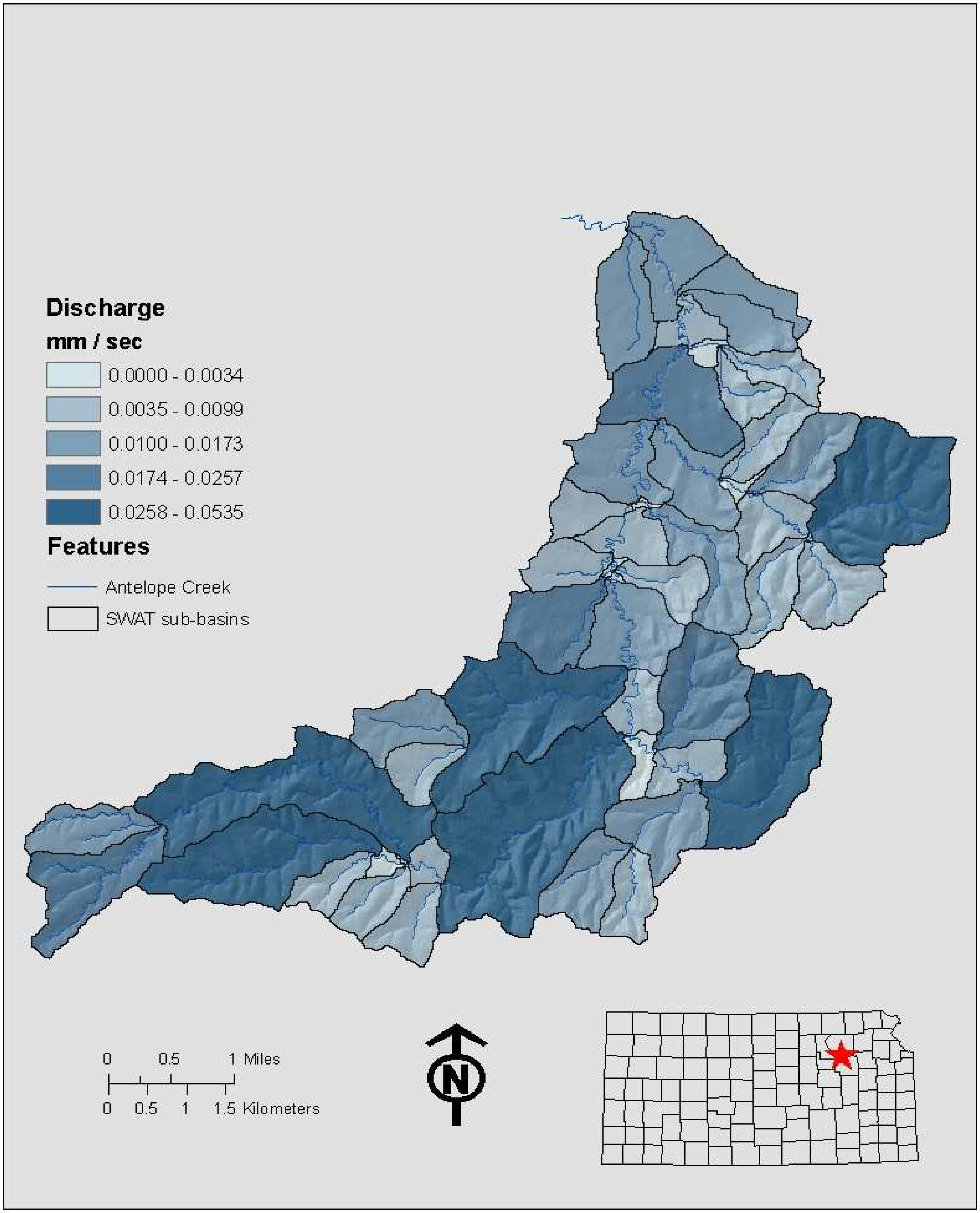
Pollutant loads associated with runoff processes were highest in similar areas as the previous scenarios. The sub-basin containing the bioreserve on the eastern edge tended to export these pollutants at a slightly higher rate than the adjoining sub-basins. This may be due to the more intense slopes, and poor soils associated with the area.

Table 4.10 Results from the Biodiversity scenario for selected pollutants

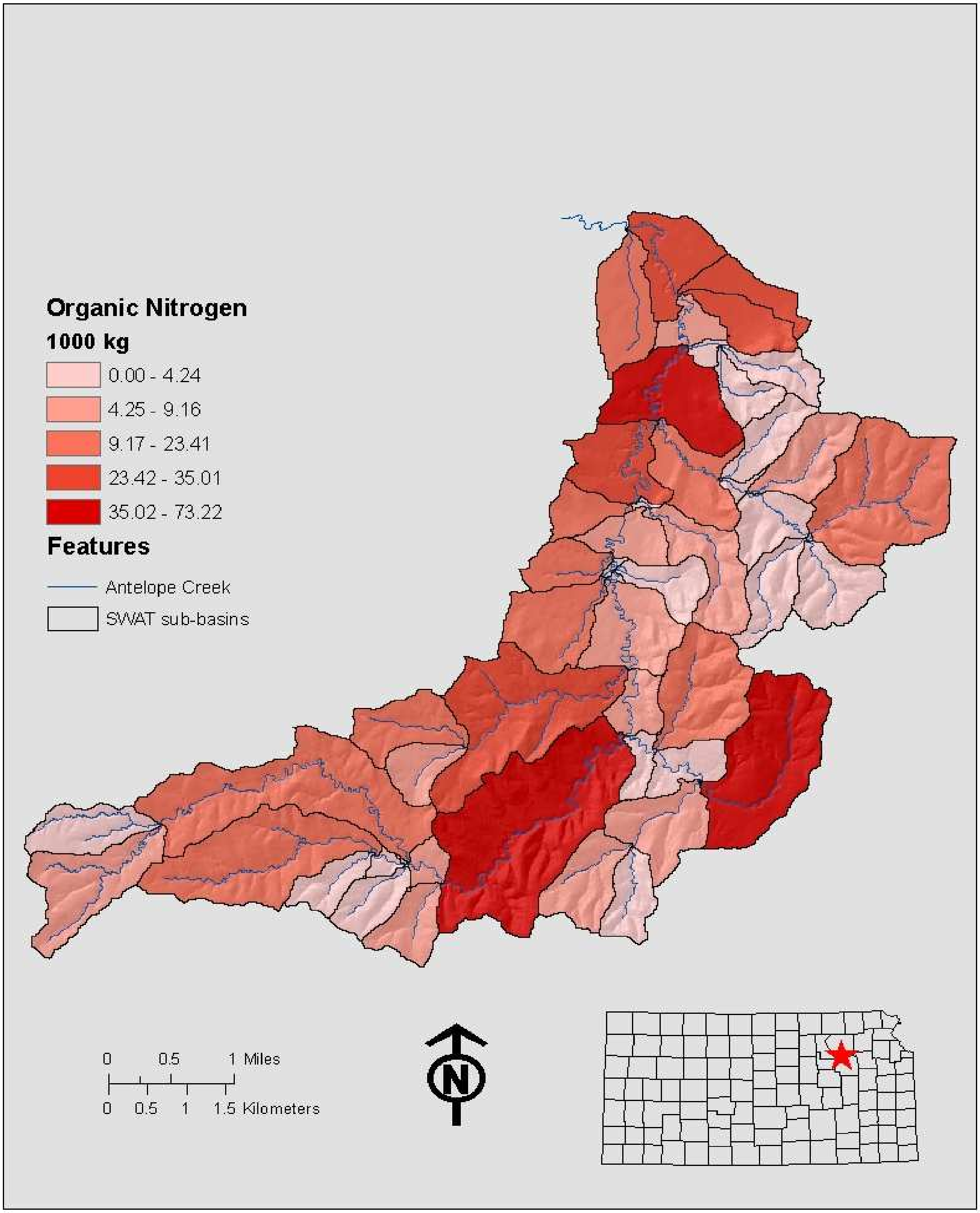
Biodiversity Scenario	
Total Sediment (tons)	**3976.03**
Total Surface Discharge (mm/sec)	**0.2706**
Organic Nitrogen (kg)	**628,759**
Organic phosphorus (kg)	**74,840**
Nitrogen In Surface Discharge (kg)	**56,292**
Soluble phosphorus (kg)	**4,048**



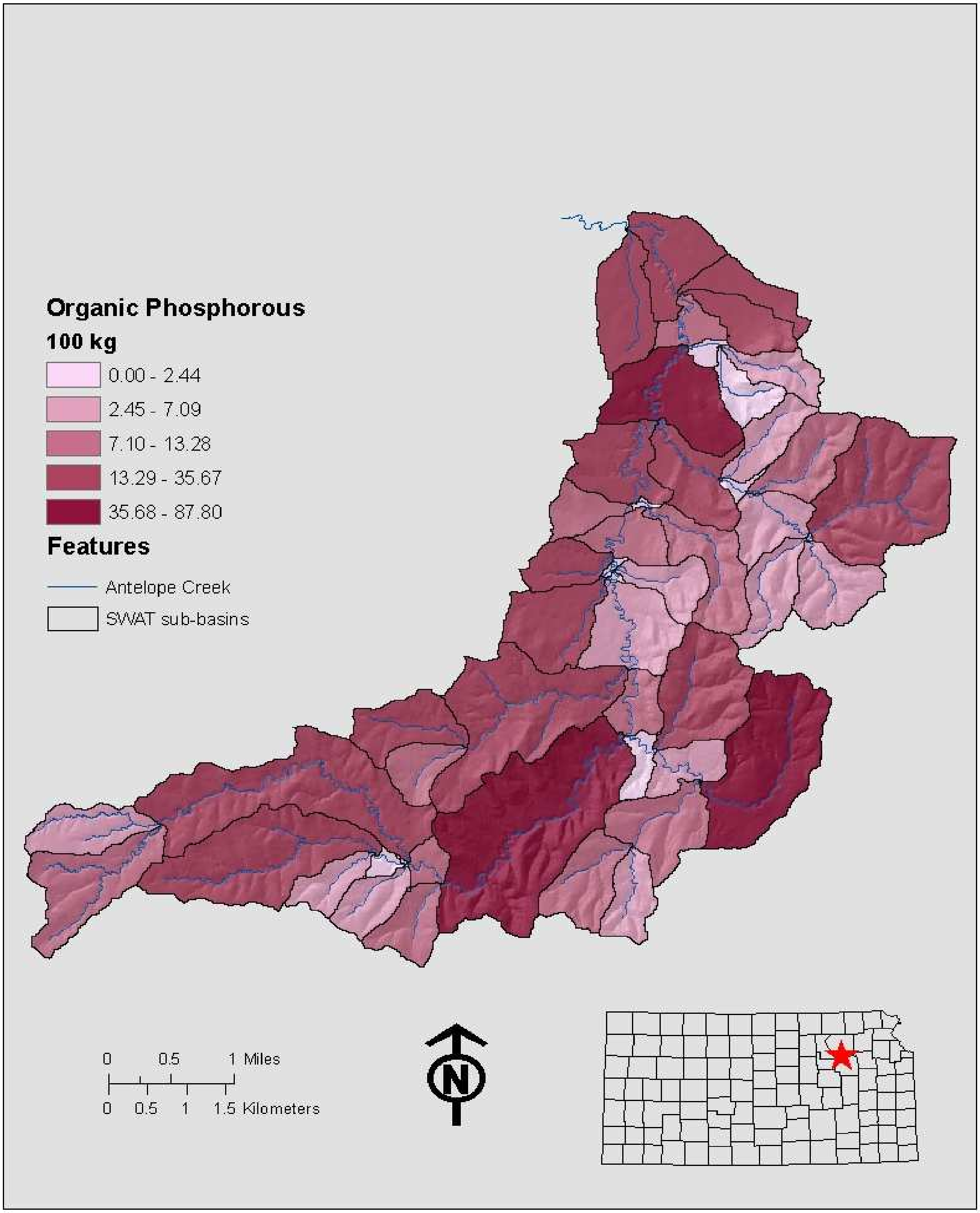
4.18 Total Suspended Sediment results map for Biodiversity scenario. (Source: Author)



4.19 Discharge results map for Biodiversity scenario. (Source: Author)



4.20 Organic nitrogen results map for Biodiversity scenario. (Source: Author)



4.21 Organic phosphorus results map for Biodiversity scenario. (Source: Author)

Scenario Comparisons

Total Suspended Sediment

Reductions in total suspended sediment (TSS) are achieved in all scenarios relative to the 2006 scenario (Table 4.11, fig 4.22, 4.23a & 4.23b). Variation over the 25 years of the simulation followed a relatively normal trend compared to the spatial variation (table 4.12). The high variability in the spatial statistics is indicative of the different sizes of the sub-basins. As shown in table 4.13, all reductions in TSS are significant, except for those occurring between the Water Quality and Biodiversity scenario. The Grassland scenario exhibits the greatest reduction in TSS at 96%. Reductions in suspended sediment from the Grassland scenario is due to an increase in continuous cover; as all land cover, with the exception of forested areas, have been converted to a mix of prairie grasses and generic rangeland. The Grassland scenario is a significantly different ecological setting than is presented in all other scenarios, which assume varying types of human manipulation of the environment. Each of the other scenarios involves the cultivation of these grasslands into some sort of row cropping practice. Cultivation leads to more areas of bare or exposed soils which contribute to yields of TSS by way of surface runoff. The increased sediment loads arise from the removal of relatively continuous grassland cover; loss of cover favors overland flow thereby increasing available energy for erosional processes. Prairie grasses also contain relatively deep root structures compared to corn or soy bean plants. Cultivation can lead to a reduction in soil stability in an agricultural area (i.e. becoming more susceptible to erosional processes). The large reduction in TSS export for the Grassland scenario also results from the removal of tillage practices.

Reductions in TSS loads for the Water Quality and Biodiversity scenarios were over half of the Base scenario amount. These reductions are likely achieved through the multiple conservation practices implemented in each of these scenarios; namely the implementation of no-till conservation practices, and the addition of contour farming in the Water Quality scenario and strip-cropping in the Biodiversity scenario. A small reduction in TSS is also achieved in the Production scenario. In this scenario, conservation practices were added to the modeling routines which likely influenced the reduction, but the increase in land area in corn and soybean production likely dampened the effect of the tillage practice.

With the addition of soil conservation management practices, the range of TSS exports from wet years to dry years is reduced. This can be seen most clearly in comparison of the Grassland and Base scenarios (fig. 4.23b). The Grassland exhibits relatively low inter-annual variance compared to the Base or Production scenarios.

Sediment (tons)		Base	Production	Water Quality	Biodiversity	Grassland
31705.47	Base	-	-28.8	-63.1	-65.3	-96.6
30208.85	Production		-	-48.11	-51.25	-95.2
12922.97	Water Quality			-	-6.04	-90.7
11952.05	Biodiversity				-	-90.1
1842.26	Grassland					-

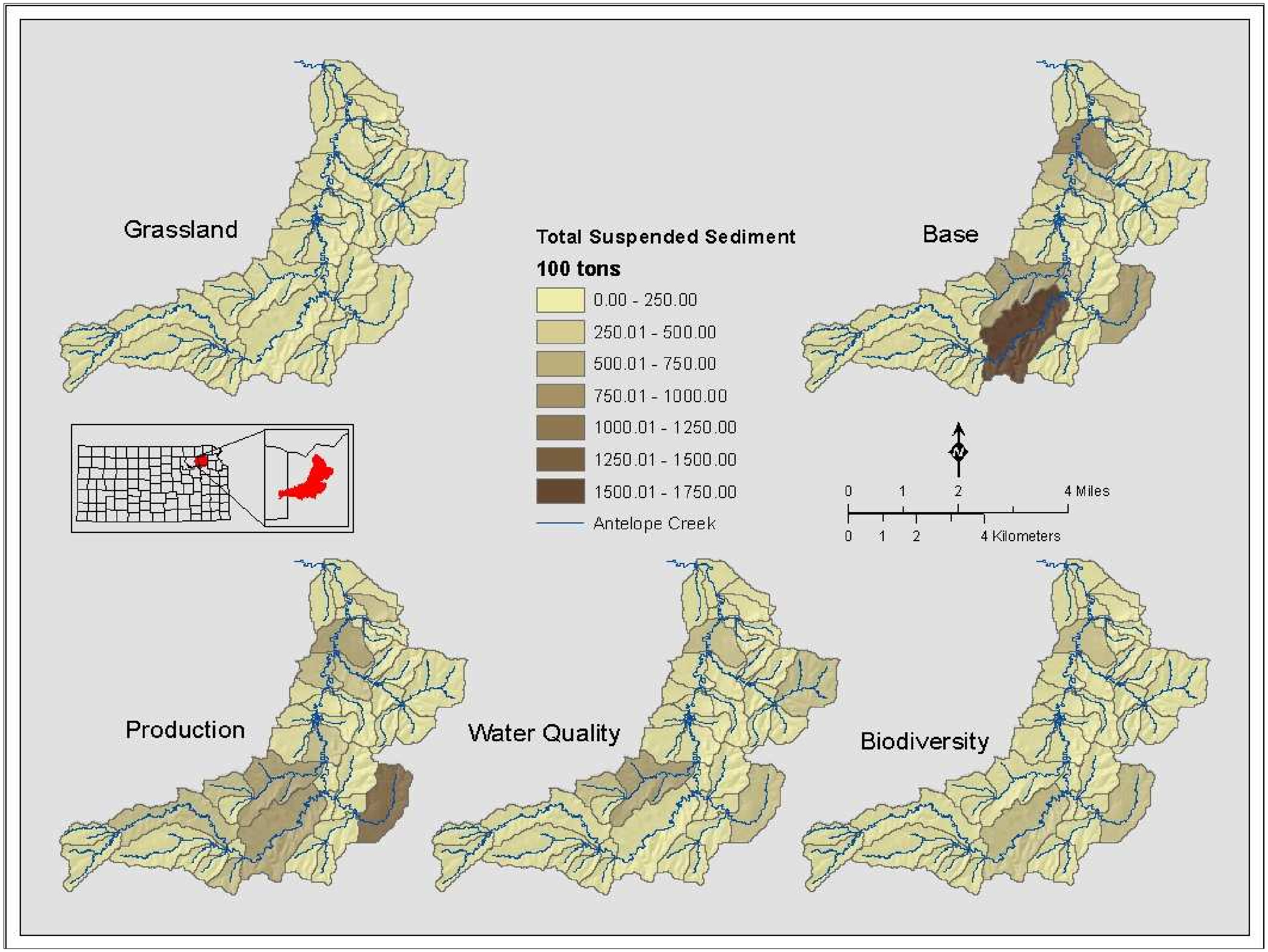
Table 4.11 Results for total suspended sediment, and the percent difference in mean annual load between each scenario and the Base scenario.

Table 4.12 Variation statistics for total suspended sediment results from each of the scenarios. Statistics are presented in terms of temporal variation (over 25 years of simulation), and spatial variation (across the 53 sub-basins in the watershed).

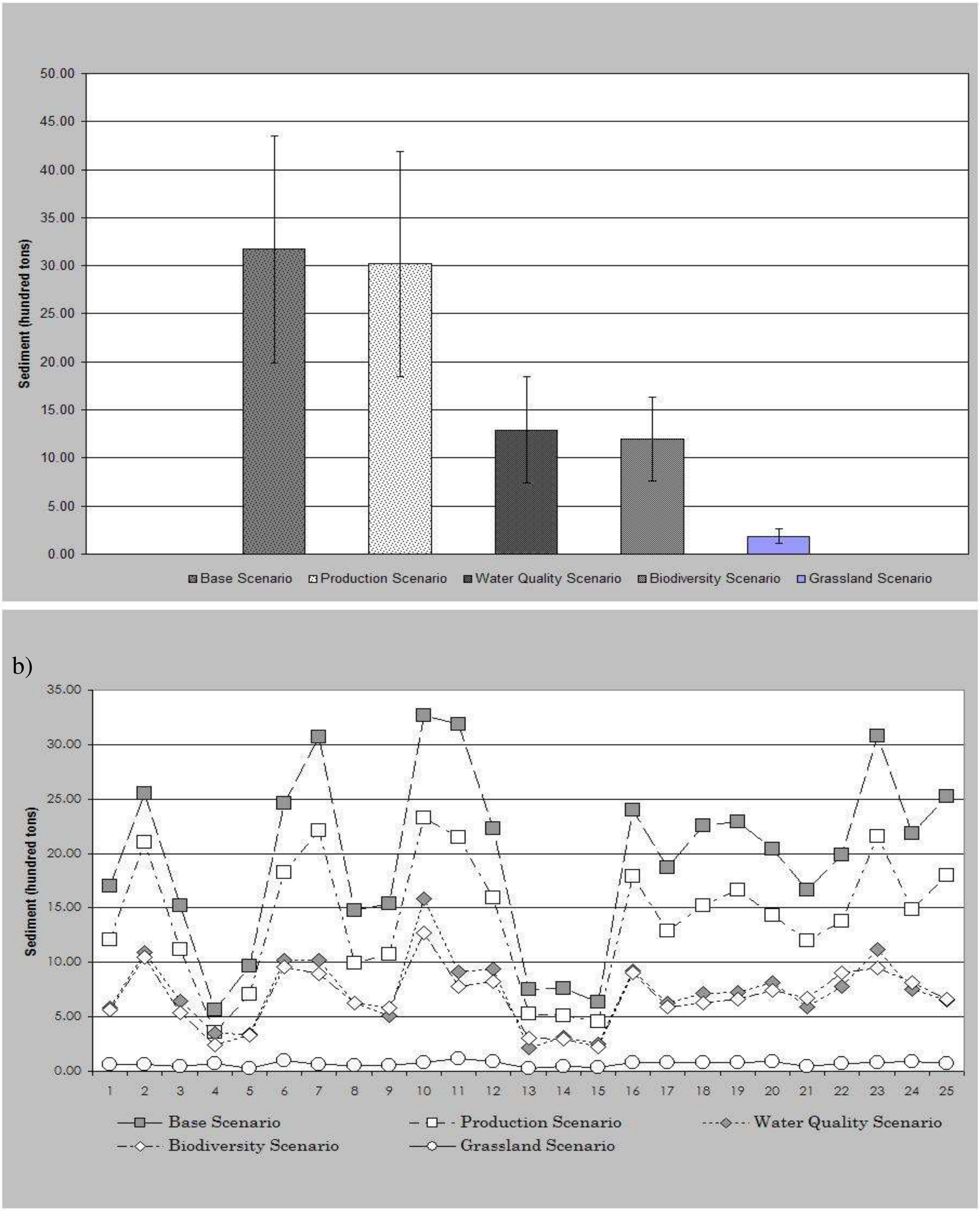
Total Suspended Sediment		25 year Variation Statistics				Sub-basin Variation Statistics			
Scenario	% Change from Base	Mean	Standard Dev.	Max.	Min.	Mean	Standard Dev.	Max.	Min.
Base	-	31705.47	11844.00	50022.16	9351.71	15585.26	27414.72	71374.36	.0235
Grassland	-96.6	1842.26	773.99	3267.61	682.11	1149.03	1474.91	865.65	.0104
Production	-28.8	30208.85	11701.04	52196.23	9244.46	14518.1	21392.37	119800.5	.0223
Water Quality	-63.1	12922.97	5485.97	24909.02	3664.14	7529.18	12740.56	52972.7	.0213
Biodiversity	-65.3	11952.05	4371.09	19985.81	3313.02	6284.13	9688.76	41731.2	.0200

Table 4.13 Matched pairs difference of mean tests for sediment among all scenarios.

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t-statistic	Degrees of freedom	Sig. (2-tail)
					Lower	Upper			
Pair 1	**Grassland/ Base**	-189.2	78.67	15.73	-221.7	-156.7	-12.03	24	0.000
Pair 2	**Grassland/ Production**	-132.8	56.95	11.39	-156.3	-109.3	-11.66	24	0.000
Pair 3	**Grassland/ Water Quality**	-65.67	30.14	6.028	-78.11	-53.22	-10.89	24	0.000
Pair 4	**Grassland/ Biodiversity**	-61.3	25.16	5.032	-71.68	-50.91	-12.18	24	0.000
Pair 5	**Base/ Production**	56.4	23.53	4.706	46.69	66.12	11.98	24	0.000
Pair 6	**Base/ Water Quality**	123.5	53.57	10.71	101.4	145.7	11.53	24	0.000
Pair 7	**Base/ Biodiversity**	127.9	57.86	11.57	104.0	151.8	11.05	24	0.000
Pair 8	**Production/ Water Quality**	67.14	32.21	6.443	53.84	80.44	10.42	24	0.000
Pair 9	**Production/ Biodiversity**	71.51	35.98	7.195	56.66	86.36	9.938	24	0.000
Pair 10	**Water Quality/ Biodiversity**	4.369	9.469	1.894	0.4605	8.278	2.307	24	0.030



4.22 Comparison maps for Total Suspended Sediment from the five scenario runs. (Source: Author)



4.23 Comparison of Total Suspended Sediment loads (a) and annual variation of Total Suspended Sediment among the five scenarios. (Source: Author)

Discharge

Results for discharge in the five scenarios are presented in tables 4.14 – table 4.16 (fig. 4.24, 4.25a & 4.25b). The Water Quality scenario led to the lowest flows relative to the other scenarios. The Grassland scenario also produced comparatively low flows, with a discharge rate only slightly higher (.85%) higher than the Water Quality scenario. The Base and Production scenarios generated the highest flows. Similar to the other results, the difference between the two highest flow scenarios is less than 1% (.87%), with the Base scenario loading slightly higher than the Production scenario. Temporal variation was again more normal than the spatial distribution (table 4.15). Statistically speaking all the reductions in discharge were significant except two (table 4.16). The differences in the Water Quality and Grassland, as well as the Base and Production scenario are not considered significantly different from one another.

Spatially, discharge results were similar among all five scenarios (fig. 4.24). Higher loading sub-basins tended to be located in areas where the ground was being cultivated on steeper slopes or those sub-basins with relatively poor soils. Due to the lack of cultivated land in the Grassland scenario, slope and soil condition may be playing a greater role than land use / land cover or management practices in these modeling results.

Discharge (mm/sec)		Base	Production	Biodiversity	Grassland	Water Quality
.0301	Base	-	-0.87	-16.6	-22.8	-23.4
.0299	Production		-	-15.8	-22.1	-22.8
.0228	Biodiversity			-	-7.46	-8.25
.0219	Grassland				-	0.85
.0222	Water Quality					-

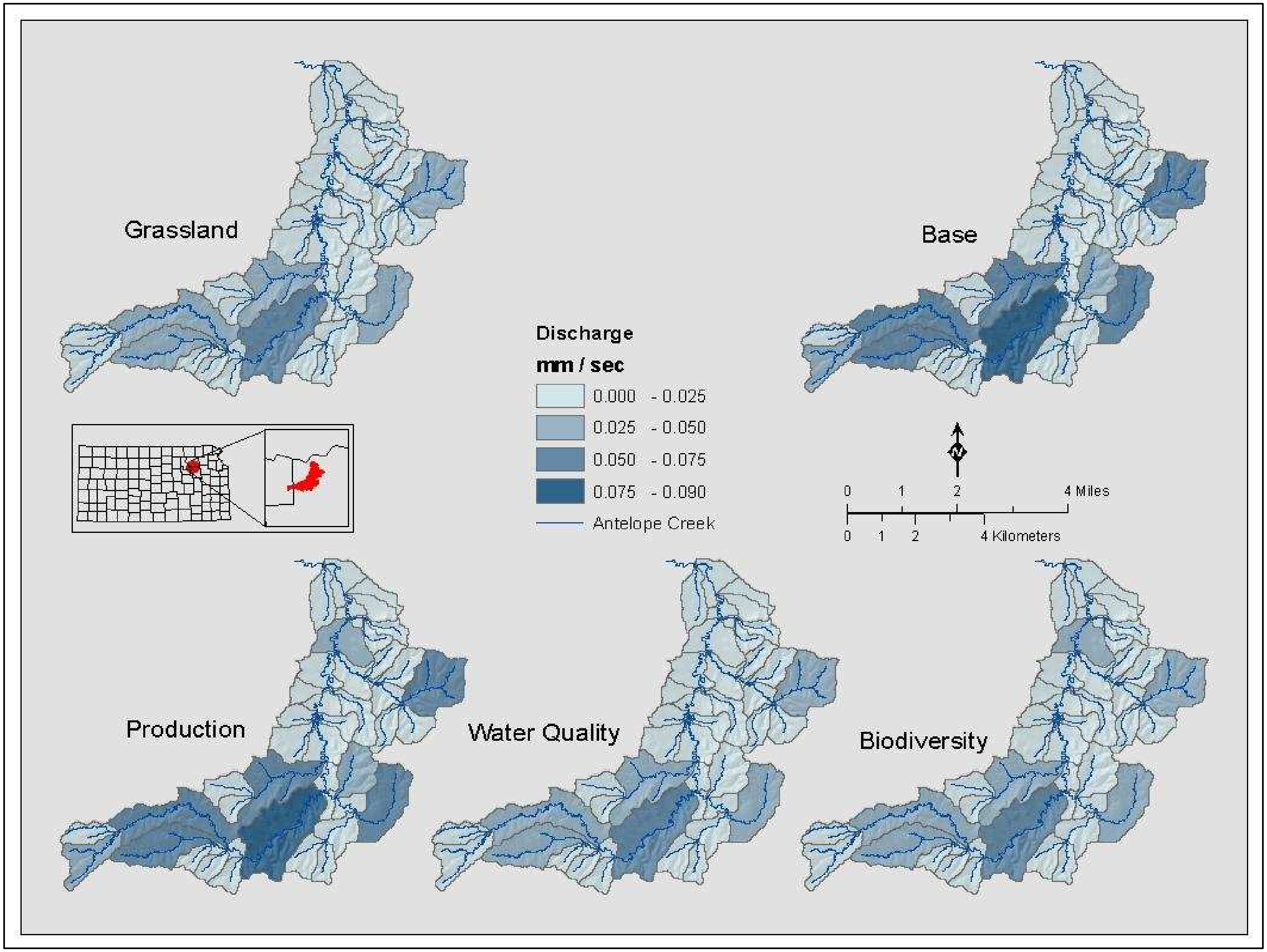
Table 4.14 Results surface discharge, and the percent difference in mean annual load between each scenario and the Base scenario.

Table 4.15 Variation statistics for surface discharge results from each scenario. Stats are presented for temporal variation (over 25 years simulated), and spatial variation (across the 53 sub-basins within the watershed).

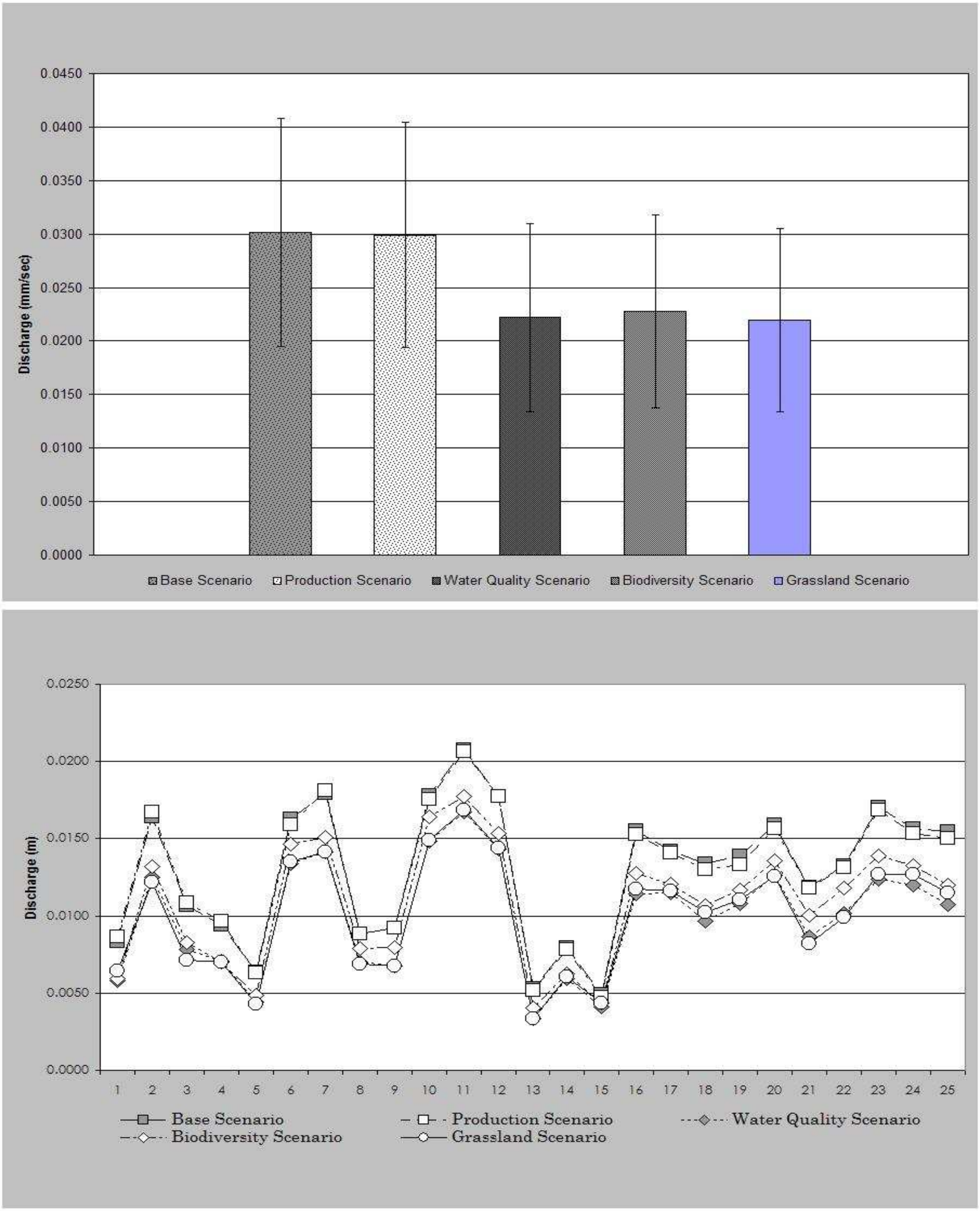
	Discharge	25 year Variation Statistics				Sub-basin Variation Statistics			
Scenario	% Change from Base	Mean	Standard Dev.	Max.	Min.	Mean	Standard Dev.	Max.	Min.
Base	-	.0301	.0106	.0529	.0108	.0173	.0179	.0783	.0001
Production	-0.87	.0299	.0105	.0526	.0108	.0173	.0183	.0822	.0001
Biodiversity	-16.6	.0228	.0090	.0418	.0077	.0124	.0119	.0535	.0001
Grassland	-22.8	.0219	.0086	.0399	.0081	.0121	.0121	.0561	.0001
Water Quality	-23.4	.0222	.0088	.0411	.0078	.0123	.0125	.0546	.0001

Table 4.16 Matched pairs difference of mean tests for discharge among all scenarios.

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t-statistic	Degrees of freedom	Sig. (2-tail)
					Lower	Upper			
Pair 1	**Grassland/ Base**	-0.0029	0.0009042	0.0001808	-0.0033252	-0.0025788	-16.32	24	0.000
Pair 2	**Grassland/ Production**	-0.00284	0.0009055	0.0001811	-0.0032138	-0.0024662	-15.68	24	0.000
Pair 3	**Grassland/ Water Quality**	0.000076	0.0003282	0.0000656	-0.0000595	0.0002115	1.158	24	0.258
Pair 4	**Grassland/ Biodiversity**	-0.000812	0.0005457	0.0001091	-0.0010372	-0.0005868	-7.44	24	0.000
Pair 5	**Base/ Production**	0.000112	0.0002315	0.0000463	0.0000164	0.0002076	2.419	24	0.024
Pair 6	**Base/ Water Quality**	0.003028	0.0009388	0.0001878	0.0026405	0.0034155	16.13	24	0.000
Pair 7	**Base/ Biodiversity**	0.00214	0.0007643	0.0001529	0.0018245	0.0024555	14.00	24	0.000
Pair 8	**Production/ Water Quality**	0.002916	0.0008975	0.0001795	0.0025455	0.0032865	16.25	24	0.000
Pair 9	**Production/ Biodiversity**	0.002028	0.0007871	0.0001574	0.0017031	0.0023529	12.88	24	0.000
Pair 10	**Water Quality/ Biodiversity**	-0.000888	0.0004622	0.0000924	-0.0010788	-0.0006972	-9.607	24	0.000



4.24 Comparison map of Discharge for the five scenario runs. (Source: Author)



4.25 Comparison of Discharge rates (a) and annual variation in Discharge rates among the five scenario runs (b). (Source: Author)

Nitrogen

Table 4.17 provides model results for organic nitrogen. The Base scenario resulted in the highest organic nitrogen loads among the five scenarios. The Production scenario also had relatively higher Organic nitrogen than any of the remaining three scenarios. The Grassland scenario produced the lowest loads among all scenarios and exhibited the lowest inter-annual variability. Temporal and spatial variations are similar to previous pollutant loads, with the spatial being highly variable as a result of sub-basins size (table 4.18, fig 4.26 & 4.27)

Results for nitrogen contained in surface discharge are given in Table 4.21 (fig 4.28 & 4.29). The Production scenario generated the highest loads, with the Base scenario nearly matching its output. The remaining three scenarios ranged from 34% - 37% less than the Base scenario, with the Grassland scenario loading the lowest among the remaining three scenarios, the Water Quality scenario the next highest load and the Biodiversity scenario having the lowest load for nitrogen in surface discharge. Temporal variation showed less variation that spatial variation, again this is indicative of the size differences in sub-basins (table 4.22). The main transport mechanism for organic nitrogen is sediment, and all loads are significantly different, including the differences between The Water Quality and Biodiversity scenarios. For nitrogen being transported by surface discharge, the statistical analysis was the same as discharge, all were statistically significant reductions except for the Grassland and Water Quality, and the Base and Production scenarios (table 4.20).

Organic N (kg)		Base	Grassland	Production	Water Quality	Biodiversity
58338.84	Base	-	-76.33	-12.59	-64.63	-61.97
8203.11	Grassland		-	-700.69	-151.56	-170.45
65681.53	Production			-	-68.58	-66.22
20635.79	Water Quality				-	-7.51
22184.91	Biodiversity					-

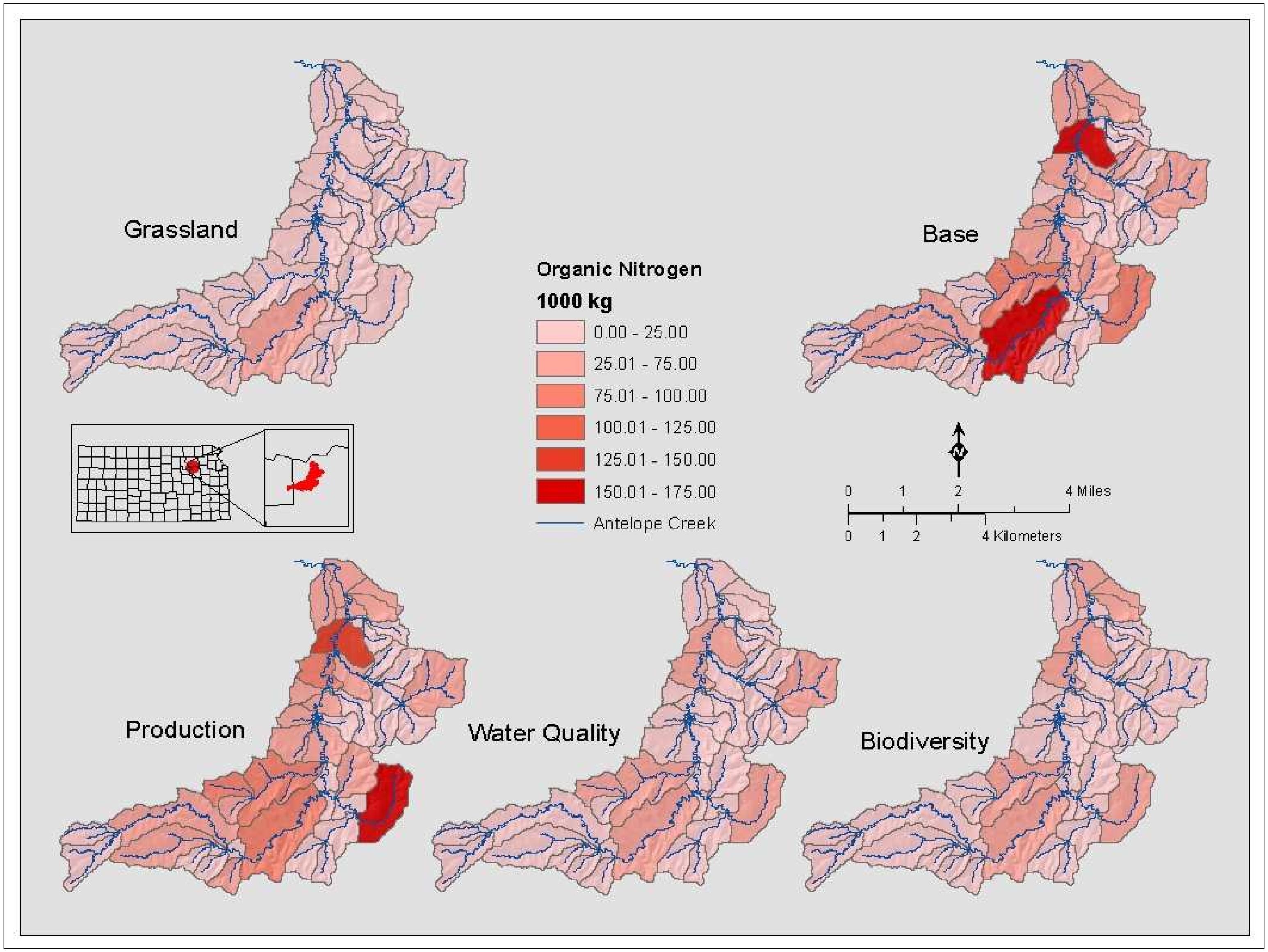
Table 4.17 Results for organic nitrogen, and the percent difference in mean annual load between each scenario and the Base scenario.

Organic nitrogen		25 year Variation Statistics				Sub-basin Variation Statistics			
Annual load- % Change from Base		Mean	Standard Dev.	Max.	Min.	Mean	Standard Dev.	Max.	Min.
Base	-	58338.84	19565.11	89463.70	24541.87	27767.27	36060.03	72108.68	.0282
Production	-12.59	65681.53	3452.53	14461.83	3074.27	5119.91	6559.85	4961.92	.0305
Biodiversity	-61.97	20635.79	22692.55	104724.41	26836.53	30964.94	35783.42	62938.90	.0256
Water Quality	-64.63	22184.91	7686.04	35621.82	6933.63	11266.27	12637.23	8241.41	.0221
Grassland	-76.33	8203.11	7483.14	35213.95	8032.01	11863.38	14492.60	3223.78	.0198

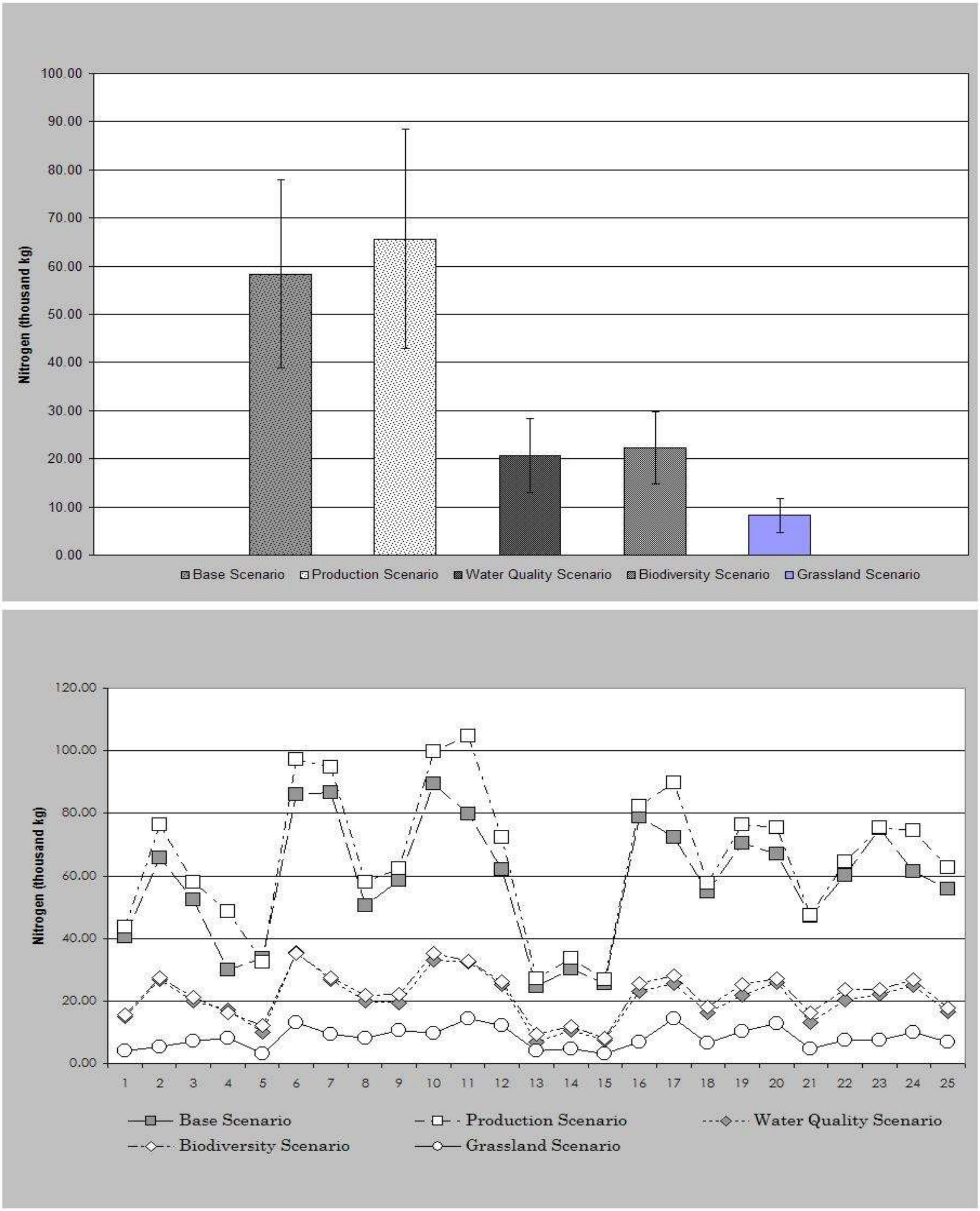
Table 4.18 Variation statistics for organic nitrogen results from each of the scenarios. Statistics are presented in terms of temporal variation (over the 25 years simulated, and in terms of spatial variation (across the 53 sub-basins in the watershed).

Table 4.19 Matched pairs difference of mean tests for organic nitrogen among all scenarios.

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t-statistic	Degrees of freedom	Sig. (2-tail)
					Lower	Upper			
Pair 1	**Grassland/ Base**	-36.96	15.22	3.044	-43.24	-30.67	-12.14	24	0.000
Pair 2	**Grassland/ Production**	-34.81	15.12	3.024	-41.05	-28.57	-11.51	24	0.000
Pair 3	**Grassland/ Water Quality**	-9.014	4.501	0.9002	-10.87	-7.156	-10.01	24	0.000
Pair 4	**Grassland/ Biodiversity**	-10.4156	4.585	0.917	-12.31	-8.523	-11.36	24	0.000
Pair 5	**Base/ Production**	2.1504	1.674	0.3348	1.459	2.841	6.423	24	0.000
Pair 6	**Base/ Water Quality**	27.9464	11.46	2.292	23.22	32.68	12.19	24	0.000
Pair 7	**Base/ Biodiversity**	26.5448	11.26	2.252	21.9	31.19	11.79	24	0.000
Pair 8	**Production/ Water Quality**	25.796	11.16	2.233	21.19	30.4	11.55	24	0.000
Pair 9	**Production/ Biodiversity**	24.3944	11.00	2.2	19.85	28.94	11.09	24	0.000
Pair 10	**Water Quality/ Biodiversity**	-1.4016	0.7793	0.1558	-1.723	-1.08	-8.993	24	0.000



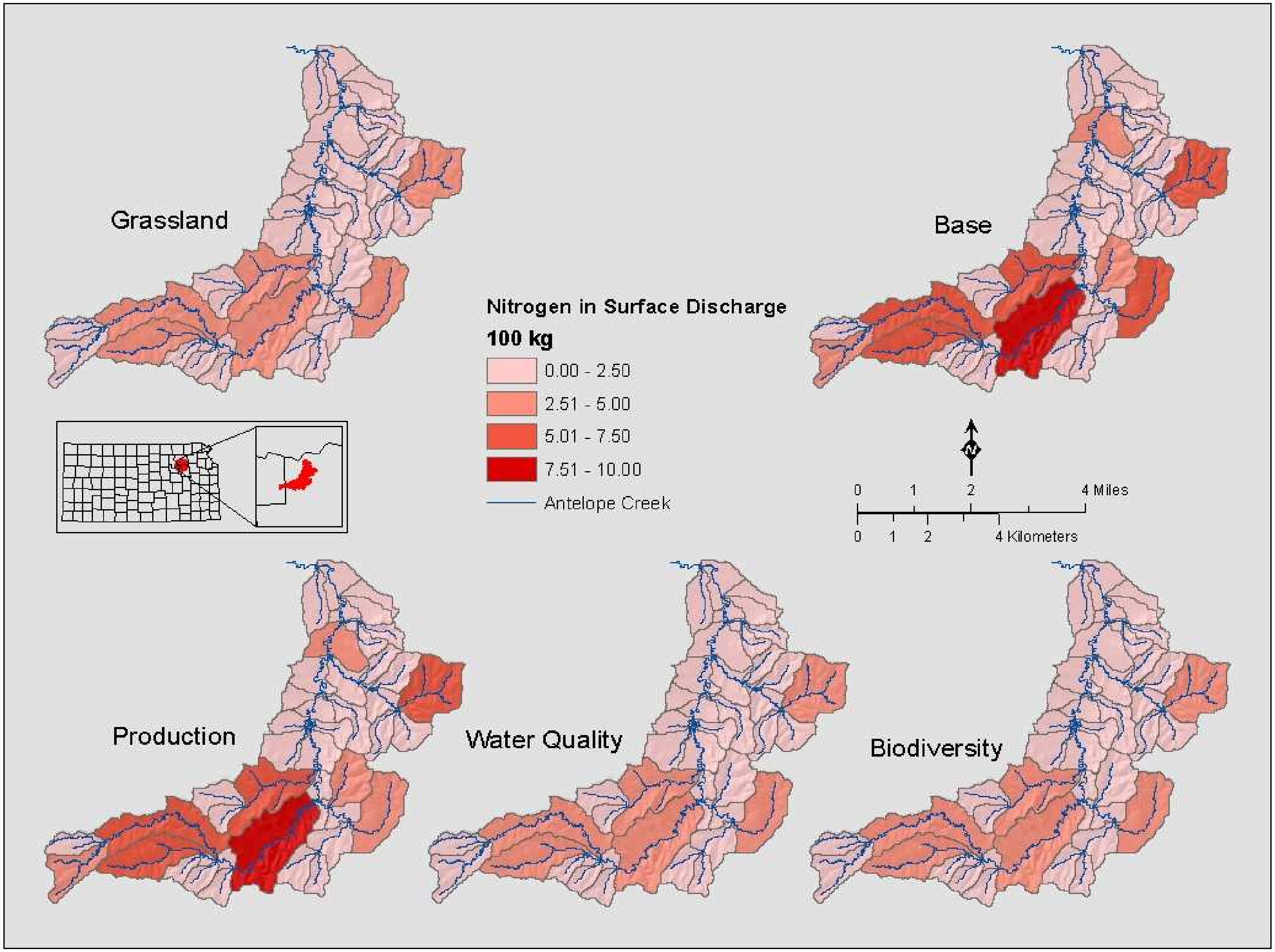
4.26 Comparison map of Organic nitrogen results among the five scenarios. (Source: Author)



4.27 Comparison of Organic nitrogen loads (a) among the five scenario runs, and annual variation (b) (Source: Author).

Table 4.20 Matched pairs difference of mean tests for nitrogen in surface discharge among all scenarios.

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t-statistic	Degrees of freedom	Sig. (2-tail)
					Lower	Upper			
Pair 1	Grassland/ Base	-0.4352	0.1694	0.03387	-0.5051	-0.3653	-12.85	24	0.000
Pair 2	Grassland/ Production	-0.458	0.1725	0.03449	-0.5292	-0.3868	-13.28	24	0.000
Pair 3	Grassland/ Water Quality	0.0152	0.06752	0.0135	-0.01267	0.04307	1.126	24	0.271
Pair 4	Grassland/ Biodiversity	-0.0852	0.08089	0.01618	-0.1186	-0.05181	-5.267	24	0.000
Pair 5	Base/ Production	-0.0228	0.06674	0.01335	-0.05035	0.00475	-1.708	24	0.101
Pair 6	Base/ Water Quality	0.4504	0.1703	0.03406	0.3801	0.5207	13.23	24	0.000
Pair 7	Base/ Biodiversity	0.35	0.1335	0.02669	0.2949	0.4051	13.11	24	0.000
Pair 8	Production/ Water Quality	0.4732	0.168	0.0336	0.4038	0.5426	14.08	24	0.000
Pair 9	Production/ Biodiversity	0.3728	0.1392	0.02784	0.3154	0.4303	13.39	24	0.000
Pair 10	Water Quality/ Biodiversity	-0.1004	0.05549	0.0111	-0.1233	-0.0775	-9.047	24	0.000



4.28 Comparison map of Organic nitrogen results among the five scenarios. (Source: Author)

4.29 Comparison of nitrogen in surface discharge loads (a) among the five scenario runs, and annual variation (b) (Source: Author).

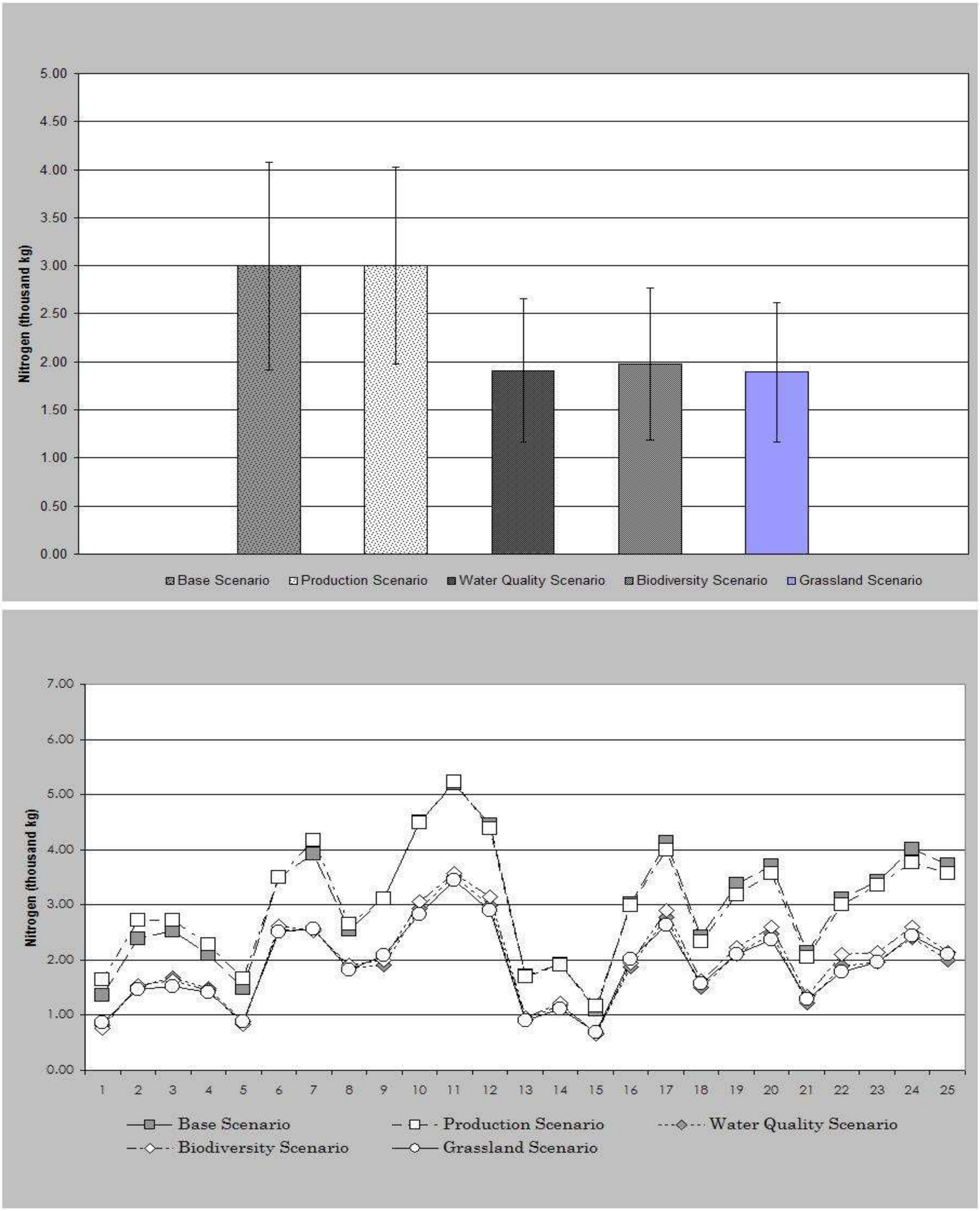


Table 4.21 Results for nitrogen in surface discharge, and the percent difference in mean annual load between each scenario and the Base scenario.

Nitrogen in Discharge (kg)	Nitrogen in Discharge	Base	Grassland	Production	Water Quality	Biodiversity
2997.28	Base	-	-36.85	0.28	-36.36	-34.00
1892.77	Grassland		-	-58.80	-0.78	-4.52
3005.79	Production			-	-36.54	-34.18
1907.47	Water Quality				-	3.71
1978.29	Biodiversity					-

Table 4.22 Variation statistics for nitrogen in surface runoff from each of the scenarios. Statistics are presented in terms of temporal variation (over the 25 years simulated), and spatial variation (across the 53 sub-basins in the watershed).

Nitrogen in Surface Discharge		25 year Variation Statistics				Sub-basin Variation Statistics			
Scenario	%Change	Mean	Std Dev.	Max.	Min.	Mean	Standard Dev.	Max.	Min.
Base	-	2997.28	1082.35	5203.29	1091.30	1716.57	1769.36	7519.51	.1345
Grassland	-36.85	1892.77	721.37	3443.11	697.34	1033.23	1021.82	4652.16	.1231
Production	.28	3005.79	1025.37	5239.07	1167.98	1748.24	1838.14	8024.58	.1378
Water Quality	-36.36	1907.47	744.92	3523.38	663.17	1050.16	1066.73	4491.98	.1289
Biodiversity	-34.0	1978.29	786.65	3568.24	658.25	1062.13	1014.45	4405.03	.1301

Phosphorus

Organic phosphorus loads for the Production and Base scenarios were the closest in the amount of phosphorus being delivered to the outlet of the watershed (table 4.23, fig, 4.30 & 4.31), but the contributing sub-basins were slightly different (figure 4.30). A spike in Organic phosphorus is evident in the second year of figure 4.31b for the Base and Production. This is believed to be an artifact of initializing model parameters, but it is unclear why the three remaining scenarios do not exhibit the same anomaly. The Grassland scenario led to the lowest organic phosphorus loading, and was significantly lower than the Water Quality or Biodiversity scenarios as well -171% and -143% respectively (tables 4.23 & 4.25). Temporal and spatial variation for organic phosphorus results are given in table 4.24.

For soluble phosphorus results, the Base scenario carries the highest load, while the Grassland scenario is approximately 12% lower, and the second highest loading among all scenarios (fig 4.32 & 4.33). The Production scenario, Water Quality, and Biodiversity scenarios follow in that order, with the Production loading at nearly 13% less, the Water Quality scenario at 25% and the Biodiversity at 54% (table 4.27). Differences between all but the Base and Production scenarios, as well as the Production and Water Quality scenarios were significant (table 4.26). Temporal and spatial variations are given in table 4.28.

Sediment attached phosphorus results are given in table 4.30. The grassland scenario generates nearly 65% less sediment attached phosphorous as the base scenario, and is the lowest loading scenario (fig 4.34 & 4.35). The Production scenario loaded the highest of all scenarios, and loaded 6% higher than the Base scenario. The Biodiversity and Water Quality scenarios produced the lowest loads of sediment attached phosphorus at 26% and 30% respectively. Matched pair t-test results are given in table 4.29. All differences in sediment attached phosphorus among scenarios are significant except for the difference between the Base and Production scenario. Temporal and spatial variations are given in table 4.31.

Table 4.23 Results for organic phosphorus and the percent difference in mean annual load between each scenario and the Base scenario.

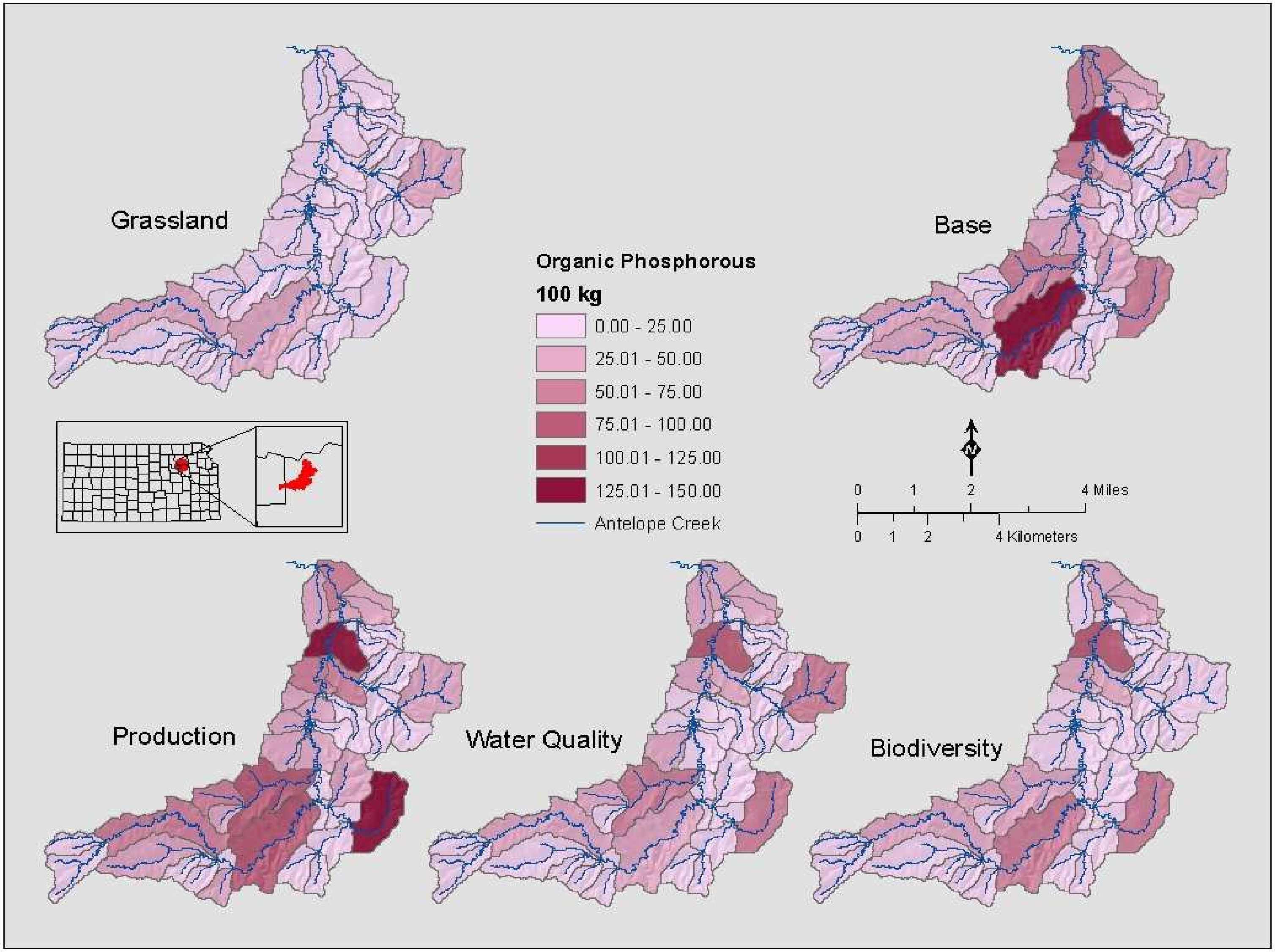
Organic P (kg)	Organic P	Base	Grassland	Production	Water Quality	Biodiversity
5116.17	Base	-	-78.09	14.60	-40.49	-46.71
1120.91	Grassland		-	-423.06	-171.61	-143.24
5863.04	Production			-	48.07	53.50
3044.54	Water Quality				-	10.45
2726.51	Biodiversity					-

Organic phosphorus		25 year Variation Statistics				Sub-basin Variation Statistics			
% Change from Base		Mean	Standard Dev.	Max.	Min.	Mean	Standard Dev.	Max.	Min.
Base	-	5116.17	159.34	656.83	24.47	2528.89	2980.50	14431.60	0.00
Production	-14.60	5863.04	95.85	441.26	76.36	2847.51	3048.16	12970.88	0.00
Water Quality	-40.49	3044.54	87.21	378.84	51.35	1653.63	1888.99	8800.36	0.00
Biodiversity	--46.71	2726.51	73.86	260.09	7.18	1412.08	1667.27	8780.01	0.00
Grassland	-78.09	1120.91	98.52	401.04	65.76	700.61	897.46	4779.05	0.00

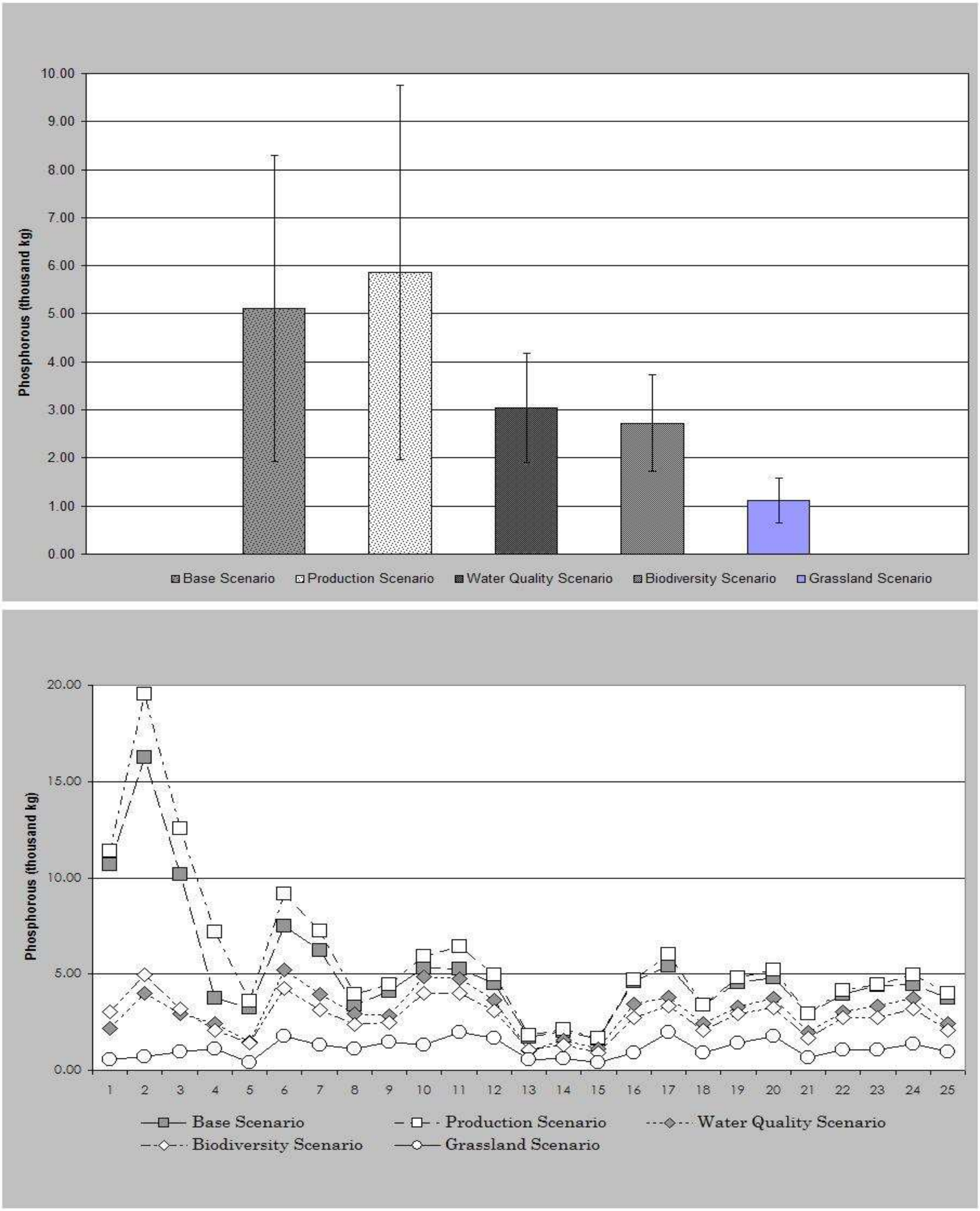
Table 4.24 Variation statistics for organic phosphorus from each of the scenarios. Statistics are presented in terms of temporal variation (over the 25 years simulated), and spatial variation (across the 53 sub-basins in the watershed).

Table 4.25 Matched pairs difference of mean tests for organic phosphorus among all scenarios.

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t-statistic	Degrees of freedom	Sig. (2-tail)
					Lower	Upper			
Pair 1	**Grassland/ Base**	-2.842	2.663	0.5326	-3.942	-1.743	-5.337	24	0.000
Pair 2	**Grassland/ Production**	-2.844	2.898	0.5796	-4.041	-1.648	-4.908	24	0.000
Pair 3	**Grassland/ Water Quality**	-1.381	0.6859	0.1372	-1.664	-1.098	-10.07	24	0.000
Pair 4	**Grassland/ Biodiversity**	-1.178	0.7233	0.1447	-1.477	-0.8798	-8.146	24	0.000
Pair 5	**Base/ Production**	-0.0020	0.3519	0.0704	-0.1472	0.1433	-0.028	24	0.978
Pair 6	**Base/ Water Quality**	1.461	2.303	0.4607	0.5104	2.412	3.172	24	0.004
Pair 7	**Base/ Biodiversity**	1.664	2.037	0.4073	0.8233	2.505	4.085	24	0.000
Pair 8	**Production/ Water Quality**	1.463	2.523	0.5045	0.4219	2.505	2.900	24	0.008
Pair 9	**Production/ Water Quality**	1.666	2.264	0.4528	0.7314	2.6005	3.678	24	0.001
Pair 10	**Water Quality/ Biodiversity**	0.2028	0.3406	0.0681	0.0622	0.3431	2.977	24	0.007



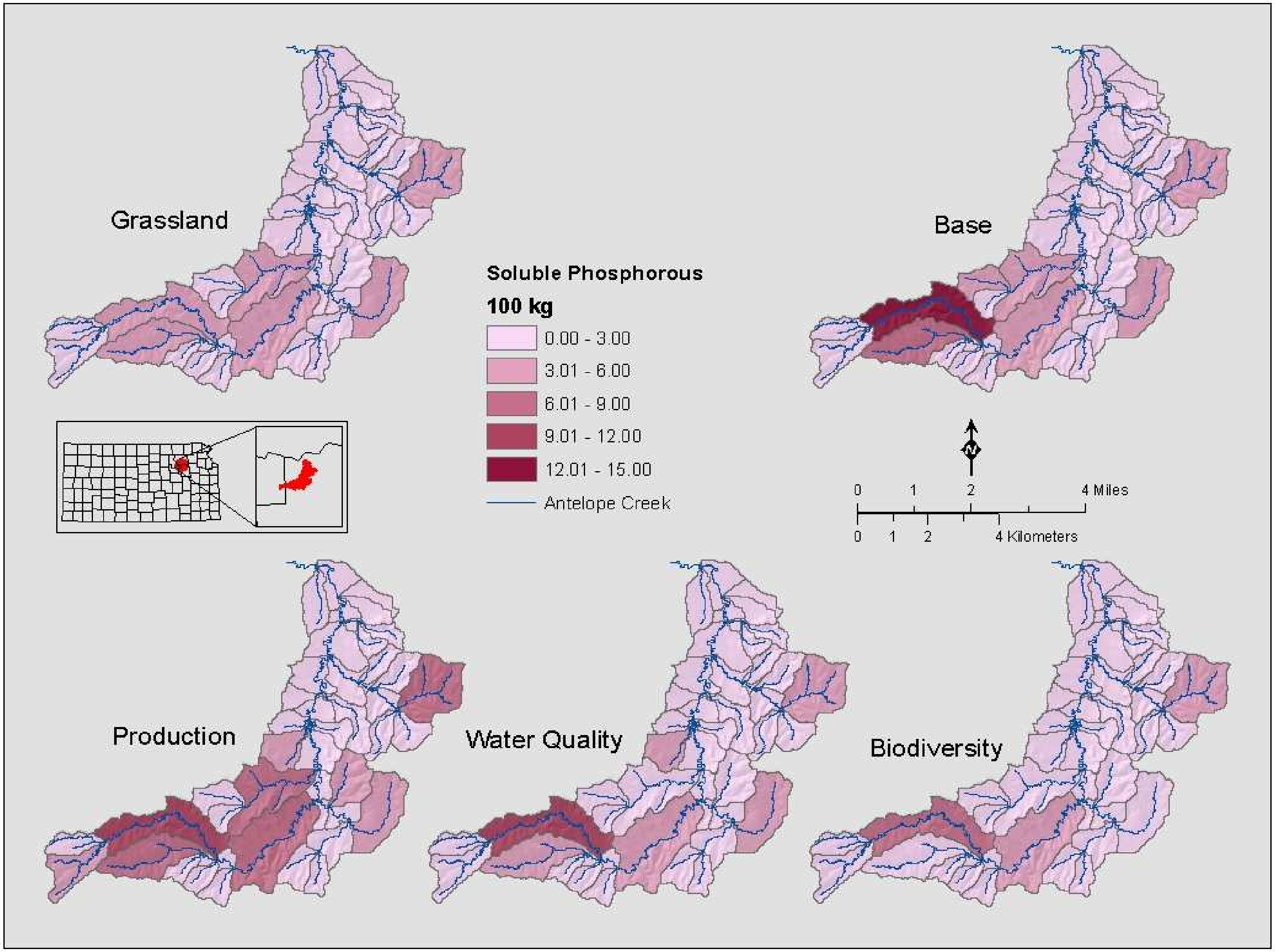
4.30 Comparison map of Organic phosphorus results from five scenario runs. (Source: Author)



4.31 Comparison of Organic phosphorus loads (a) and annual variation of Organic phosphorus among scenario runs (b). (Source: Author)

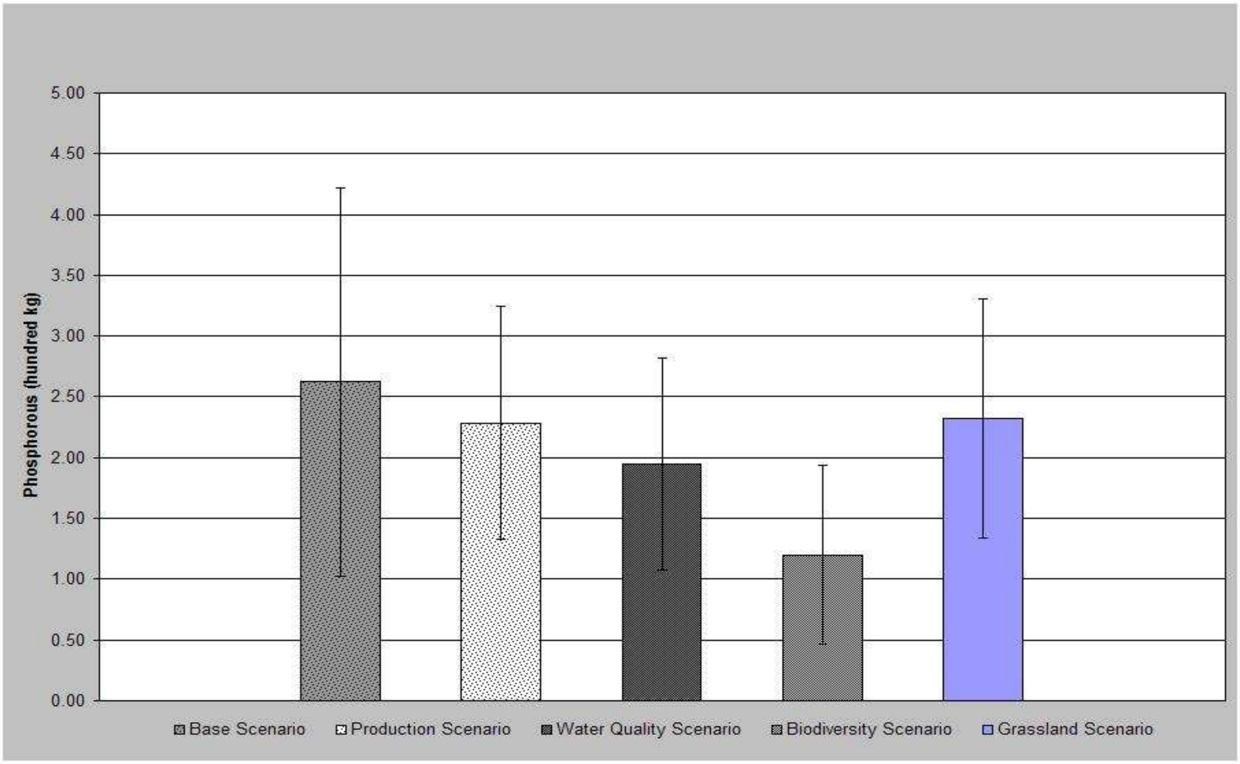
Table 4.26 Matched pairs difference of mean tests for soluble phosphorus among all scenarios.

		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t-statistic	Degrees of freedom	Sig. (2-tail)
					Lower	Upper			
Pair 1	**Grassland/Base**	0.5104	0.2756	0.0551	0.3966	0.6242	9.26	24	0.000
Pair 2	**Grassland/ Production**	0.4252	0.3309	0.0662	0.2889	0.5618	6.425	24	0.000
Pair 3	**Grassland/ Water Quality**	0.4224	0.2483	0.0497	0.3199	0.5249	8.507	24	0.000
Pair 4	**Grassland/ Biodiversity**	0.66	0.2563	0.0513	0.5542	0.7658	12.88	24	0.000
Pair 5	**Base/ Production**	-0.0852	0.1775	0.0355	-0.1585	-0.0119	-2.4	24	0.025
Pair 6	**Base/ Water Quality**	-0.088	0.1381	0.0276	-0.145	-0.03098	-3.185	24	0.004
Pair 7	**Base/ Biodiversity**	0.1496	0.1282	0.0257	0.0967	0.2025	5.833	24	0.000
Pair 8	**Production/ Water Quality**	-0.0028	0.1316	0.0263	-0.0571	0.0515	-0.106	24	0.916
Pair 9	**Production/ Biodiversity**	0.2348	0.1544	0.0309	0.1711	0.2985	7.604	24	0.000
Pair 10	**Water Quality/ Biodiversity**	0.2376	0.1134	0.0227	0.1908	0.2844	10.47	24	0.000



4.32 Comparison map of soluble phosphorus results from five scenario runs. (Source: Author)

4.33 Comparison of soluble phosphorus loads (a) and annual variation of soluble phosphorus among scenario runs (b). (Source: Author)



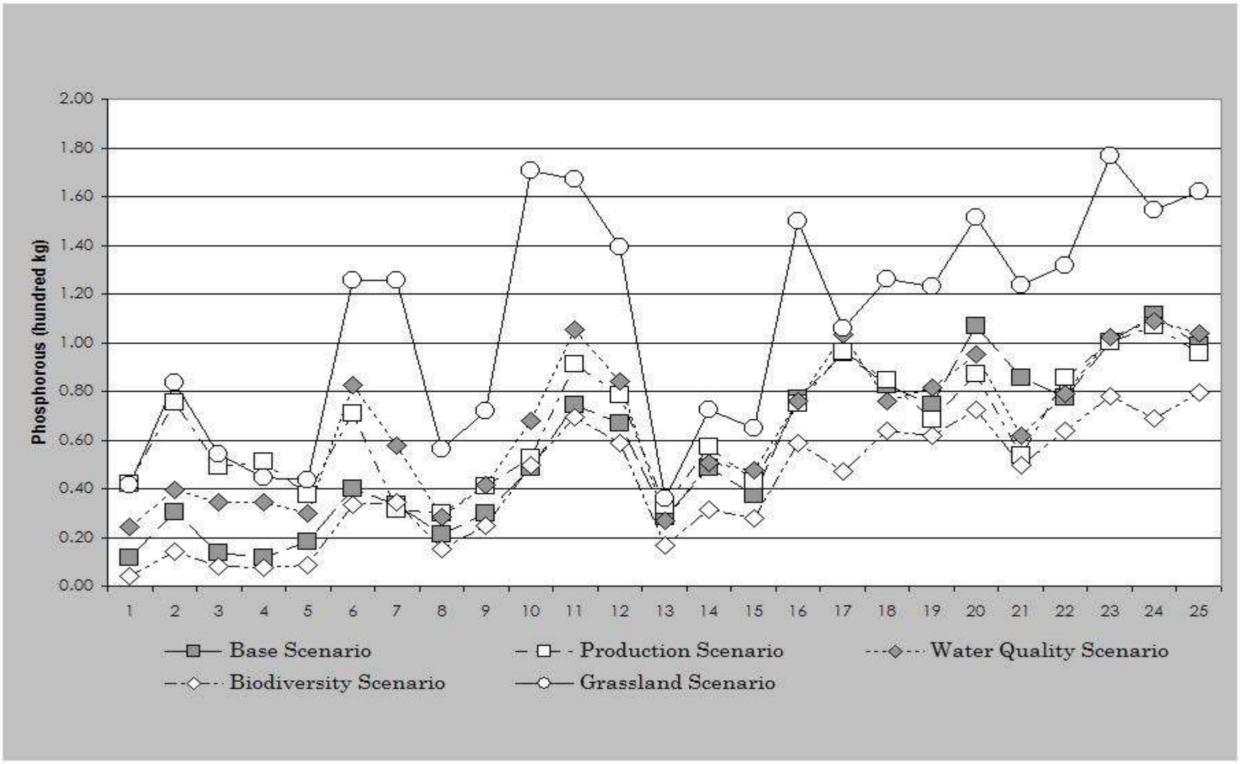


Table 4.27 Results for soluble phosphorus and the percent difference in mean annual load between each scenario and the Base scenario.

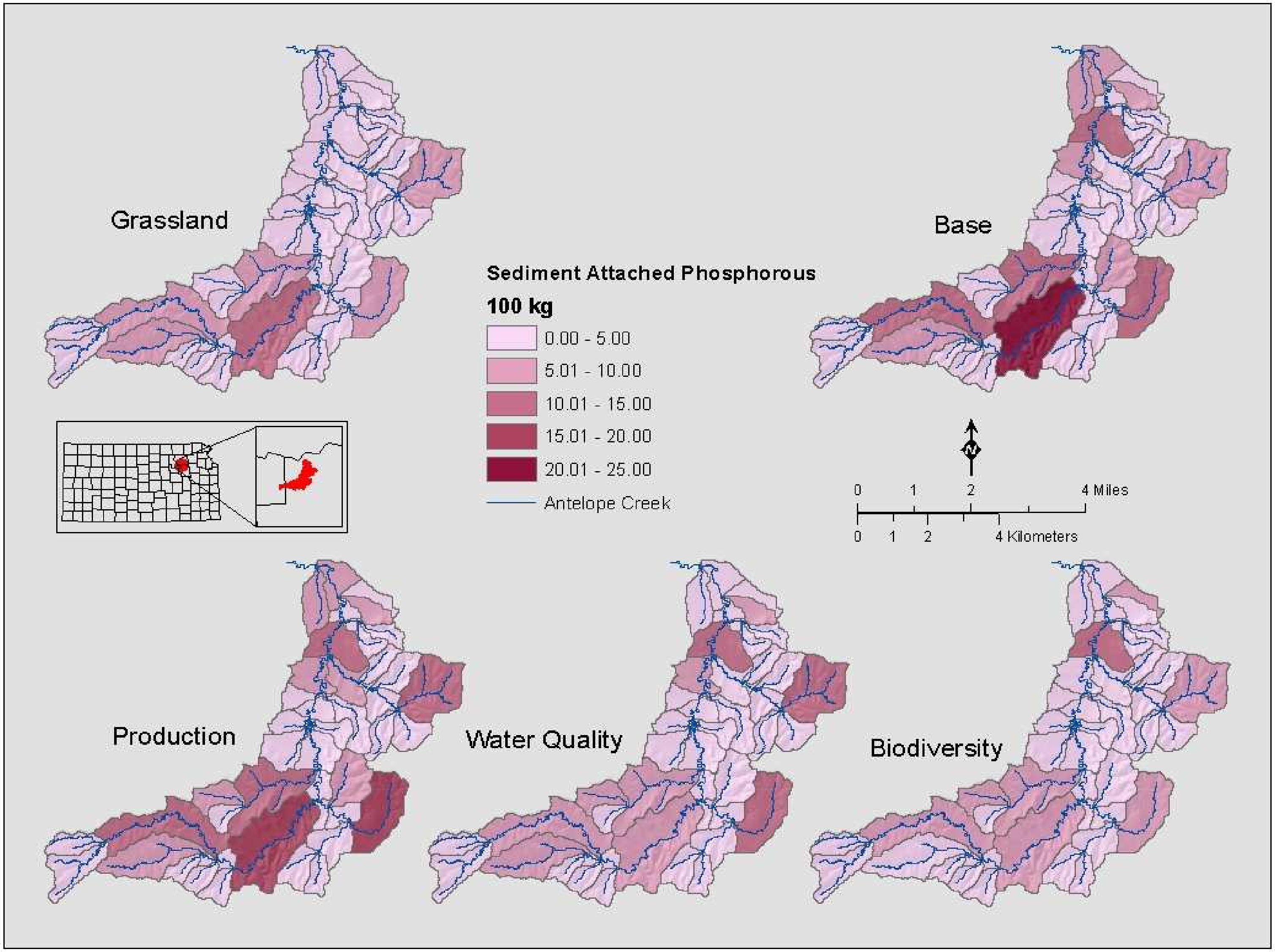
Soluble P (kg)	Soluble P	Base	Grassland	Production	Water Quality	Biodiversity
262.20	Base	-	-11.36	-12.93	-25.70	-54.21
232.41	Grassland	▨	-	-1.77	-16.17	-48.33
228.29	Production	▨	▨	-	-14.66	-47.40
194.82	Water Quality	▨	▨	▨	-	-38.37
120.07	Biodiversity	▨	▨	▨	▨	-

Table 4.28 Variation statistics for soluble phosphorus from each of the scenarios. Statistics are presented in terms of temporal variation (over the 25 years simulated), and spatial variation (across the 53 sub-basins in the watershed).

Soluble phosphorus		25 year Variation Statistics				Sub-basin Variation Statistics			
Scenario	% Change from Base	Mean	Standard Dev.	Max.	Min.	Mean	Standard Dev.	Max.	Min.
Base	-	262.20	159.34	656.83	24.47	145	219.89	1303.9	0.00
Production	-12.93	228.29	95.85	441.26	76.36	156	225.39	906.68	0.00
Water Quality	-25.70	194.82	87.21	378.84	51.35	114.89	162.4	911.75	0.00
Biodiversity	-54.21	120.07	73.86	260.09	7.18	76.4	108	611.5	0.00
Grassland	-11.36	232.41	98.52	401.04	65.76	133.4	136.2	566.2	0.00

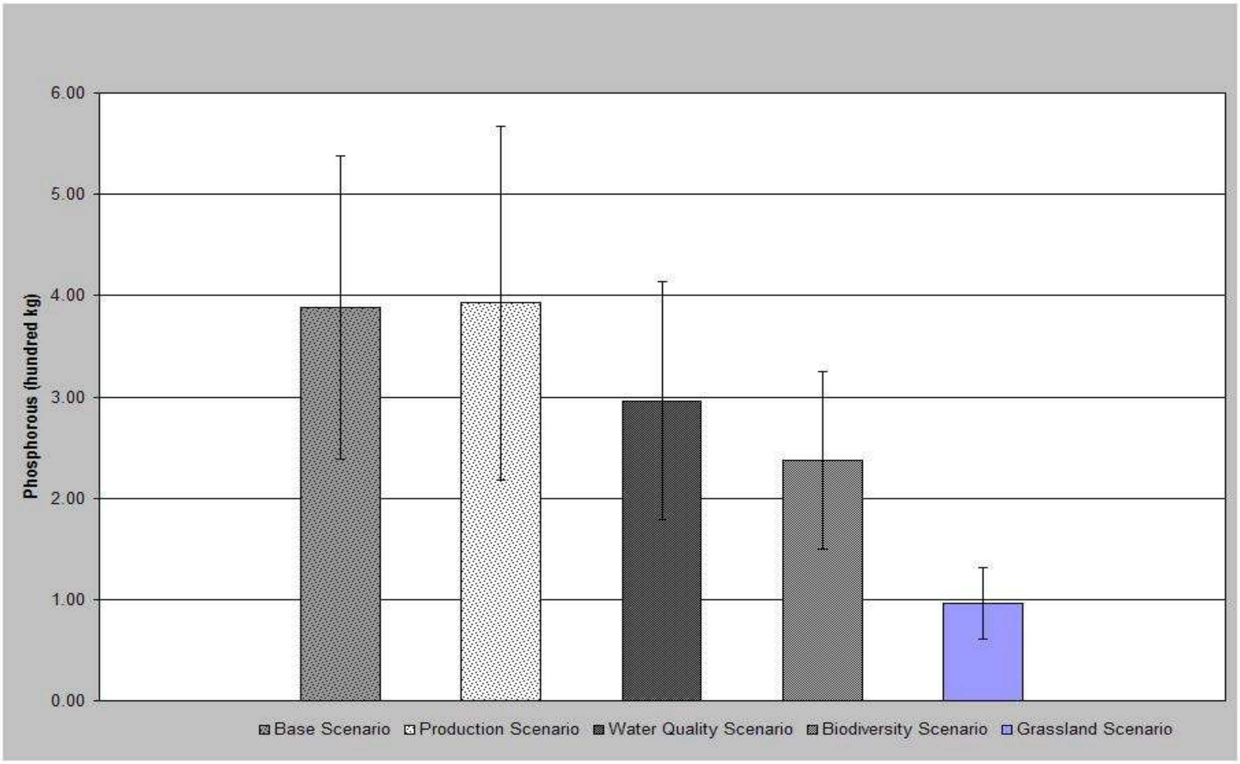
Table 4.29 Matched pairs difference of mean tests for sediment attached phosphorus among all scenarios.

					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t-statistic	Degrees of freedom	Sig. (2-tail)
Pair 1	Grassland/Base	-2.923	1.378	0.2756	-3.492	-2.354	-10.6	24	0.000
Pair 2	Grassland/Production	-2.962	1.665	0.333	-3.649	-2.275	-8.894	24	0.000
Pair 3	Grassland/Water Quality	-1.997	1.006	0.2012	-2.412	-1.582	-9.926	24	0.000
Pair 4	Grassland/ Biodiversity	-1.416	0.7252	0.145	-1.715	-1.116	-9.76	24	0.000
Pair 5	Base/ Production	-0.0392	0.3979	0.0799	-0.2034	0.125	-0.493	24	0.627
Pair 6	Base/ Water Quality	0.926	0.5661	0.1132	0.6923	1.16	8.179	24	0.000
Pair 7	Base/ Biodiversity	1.507	0.7431	0.1486	1.201	1.814	10.14	24	0.000
Pair 8	Production/ Water Quality	0.9652	0.8752	0.175	0.6039	1.327	5.514	24	0.000
Pair 9	Production/ Biodiversity	1.546	1.055	0.2111	1.111	1.982	7.327	24	0.000
Pair 10	Water Quality/ Biodiversity	0.5812	0.3199	0.064	0.4492	0.7133	9.084	24	0.000



4.34 Comparison map of sediment attached phosphorus results from five scenario runs. (Source: Author)

4.35 Comparison of sediment attached phosphorus loads (a) and annual variation of soluble phosphorus among scenario runs (b). (Source: Author)



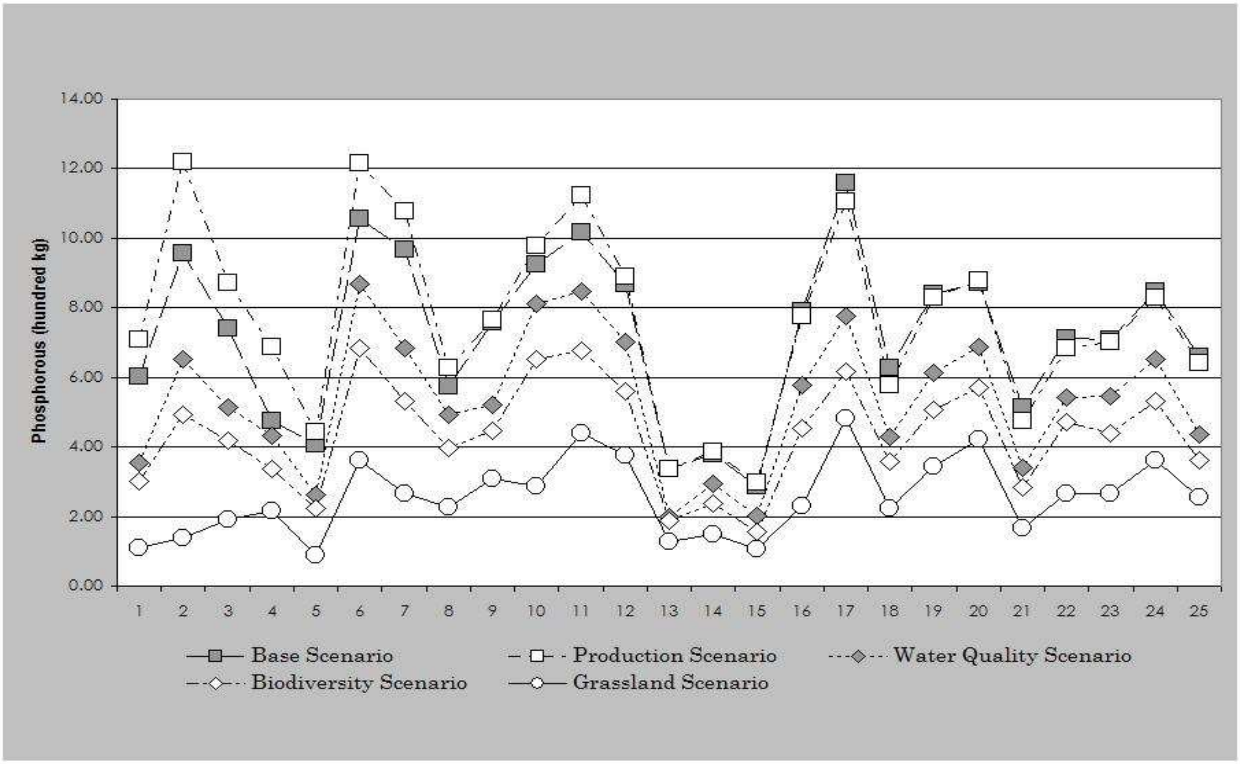


Table 4.30 Results for sediment attached phosphorus and the percent difference in mean annual load between each scenario and the Base scenario.

Sediment Attached P (kg)	Sediment Attached P	Base	Grassland	Production	Water Quality	Biodiversity
723.12	Base	-	-64.58	5.85	-25.63	-39.73
256.11	Grassland		-	-198.85	-109.97	-109.97
765.41	Production			-	-29.74	-43.06
537.78	Water Quality				-	-18.96
435.82	Biodiversity					-

Sediment Attached phosphorus		25 year Variation Statistics				Sub-basin Variation Statistics			
Scenario	%Change	Mean	Standard Dev.	Max.	Min.	Mean	Standard Dev.	Max.	Min.
Base	-	723.12	235.5	1158.09	288.18	374.8	400.8	2016.1	0.00
Grassland	-65.48	256.11	109.55	480.37	90.05	160.4	203.1	1055.5	0.00
Production	5.83	765.41	263.75	1217.79	296.06	407.4	413.8	1719.9	0.00
Water Quality	-25.63	537.78	194.92	866.97	199.87	295.9	313.8	1236.5	0.00
Biodiversity	-39.73	435.82	151.41	683.03	156.00	234.73	252.3	1117.1	0.00

Table 4.31 Variation statistics for sediment attached phosphorus from each of the scenarios. Statistics are presented in terms of temporal variation (over the 25 years simulated), and spatial variation (across the 53 sub-basins in the watershed).

CHAPTER 5 - Discussion and Conclusions

The goal of the research presented was to test the transferability of the methods used in a Iowa study to the Northern Flint Hills of Kansas. Several interesting asides arose in the process of applying the Iowa design framework. Among the more interesting is the similarity in spatial patterns amongst the Base scenario and the three future scenarios, but the stark contrast between some of their resulting pollutant loads.

The Grassland scenario was created in order to compare a pre Euro-American settlement landscape with current and potential conditions. Results from the modeling runs show the Water Quality and Biodiversity scenarios were closer to the Grassland scenario than the Base or Production scenario. Empirically, this isn't the case. Both the Water Quality and Biodiversity scenarios are relatively fragmented relative to the Grassland scenario and contain several different types of cover (e.g. urban, pasture, cropland). These two scenarios are much closer to the Base and Production scenarios than the Grassland scenario. The relative differences and similarities suggest that modest changes to agricultural management practice could achieve significant improvements in water quality. By incorporating practices such as contour farming, strip-cropping, or more conservation minded tillage, it may be possible to greatly reduce the impact agriculture has on adjacent ecosystems.

One unfortunate oversight was in the creation of the Production scenario. Differences between the Base and Production scenarios may not be apparent on first sight. As previously stated, the Production scenario is an attempt to maximize agricultural production in the watershed. To this end, fields located on poorer (and previously uncultivated) soils are broken out and planted in the Production scenario. A grassland buffer zone is ser aside in each of the future scenarios. In the Production scenario the width of the buffer is 30 meters wide. The 30 meters is measured from the stream bank, and does not take into account the riparian corridor already present in the watershed. In the case of Antelope Creek watershed, the riparian corridors are wider than 30 meters, and as such are not adding a great impact/benefit to the Production scenario.

The ability to produce scenarios for use in land management and policy decision making is an invaluable tool for sustainability. This research presents an effort to apply a modeling framework developed for physiographic regions in Iowa to the Flint Hills of Kansas. Building on the work of the Iowa group, five scenarios were created to model the hydrology of Antelope Creek in Wabaunsee County, Kansas. In addition to applying the Iowa methods to produce these scenarios, a toolset was also created to automate the process of scenario creation in the GIS environment.

The major results from this study can be summarized as follows:

- Scenario design methods were successfully transferred from work on watersheds in Iowa, to the Antelope Creek in the Northern Flint Hills of Kansas.
- A GIS toolset was developed to improve the efficiency of the scenario building process in future efforts to adapt design rules. This toolset is meant to create a dataset that can be queried to match scenario design specifications for a given study area.
- In transferring decisions rules from Iowa to Kansas, grazing management was included due to the large amount of rangeland present in the Flint Hills.
- Design rules and management practices for cropland were modified and adapted to fit current agricultural conservation practices in the Flint Hills. This included the widening of riparian grass buffers to account for steep slopes along streams, the use of Land Capability Class soil rating for creation of all scenarios.
- Differences in models results between SSURGO and STATGO datasets are somewhat variable, but tended to indicate slightly higher pollutant export with increasing levels of detail.
- Results from comparison runs also indicate that the selection of a Hydrologic Response Unit option in SWAT may be equally, if not a more important factor in influencing results than the resolution of the soil dataset used.
- Spatial variation within the scenarios tended to be driven by slope and soil conditions. While the addition of crops to areas with poor soils or relatively steep

slopes created increased pollutant exports, the physical features of the landscape dictated where the higher pollutant loads were located.

- Comparison among scenarios indicated that reductions in pollutant exports can be achieved with the addition of conservation management practices to working agricultural lands.

Directions for the Future

In the process of creating scenarios for Antelope Creek in Wabaunsee county Kansas there were several issues and ideas that emerged. These concerns ranged from data availability to the types of models that could be used in future modeling studies. While the methods and tools used for this research were adequate for the goals in mind, future work in scenario development may need to use alternative strategies.

The SWAT model is one of the most powerful hydrologic models available to users today. With the extensive capabilities of the SWAT model, also comes an inherently higher level of complexity. The model user may have an understanding of how the processes of the model function, but it is perhaps more important that model strengths and limitations be communicated to stakeholders. It’s for this reason that it may be more prudent to incorporate simpler models into this type of research.

Using the GIS toolset discussed in Appendix A of this work, routines could be incorporated to create scenarios that are ready for use in models such as TR-55, STEPL, or L-THIA. These are all widely used hydrologic models that contain varying levels of complexity and detail. There is also benefit in creating scenario datasets that can be incorporated into models from disciplines such as economics or ecology.

The GIS tool created for this work was used to facilitate data pre-processing for scenario creation. Even though the tool created here is limited to preparing several datasets for scenario creation, it is possible to expand it to cover the actual scenario creation process. Such an expanded tool, while helpful to expedite scenario creation, should be critically evaluated by future users to ensure the integrity of the generated data in their specific study area. As scenario development research progresses, a cache of these toolsets could be help increase efficiency in the scenario creation process, as well as provide a record of past techniques in scenario creation.

The Flints Hills are somewhat unique in the fact that burning has been a constant factor in the maintenance tallgrass prairie and rangeland management. While research work has been done to address the effects of burning on surface hydrology, relatively little has been done to incorporate the practice in statistical or physically based hydrologic models for grassland environments. Burning has been a major influence on the Flint Hills region throughout human occupation. Advances in model development, that includes spring burning as an important rangeland management practice, will be a welcome contribution.

Carrying the Antelope Creek work forward, one major addition would be the inclusion of stakeholders form the watershed in the scenario design process. Stakeholders were not involved with this project, but would play a major role were these methods and tools to be applied in a real world situation. Stakeholder involvement is vital to any planning or management effort. Local stake holders can provide insight to latent variables or interactions that a policy maker, planner, or researcher may not have otherwise accounted for. For example Di Luzio *et al.* (2005) point out the importance of accurate land cover representation for model performance. Local knowledge (e.g. local farmers reporting what crops they've planted for the year) could vastly improve the accuracy of the modeling efforts.

Stake holder involvement is also equally, if not more, important in any creation and implementation of new management strategies. Management and planning efforts which include the local stake-holders and managers will allows those directly impacted by the changes to have an active voice in the way the strategies are implemented. Inclusion of stake holders in the scenario design process should allow for a smoother collaboration between entities prescribing change and those that are affecting the change.

An added benefit of involving stake holders is a raised awareness of downstream impacts of agricultural management, as well as a more robust understanding of connections within the system. For policy makers and researchers, collaboration with stake holders may allow us to gain a better understanding of social, political, and economic components, as well as inherent feedbacks within the agricultural ecosystem.

Conclusions

In transferring methods from the Iowa based research some techniques were altered to suit the needs of the Antelope Creek study area. Other techniques employed for the Iowa work were utilized in the Kansas watershed due to the similarity in the two landscapes. Given the nature of this similarity, we are left to speculate about the transferability of the Iowa methods to other physiographic regions. For instance in both cases (Iowa and the Kansas watersheds), row crops were a significant portion of the land use / land cover. The similarities between the two areas allowed for the application of Iowa's design rules to the Kansas study area. In the case of the Biodiversity scenario, the practice of strip-cropping and the establishment of a bio-reserve were implemented in the same manner for both study areas. If a study area were located in the Western United States, would the relatively large amount of public land preclude the need for such a reserve, or at least affect the size of a reserve? Would it be possible to apply these rules to an urban, sub-urban, or peri-urban landscape? Questions of this nature loom large in the transferability of design rules to other physiographic regions. It will be the task of future research endeavors to address the applicability of these methods in non-agriculturally dominated landscapes.

In transferring the scenario design methods from Iowa to Antelope Creek watershed, an effort was made to alter the method framework as little as possible, but create scenarios that were plausible for the Northern Flint Hills of Kansas. The research here confirms that it is feasible to apply the Iowa design methods for a Kansas landscape with some similarity. As discussed earlier, there were several manipulations that were applied to tailor these scenarios to Antelope Creek including adjustments to buffer widths, the addition of grazing, and the application of agricultural practices that are more suited to Kansas.

The aim(s) of the present research was to test the transferability of the aforementioned Iowa methods, as well as create a suite of scenarios for a Kansas watershed. Considering this, the results of the Antelope Creek scenarios were analyzed in terms of their relative difference to each other rather than their predictive ability. However, it is not beyond our scope of interest to ensure the scenarios perform in a manner considered to be representative of the physical systems being replicated. Taking into account the manipulations that were applied to different scenarios, we tended to see resulting pollutant loads that make sense. For example, in the Water Quality and Biodiversity scenarios in order to implement contour farming and strip-cropping, two factors were manipulated in the modeling routines for each of the practices (adjustment of the SCS curve number and MUSLE C-factor). The impact of these changes can be seen in the results of several of the pollutant loads as the Biodiversity and Water Quality scenarios generally loaded lower than either the Base or Production scenarios.

The scenarios also highlight the potential of different management practices to drastically reduce the amount of pollutants leaving agricultural areas via water. Results indicate the addition of practices such as contour farming and strip-cropping may result in pollutant loads more closely resembling that of native grassland than current conditions or an expansion of agriculture. It seems likely that what could be considered as minor changes in the way that agricultural areas in Antelope Creek watershed are managed could lead to major reductions in the amount of unwanted pollutants entering the hydrologic system.

Since Antelope Creek is an ungauged stream section, it would be difficult to make any claims as to the accuracy of model runs to predict actual loads. An effort has been made to present the relative differences among the past, present, future scenarios, so that some assertions about the nature of possible future management strategies can be made.

First, it is evident from our modeling results that relatively minor changes to management practices and strategies could result in significant reductions in Antelope creek. The reductions achieved by the Water Quality and Biodiversity scenarios are an example of the type of goals future managers and policy makers could be striving to achieve. The heterogeneous spatial grain of these two scenarios, which tends to resemble the Base and Production scenarios, are much closer to the Grassland scenario in their pollutant export.

It should be noted that modest reductions were achieved by the Intensification of Agriculture for selected pollutant loads. One may wonder what types of pollutant reductions could be achieved with scenarios that combined properties from the Intense Agriculture, Water Quality, and Biodiversity scenarios. The ability to manipulate, and re-run the Production scenario again highlights the flexible nature of the alternative future scenarios, and the ability to quickly and efficiently project the impacts of potential management practices.

The creation of a GIS toolset to expedite the process of building alternative future scenarios is also another step in making this process more efficient. While the current version of the scenario query tool contains no design specifications. Including such scenario specific routines is a possibility for future modeling efforts. It should be cautioned that putting this detail into such a tool may present potential pitfalls to the user. Care should be taken to ensure the design rules applied in the scenarios are representative of the character of a specific study area. It would be of little benefit to model scenarios with no context in the area for which they're being applied.

New and innovative tools will be necessary to deal with ongoing environmental degradation from agricultural production. Scenario modeling is a promising avenue to address agricultural, as well as other environmental issues affecting the planet. Scenarios offer a unique opportunity to project possible outcomes of local management decisions or larger scale policy influence on local places.

Changing policy and management practices have moved faster than humans' ability to anticipate the effects on agricultural ecosystems. Using scenario and modeling tools, outcomes of agricultural policy and management can be projected with a suite of future scenarios as presented in this work and, the original research conducted in Iowa. Scenarios are not intended to predict the future, but rather offer a glimpse of what may be possible if a decision is made, or a practice is implemented. Scenario and modeling results can be used as decision making tools to aide policy makers, stakeholders, and managers in making decisions to maximize benefit for the economic and ecological aspects of agricultural ecosystems.

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Appendix A - A GIS Toolset to Aid in Scenario Development

ESRI Model Builder

Model builder is a tool contained in the ArcGIS software package. The purpose of the model builder tool is to help automate geoprocessing tasks. Using the model builder tool, a modeler can not only automate several geoprocessing tasks, but also share this new tool with others who may be undertaking the same model building endeavor. As this work and other research involving scenario creation moves forward, the hope is that the toolset created here can be of some assistance in stream-lining the process.

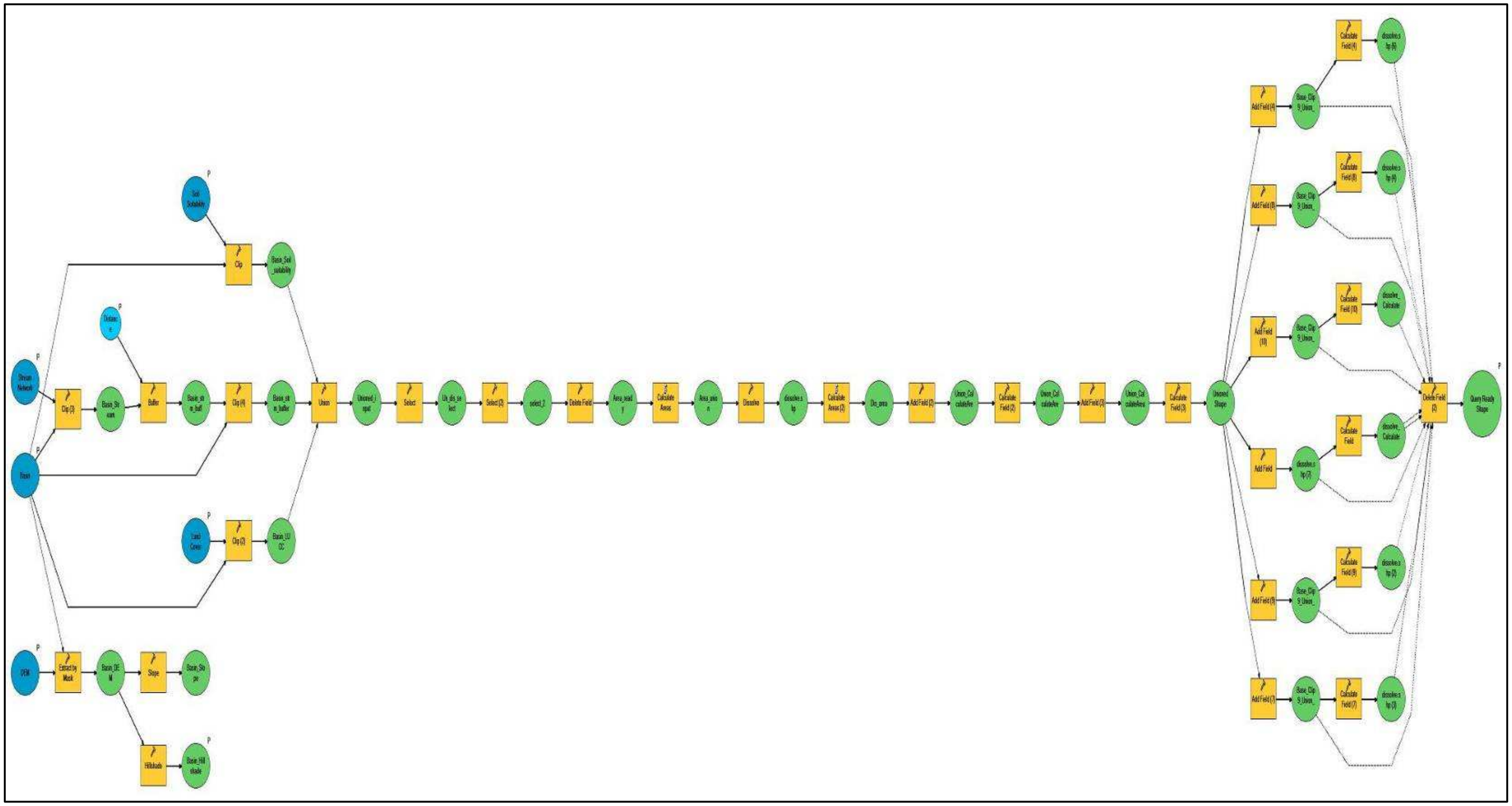
The Querying Dataset

In this research model builder was used to create a toolset which could be used to expedite some of the tasks associated with building scenarios (Figure A.1, A.2). This toolset involves combining the attributes of several datasets using an overlay function (union), focusing these datasets to a watershed boundary, and calculating the areas of new polygons which are created after the datasets are overlaid. Datasets which are required for this tool to work are as follows:

- Watershed or Basin boundary shapefile
- Soil suitability rating shapefile
- Stream network shapefile
- Landcover dataset (must be converted to shapefile prior to incorporation with model)
- A Digital Elevation Model (DEM) raster

Another important component of this toolset is the creation of a buffer around stream datasets. The width of this buffer is specified by the modeler, in accordance with the design specification for the scenario being created.

The model starts by clipping all input datasets to the Watershed boundary file. Using the DEM, slope and hillshade functions are carried out. The hillshade raster is used for visualization purposes, and the slope raster can be used to help determine how and where management practices will be applied in other scenarios. In the next model routine, the land cover, soil suitability and stream buffer are overlaid using the union tool. Once these files have been unioned, a tool is used to calculate the area (in square meters, square feet, and acres) of individual polygons in the new shapefile. When the toolset has finished, the end product is a shapefile which contains attributes for landcover type, soil capability, location within or outside the stream buffer, and the area of a polygon in square feet, square meters, and acres. This dataset is ready for a modeler to apply their design specifications through querying and updating the attributes.



A. 1 Full toolset used to automate portions of scenario building process. (Source: Author)

A. 2 Focusing and overlay portion of toolset. (Source: Author)