# GIS-BASED EVALUATION OF THE CONSERVATION RESERVE PROGRAM IN TEXAS COUNTY, OKLAHOMA

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# Chapter 1 INTRODUCTION AND LITERATURE REVIEW

## 1.1 BACKGROUND

Soil is the major natural resource on which society depends for the production of food. Degradation processes like soil erosion further stress already limited land resources. Soil degradation, through either human activities or natural forces, has reduced the productivity of soils. Soil degradation can result from accelerated soil erosion and loss of vegetative cover. Worldwide, erosion by water, wind, tillage, and irrigation remains a major cause of soil degradation and a primary environmental concern (Pilesjo 1992).

Soil loss is defined as the amount of soil lost in a specified time period over an area of land, which has experienced net soil loss and expressed in mass per unit area (e.g. ton/ha/year or kg/m$^2$/year). The actual amount of eroded material passing a given point in a watershed (usually the outlet) within a given amount of time is termed sediment yield (Nearing and Nicks 1998). Soil erosion is one of the major problems threatening the sustainability of agriculture and the quality of water. The effects of erosion are not restricted to washing away topsoil, that decrease soil fertility and water quality, or land gullying, but to clogging canals with sediments and silting up reservoirs, reducing the capacity of rivers and lakes (Pilesjo 1992). Soil erosion from productive farmlands diminishes on-site land value, and causes off-site environmental damage (Bhuyan et al. 2002). On-site impacts of erosion include reduced productivity through loss of plant nutrients and organic matter and frequently the ability for the soil to absorb and retain water for subsequent plant use (Nearing and Nicks 1998). Soil erosion can also lead to loss of applied fertilizers, increased susceptibility of plants to diseases, and decreased value of fruits and vegetables. Increased expenditures on fertilizers are expected to maintain fertility, but in some cases yields become poor enough that lands are taken out of cultivation (Nearing and Nicks 1998). Off-site damages can have significant environmental and economic impacts, including sedimentation of water bodies, downstream damage to land and structures (e.g., bridges, buildings, and roads) due to increased surface runoff, degradation of water quality by salinization, and presence of harmful chemicals (USDA Agriculture Research Service 2001). Forman et al. (2000) divided the pollutant effect of erosion into physical and chemical. The destruction of riparian habitats due to sediment aggradation in rivers is an example of physical pollutants. Chemical pollutants consist of soil nutrients such as phosphorous and nitrogen, and other contaminants such as heavy metals and pesticides leading to eutrophication of lakes and reservoirs.

Soil erosion occurs in a natural, undisturbed environment, but under such conditions soil formation generally compensates for erosion, thereby maintaining a state of equilibrium. Human interference may disturb this natural balance and lead to widespread removal of the soil cover. Conversion of natural grazing land into cropland, overgrazing, agricultural intensification, and deforestation are a few examples of these adverse human activities. Because agricultural efforts are focused on increasing food production, soil degradation worldwide has increased. Soil erosion is aggravated when farms operate strictly as a business so that crop yield in the short-term is maximized at the expense of long-term fertility and productivity. In addition to soil erosion resulting from poor land management, it is accelerated by population increase, use of powerful machines, and the fertilizers and pesticides that move downstream with the displaced soil.

If the current degradation continues, our needs and demands for more food from smaller agricultural land cannot possibly be met (Taylor et al. 1994; Thirgood 1981). The cost of off-site soil erosion damages in the United States amounts to more than two billion dollars a year (Clark et al. 1985).

Agriculture has been identified as the major contributor to nonpoint source pollution of surface and groundwater systems in the United States (EPA 1990; Myers et al. 1985). Routine agricultural activities are responsible for over 50-70 percent of the surface water pollution problems nationwide (EPA 1990). An average of about 13 tons/ha/year is lost from water and wind erosion on lands of row crops in the US (NRCS National Resources Inventory 2001).

Part of the chemicals applied to farmlands as fertilizers and pesticides is absorbed to soils and transported to water bodies. These chemicals also can be transported as dissolved substance with surface runoff to the water supplies. These processes cause water pollution and increase the risk of health hazards for living organisms including humans. Accelerated erosion of productive crop land; leaching of nutrients (mainly N and P); and runoff of pesticides from agricultural lands were cited as the primary causes of water quality degradation (Liao and Tim 1994).

Soil erosion can be minimized by suitable land management practices. Evaluation of the proper land management practices needs accurate estimation of soil loss from various cropped farmlands (Bhuyan et al. 2002). Erosion hazard assessment can be very useful to overcome the damage that may affect agricultural highlands. The assessment of erosion hazard is a specialized form of land resources evaluation, the objective of which is to identify areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss (Morgan 1995). Soil erosion occurs by the action of water, wind and glacial ice. Water erosion occurs when rain wear away and transport soil particles. The main types of water erosion are splash erosion, sheet erosion, rill erosion, gully erosion, and channel erosion. Splash erosion occurs when raindrops impact the ground and dislodge soil particles. In sheet erosion, a thin sheet of flowing water removes soil particles. Rill erosion occurs when the surface creates small channels (rills) small enough to be smoothed by normal agricultural tilling. Gully erosion refers to soil erosion that result in larger channels that cannot be smoothed completely by normal agricultural tilling. Channel erosion occurs in watercourse channels and streams and includes both streambed and stream bank erosion (Morgan 1995).

## 1.2 ESTIMATION OF SOIL EROSION

Soil erosion research provides information on natural hazards and human impacts, and serves as a basis for regulating land management. However, quantification of soil loss is a challenging task in natural resources and environmental planning. The purpose of estimating the rate of soil erosion is to compare with an acceptable value of soil loss tolerance e.g. 10 tons/ha/year (Institute of Applied Sciences 2003), and to evaluate the effects of different conservation strategies. Soil erosion modeling is a method by which soil loss is predicted under known or specified environmental conditions. To be useful for decision makers, soil erosion models must have simple data requirements, must consider spatial and temporal variability in hydrological and soil erosion processes, and must be applicable to a variety of regions with minimum calibration (Renschler and Harbor 2002). Most of the models used in soil erosion prediction are of empirical black-box type.

They are based on defining the most important factors through observation and experiments and relating them to soil loss (Morgan 1995). In the last two decades of the 20th century significant advances have been made in understanding the processes of soil erosion and the physically based models have emerged as the new technology in soil erosion prediction. Soil erosion models can range from simple equations, empirical models, to complex equations (physical-based models) related to the fundamental physics or mechanics of the process (Morgan 1995).

### A. Empirical models

Empirical erosion models are generally in the form of a single equation that computes soil erosion by assigning values to factors that represent the major factors of climate, soil, topography, and land use. Empirical models are restricted to regions such as the Universal Soil Loss Equation (USLE) in the Midwest. These models lack temporal and spatial resolution and yield only annual averages.

Zingg (1940) developed the first erosion prediction equation used for the evaluation of soil erosion problems and selection of the proper conservation practices to reduce excessive soil erosion. His equation of soil loss expressed nonlinear relationship with slope steepness and slope length. Smith and Wittt (1948) improved the soil erosion prediction by adding parameters that reflect the influence of land cover and management. Browning et al. (1948) included a soil erodibility factor to Smith’s equation. Later, rainfall erosivity and soil erodibility factors were added to the before mentioned equations to account for differences in rainfall patterns and soil characteristics (Meyer 1984; Wischmeier and Smith 1978; Musgrave 1947). Wischmeier and Smith (1965) analyzed a vast amount of plot data and developed the Universal Soil Loss Equation (USLE), which became the most widely used equation for estimating interrill and rill erosion. The equation is based on statistical analysis of soil erosion data collected from small erosion plots.

The USLE underwent several revisions (Renard et al. 1991; Williams et al. 1985; Wischmeier and Smith 1978). It has been revised using data from rainfall simulators (Wischmeier and Smith 1978). Soil erodibility nomograph and the cover factor values were derived from rainfall simulators. The Modified Universal Soil Loss Equation (MUSLE) was developed by replacing the rainfall runoff factor (R) in USLE with a runoff term in the form $95(Qq_p)^{0.56}$, where Q is the runoff volume ($m^3$), and $q_p$ is the peak flow rate ($m^3/s$) (Williams 1975). The MUSLE is expressed as:

$$Y = 11.8\,(Q_{surf} * q_{peak} * A_{hru})^{0.56} * K * C * P * LS * CFRG, \quad \text{where}$$

Y = sediment yield (metric tons)

$Q_{surf}$ = the surface runoff volume ($m^3$)
$q_{peak}$ = the peak runoff rate for the subbasin ($m^3/s$)
$A_{hru}$ = area of the HRU (ha)
K = the USLE soil erodibility factor
C = the USLE cover and management factor
P = the USLE support practice factor
LS = the USLE topographic factor
CFRG = the coarse fragment factor

This equation has been used successfully to simulate watershed sediment in models such as SWRRB (Simulation for Water Resources in Rural Basins) (Williams et al. 1985), SPUR (Simulation of Production and Utilization of Rangeland) (Wight and Skiles

1987), and SWAT (Soil and Water Assessment Tool) (Arnold et al. 1998). Several concepts from process-based erosion modeling have been incorporated in RUSLE (Revised Universal Soil Loss Equation) to improve soil erosion predictions (Renard et al. 1991). The model is computerized and the equations used to calculate the factors in USLE are significantly modified (Renard et al. 1995). Major modifications included the time-varying k-factor, the new algorithms for the topographic factor, and the new techniques for estimating support practices. However, despite the wide use of these models, they suffer important shortcomings. The USLE and RUSLE do not provide information about sediment yield downstream of the upland areas. The two models predict on-site erosion for parts of the landscape, but do not address the problem of sediment deposition. Management practices such as contouring change the hydrology and are difficult to address in both models (Renard et al. 1995). Most importantly, empirical models cannot be universally applied for two main reasons: 1) they are not able to simulate water and sediment movement over the land surface, and 2) they cannot be used on large-scale watersheds.

### B. Deterministic models

The great concern about the off-site consequences of erosion and identification of non-point source pollution have led to the development of models that predict the spatial distribution of runoff and soil loss over the land surface. These models are based on fundamental hydrologic and erosion processes used to estimate soil loss by sheet and rill erosion, and erosion by concentrated flow (gully) in field-sized areas (Renard et al. 1995).

Deterministic models can be separated into “lumped” and “distributed” models. Lumped models, such as CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems), describe an overall or average response of the watershed (Beasley 1986). Lumped models “lump” land form, land use, and physical processes into single average values for entire watershed or subwatersheds. Distributed models, such as SWAT (Soil and Water Assessment Tool), utilize the spatial variability within the area of study resulting in an increased accuracy of simulation. These models have the ability to simulate conditions at all points within a watershed simultaneously (De Roo et al. 1989).

Hydrologic models such as SWAT, CREAMS, and WEPP (Water Erosion Prediction Project**)** are able to address sediment detachment, transportation, and deposition. Using these models the user can predict on-site soil erosion and off-site sediment yield. Off-site predictions of sediment yield by hydrologic models can be used in soil conservation, farm planning, pollution control and environmental protection. Some other widely used models include, EPIC (Erosion Productivity Impact Calculator) (Williams et al. 1983), ANSWERS (Areal NonPoint Source Watershed Environmental Response Simulation) (Beasley et al. 1980), AGNPS (Agricultural Non Point Source) (Young et al. 1989), SWRRB (Simulator for Water Resources in Rural Basins) (Arnold et al. 1990), and ROTO (Routing Outputs to Outlets) (Arnold 1990).

Each model addresses specific issues along with a set of assumptions and variable input requirements. Models are either non-spatially distributed (EPIC, CREAMS), or spatially distributed (SWAT, ANSWERS, AGNNPS, SWRRB); single event (AGNPS, ANSWERS), or continuous time-scale (SWAT, EPIC, CREASM, SWRRB, ROTO); field-scale (WEPP, EPIC, CREAMS), or basin-wide (SWAT, ANSWERS, AGNPS, SWRRB) (Srinivasan and Arnold 1994). The following is a brief description of some of these models:

### 1. The Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS)

The USDA-Agricultural Research Service (ARS) developed the field-scale model CREAMS to assess non-point pollution and to simulate the long-term impact of land management on water quality (Knisel 1980). CREAMS linked hydrology, erosion, and sediment, nutrient and pesticide delivery from small watersheds (Laflen 1998). Several other developed models have originated from CREAMS include GLEAMS (Groundwater Loading Effects of Agricultural Management System), EPIC (Erosion Productivity Impact Calculator), and AGNPS (Agricultural Non-point Source) (Arnold et al. 1990; Williams et al. 1985). CREAMS was used to predict the annual soil loss for several sites in Bedfordshire, England (Morgan 1995).

### 2. The Erosion Productivity Impact Calculator (EPIC)

The EPIC model (Williams et al. 1983) also known as the Environmental Policy Integrated Climate was developed primarily to predict soil erosion and to determine the relationships between erosion and soil productivity throughout the USA. It consists of physical/chemical process based components and continuously simulate the processes associated with erosion, using a daily time step and readily available inputs (Sharpley and Williams 1990). The hydrology component of the model predicts surface runoff for daily rainfall using the Soil Conservation Service (SCS) Curve Number (CN) equation (USDA

1972). For calculation of soil loss, EPIC allows the use of any of the following methods: USLE (Wischmeier and Smith 1978); MUSLE (Williams 1975), the Onstead-Foster (AOF) equation (Onstead and Foster 1975) and MUSS (MUSLE for small watershed); and MUST (another version of MUSLE).

### 3. The Water Erosion Prediction Project (WEPP)

WEPP is a daily simulation model that predicts erosion and sediment delivery at different scales. WEPP (Nearing and Nicks 1998) is a process-based, soil erosion prediction model based on fundamentals of hydrology, soil physics, plant science, hydraulics, and erosion mechanics. It is a continuous simulation model for predicting daily soil loss and deposition from rainfall, snowmelt, and irrigation. The WEPP erosion model computes soil loss along a slope and sediment yield at the end of a hillslope. Interrill and rill erosion processes are considered, and it uses a steady state sediment continuity equation as a basis for the erosion computations (Foster and Lane 1987).

### 4. The Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS)

ANSWERS model was developed to simulate the sediment movement on watersheds having agriculture as the primary use (Beasley et al. 1980). It computes the soil loss during and immediately following a rainfall event. It is a distributed-parameter watershed model and incorporates the influence of the spatially variable controlling parameters, for example, topography, soil and land use. It uses different relationships that describe the erosion of soil particles by raindrop impact and by overland flow. Detachments by raindrop impact and overland flow are calculated as described by Meyer and Wischmeier (1969) and modified by Foster (1976). The watershed to be modeled by ANSWERS is assumed to be composed of square elements. An element is defined as an area within which all hydrologically significant parameters are uniform. ANSWERS has the advantage of being easy to link to raster-based geographical information systems (De Roo 1993).

### 5. Soil and Water Assessment Tool (SWAT)

SWAT model has been widely applied in various scenarios and watersheds (Spruill et al. 2000). It provides opportunities to improve watershed modeling accuracy and better long-term prediction of hydrologic components (Arnold et al. 1998). In addition, SWAT allows a great deal of flexibility in watershed configuration (Peterson and Hamlett 1997). SWAT model overcome limitations in previous models such as operating on large watersheds with hundreds or thousands of subbasins. Previous applications of SWAT in other parts of the United States have shown promising results (Rosenthal et al. 1995; Srinivasan and Arnold 1994).

SWAT model is public domain software developed by the USDA-Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas. SWAT is a continuous-time model that operates on a daily time step to predict the impact of management on sediment, water and agricultural chemical yields in large ungaged basins (Arnold et al. 1995). SWAT model uses readily available inputs (digital elevation model, land use land cover, soil, etc) and computationally efficient that operates on large basins in a reasonable time. The SWAT model is a physically based model capable of simulating long periods of management operations. It is a distributed hydrologic model (Arnold et al. 1998) that allows a watershed to be subdivided into smaller subbasins to incorporate spatial detail. The concept of HRUs (Hydrologic Response Units) override more detailed modeling in SWAT. Each subbasin can be subdivided into units with unique land use land cover and soil type called Hydrologic Response Units (HRU) that capture the variability within the subbasin. Processes in each individual HRU are calculated independently, and the output for the subbasin is the output summation of all HRUs within that subbasin. The SWAT model structure can be placed into eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management. SWAT requires the following primary data: digital elevation model, soil data and land use land cover data. Other optional data include stream network, weather data, and management data.

SWAT is model combination of ROTO (Routing Outputs of Outlets) (Arnold et al. 1995) and SWRRB (Simulator for Water Resources in Rural Basins) (Arnold et al. 1990; Williams et al. 1985). SWRRB can only be used to model watersheds of several hundred square kilometers in area with a maximum 10 subbasins. Many hydrologic models contributed to the development of the SWAT model includes EPIC (Erosion Productivity and Impact Calculator), CREAMS (Chemical, Runoff and Erosion from Agricultural Management Systems) and GLEAMS (Groundwater Loading Effects on Agricultural Management Systems). SWAT was used in the HUMUS (Hydrologic Unit Model for the United States) project to model 350 watersheds in the 18 major river basins in the United States (Srinivasan et al. 1997).

Modeling applications:

Rosenthal et al. (1995) tested SWAT predictions of streamflow volume for the Lower Colorado River Basin in Texas. The model closely simulated monthly streamflow with a regression coefficient of 0.75. The model underestimated streamflow volume during extreme events, where precipitation was scattered with high intensity. Binger (1996) evaluated the SWAT model in Goodwin Creek Watershed in Northern Mississippi. The Nash-Sutcliffe coefficients, $R^2$, values computed with observed monthly flow were all close to 0.80 except one measuring station, which was predominantly in forest. Smithers and Engel (1996) used the SWAT model to monitor the Animal Science and Greenhill watersheds in west central Indiana. The model underestimated totals for both while simulating none or very little baseflow. Possible reasons of poor simulation were inappropriate soil input parameters or water budgeting procedures, which resulted in little drainage.

Montas and Madramootoo (1991) used the ANSWERS model to predict the soil loss from a small agricultural watershed and found that ANSWERS under predicted sediment yield from all events. Puurveen et al. (1997) found that the EPIC model adequately estimated sediment yield from snowmelt events. Yoong et al. (1997) used three models GLEAMS, EPIC, and WEPP to simulate the effects of two systems of conservation and conventional tillage on losses of sediment, N and P from a field-size watershed in the Tennessee Valley Region of Alabama. GLEAMS and EPIC under predicted $NO_3$-N losses in runoff for both tillage systems. EPIC simulated tillage effects on soluble-P losses better than GLEAMS. However, EPIC poorly predicted the annual losses of organic-N and P in sediment. WEPP predicted sediment losses close to the measured values for both tillage systems. However, EPIC simulation of sediment loss was not as accurate. SEDIMOT II is a batch-mode, DOS platform program to evaluate the hydrology and sedimentology response of agricultural and disturbed watersheds. Sedimot II is designed to generate and route hydrographs and sediment loads through multiple subareas, reaches and reservoirs. The program can predict peak sediment concentration from a flow event, trap efficiency of a sediment retention basin, sediment load discharge, peak effluent sediment concentration, and peak effluent settleable concentration (Warner et al. 1989).The West Valley Nuclear Services Company, Inc. (1993) estimated the quantity of sheet and rill erosion occurring during major storm events using the SEDIMOT II surface erosion model.

Zhang et al. (1996) evaluated the performance of the WEPP model in predicting soil loss from croplands. They found that WEPP slightly over predicted soil loss for small storms and for years with low runoff and soil loss rates. On average, soil losses for different cropping and management systems were predicted adequately. Ghidey et al. (1995) found that WEPP over predicted in years of low soil loss and under predicted during years of high soil loss. However, the overall soil loss prediction compared well to measured values. Kramer and Alberts (1995) reported that the mean annual simulated soil loss was over predicted the observed values for conventional tilled cropped lands.

Bhuyan et al. (2002) used three models WEPP, EPIC and ANSWERS to predict sediment yield from three different tillage systems (ridge-till, chisel-plow, and no-till). Results showed that all the three models performed reasonably well and the predicted soil losses were within the range of observed values. For ridge-till and chisel-plow systems, WEPP and ANSWERS gave better predictions than those by the EPIC model. For no-till systems, WEPP and EPIC predictions were better than those by ANSWERS. The overall results indicate that WEPP predictions were better than those by the other tow models in most of the cases.

## 1.3 GEOGRAPHIC INFORMATION SYSTEMS and ENVIRONMENTAL MODELING

A model is a simplification of nature representing a set of objects and their relationships and often describes a phenomenon that cannot be directly observed. Environmental models are developed to better understand natural phenomena and to better manage the natural resources (Rao 1996). Growing concern about the impact of human activities (e.g. agricultural projects) on the natural environment makes the prediction and analysis of environmental impacts the basis for a rational management of our environment. Environmental modeling, as one of the scientific tools for this prediction and assessment, is a well-established field of environmental research. Most environmental problems have a spatial dimension. Distributed environmental models describe environmental phenomena in one, two or three dimensions (Fedra 1993). Determining the amounts of pollutants from agricultural land can be achieved through long-term, on-site monitoring and/or simulation modeling. However, on-site monitoring is a very labor intensive and often expensive. Therefore, simulation modeling of nonpoint source pollution has been used frequently to provide guidelines in the development and planning of agricultural management strategies (Liao and Tim 1994).

Computer simulation models provide useful information for decision-makers and planners to take appropriate land management measures. Although simulation models working at a regional scale may be less accurate than soil loss predictions at plot or field scale, decision-makers are usually more concerned about the hazardous effects of soil erosion (De Jong et al. 1999). Computer simulation models are devoted toward the study of natural processes involving various environmental components such as soil, climate and plants (Rao 1996). Many computer models have been developed to perform watershed assessments integrating hydrologic models (rainfall/runoff) with erosion models and identifying point and nonpoint pollution sources and assessing their impact on water quality within the watershed. The database of information required by hydrologic models is vast and complex. Therefore, computer-based models have two primary advantages for soil erosion modeling including 1) the potential to consider different data input and management practices, and 2) improved soil erosion estimation and conservation.

Several limitations including the inability to manipulate the large amount of input data have restricted the use of simulation models. Furthermore, the existing simulation models are complex, data intensive, and require considerable skills and capital resources for their use (Liao and Tim 1994). Since all the basic units in environmental modeling do have a spatial distribution, and this distribution does affect the processes and dynamics of interaction considerably, geographic information systems have a lot to offer to environmental modeling.

The term geographical information system (GIS) is generally defined as a computer-based system for the manipulation of geographical data. A GIS includes hardware, software, data input and output devices (scanners, printers, etc) (Bernhardsen 2002) and is capable of assembling, storing, manipulating, and displaying geographically referenced information. Geographic Information Systems (GIS) are a new introduction into the fields of environmental modeling and watershed analysis. Environmental models simulate the environmental processes that are spatially described by geographic information systems. GIS can display the outputs from theses models for better understanding the environment. Thus, GIS can serve as a common data and analysis framework for environmental models (Maidment 1993). There are now large amounts of data derived from remote sensing, ground surveys and others sources that can be processed within GIS to aid in hydrologic models. GIS becomes a useful tool when dealing with large amounts of data that must be entered into a model. Soil erosion formulas can be programmed in the GIS application, the necessary parameters extracted from the appropriate coverages (e.g. slope from DEM), and the results stored in a new coverage and/or database. GIS is capable of handling various spatial variables and performing complicated spatial operations and can also be used to graphically present the results from the soil loss analyses.

Hydrologic models become complex at large extents because of the complexity of the input data and amount of knowledge required to run the model (Hernandez and Miller 2000). With the advancement of GIS technology and the widespread availability of digital data, the development and use of hydrologic models has become more efficient. Information about watersheds and their associated features can be compiled in GIS using the different data structures, shapes and grids, supported by the system. The GIS can derive the input files required for watershed modeling. The results from these models can be exported to a GIS format for display and further analysis. Digital data are becoming more readily available, making the use of GIS more practical. Digital elevation data and land use data can be obtained from the U.S. Geological Survey. Soil data can be obtained from the Natural Resources Conservation Service (NRCS). These digital data represent the area of the watershed. The geospatial data of watershed are digitized, scanned or captured by remote sensing techniques.

ARC/INFO and ArcView, developed by the ESRI (Environmental Systems and Resource Institute 2004), are the most commonly used GIS software packages (Srinivasan and Arnold 1994). GRASS (Graphical Resources Analysis Support System), developed by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory, is another GIS software package used in watershed modeling. GRASS is a public domain raster GIS developed for land and environmental planning at military installations (Srinivasan and Arnold 1994).

There are two approaches for integrating NPS (nonpoint source pollution) models with GIS: a) linking models with GIS and b) modeling within the GIS. The former approach entails passing information between GIS and the NPS model. In the second approach GIS is used to derive the necessary parameters to calculate soil erosion for each cell (Poiani and Bedford 1995) and to display results. The Graphical User Interface (GUI) allows rapid and accurate application of hydrologic models at a range of basin scales given a minimum of expertise and input data (Hernandez and Miller 2000). Data outputs are represented in a variety of ways ranging from the image on the computer screen, through hardcopy output. ArcView GIS, for example, can be used to delineate watersheds and subbasins within the watershed and determine flow directions and accumulation from a DEM. Land use and soil type GIS data are used to determine some of the parameters required by the hydrologic models. ArcView extracts and prepares hydrologic, topographic and other physical characteristics from geospatial data to hydrologic models. Slope length and steepness factors, for example, in the USLE equation can be estimated from GIS data. The sediment yield equations, RUSLE for example, can be programmed in the GIS application, the necessary parameters extracted from the appropriate GIS layers, and the results are stored in a new GIS layer. GIS can also be used to graphically present the results from the analyses.

Geographic information systems have been successfully integrated with environmental models such as AGNPS (Agricultural Non Point Source), ANSWERS (Areal Non Point Source Watershed Environmental Response Simulation) and QUAL2E (The Enhanced Stream Water Quality Model) (Yang et al. 1999; Srinivasan and Arnold 1994). The use of GIS improves estimation of watershed parameters by using data such as DEM and digitized thematic maps. Rao et al. (2000) integrated EPIC (Erosion Productivity Impact Calculator) model with ArcView GIS. These linkages have proved to be an effective way to manipulate and analyze the input data, and display the outputs. The integrated system assists with development of models input from GIS layers. The interface significantly reduces the time required to obtain input data and simplifies model operation (Srinivasan and Arnold 1994).

Since management of the CRP and computations of the environmental benefits index (EBI) involve several spatial variables from soil, land use, climate, topography, hydrology and socioeconomy (USDA 1996) GIS can be applied in the management of CRP. GIS can aid in calculating the environmental benefit index (EBI), which is currently calculated manually and can aide also in manipulating the complex spatial variables (Padgitt 1989). Rickerl et al. (1999), for example, used GIS to select environmentally sensitive CRP tracts in Lake County, South Dakota.

He et al. (1993) and Tim and Jolly (1994) integrated GIS technology with non-point source pollution (NPS) models to evaluate alternative management strategies. ArcView nonpoint source pollution modeling (AVNPSM) an interface between ArcView GIS and AGNPS was developed and applied to study the Dowagiac watershed in Michigan (He 2003). AVNPSM was used to simulate the impact of change in land use on runoff, sediment and nutrient yields. The ANSWERS model and GIS were linked to simulate runoff and soil erosion (De Roo 1993; De Roo et al. 1989). GIS interfaces have been developed for SWAT using both the Graphical Resources Analysis Support System (GRASS) and ArcView. Linking SWAT with ArcView 3.2 facilitates data preparation and results presentation (Di Luzio et al. 2002a). Within ArcView the watershed parameters and characteristics are extracted, the input files are written in the proper format and the model is executed. Srinivasan and Arnold (1994) integrated SWAT (Soil and Water Assessment Tool) and GRASS (Geographic Resources Analysis Support System) GIS to assist with the management of erosion, runoff and other watershed variables. An integrated system of SWAT and GRASS (Geographic Resources Analysis Support System) GIS was applied to simulate the Seco Creek Basin, South Central Texas. The average monthly predicted streamflow was in agreement with measured monthly streamflow values (Srinivasan and Arnold 1994). GRASS GIS was also integrated with AGNPS (Srinivasan and Engel 1991a, 1991b) and with ANSWERS (Rewerts and Engel 1991) to extract input data and visualize the outputs.

## 1.4 PROBLEM STATEMENT

Continued human population growth and increasing demand for sustainable agriculture underscore the need for restoration of degraded cultivated soils (Doran and Parkin 1994). Important soil restoration goals include reducing erosion, enhancing soil structural stability, and increasing soil nutrient conservation (Baer et al. 2000).

As a result of the intensive agricultural production, soil erosion has prevailed in the United States croplands. The 1982 National Resource Inventory showed that 41.2 million acres were eroding at rates exceeding 10,000 cubic meters per acre per year (Hughes et al. 1995). In the same year, the U.S. Department of Agriculture estimated 1.93 million cubic meter of lost soil annually due to crop production (Clark et al. 1985). With soil conservation as the principal environmental problem, the Conservation Reserve Program (CRP) was initiated in 1985 with the passage of the Food Securities Act. The CRP is a voluntary program in which landowners are encouraged to remove highly erodible land (HEL) from production and plant native grasses or other protective vegetation for 10-15 years (Lindstrom et al. 1994; Skold 1989). Farmers are paid an annual per-acre rent, plus one-half of the costs of establishing permanent land cover (USDA Farm Service Agency 2003a; Young and Osborn 1990). The CRP was established primarily to bring crop production more in line with demand and to conserve and improve soil and water quality. The emphasis was on reduction of soil erosion and stream sedimentation and on improvement of water quality on erodible or eroding lands and tilled wetlands (Hughes et al. 1995). By reducing water runoff and sedimentation, CRP protects the topsoil and groundwater and helps improve the condition of surface water resources. Acreage enrolled in the CRP is planted to resource-conserving vegetative covers, making the program a major contributor to increased wildlife populations in many parts of the country (USDA FSA 2003b). The CRP established permanent cover (grass or tree) on more than 14.5 million hectares of highly erodible land (Karlen et al. 1999; Taylor et al. 1994). The public cost for this program is estimated at about $1.8 billion a year (Wu et al. 1997; Hughes et al. 1995; Young et al. 1994). Removing of 33.9 million acres of cropland from agricultural production was estimated to lower agricultural output by about $191 million, and also reduces welfare because of the paid rent by about $195 million (Boyd et al. 1992). Ribaudo (1989) estimated the net profit from CRP land ranged from 3.4 to 11.0 billion dollars. Other studies show benefits range from 6 to 13.4 billion dollars, far short of its costs (Hughes et al. 1995). The program is estimated to have saved seven million tons of soil per year from erosion (DeVore 1994). Nationwide, average reductions in soil erosion are from a pre-CRP total of 29,700 cubic meters per acre to a post-CRP total of 1600 cubic meter/acre (94.60%) (Davie and Lant 1994). Lindstrom et al. (1994) claimed an average erosion reduction of 19,000 cubic meters per acre for lands enrolled in the CRP.

The CRP achieved desirable objectives, including 1) reduced sedimentation in water bodies, 2) reduced nonpoint-source pollution, 3) improved water quality, and 4) establishment of wildlife habitat (Kinsinger 1991; Huang et al. 1990, Young and Osborn 1990). The CRP has succeeded in reducing soil erosion in severely eroded lands after the establishment of permanent vegetative covers and development of a stable soil structure (Davie and Lant 1994; Lindstorm et al. 1994, 1999). Enrollment of highly erodible croplands in the CRP greatly reduced waterborne soil erosion (Davie and Lant 1994). In addition, CRP areas that are tilled are initially much less erodible than fields that were continuously cultivated using conventional techniques (Gilley and Doran 1998). Young and Osborn (1990) claimed that the CRP resulted in an average reduction of 17 tons per acre in soil loss, or a total reduction of about 800 million tons per year. Enrollment in the program had a positive effect on several soil quality indicators, physical, chemical and biological, especially if the management practices being used for crop production involved intensive tillage operations or the use of fallow periods (Gewin et al. 1999; Karlen et al. 1999). The program also enhanced the quality of soil physical and chemical properties such as air permeability and hydrologic conductivity (Baer et al. 2000; Gewin et al. 1999; Karlen et al. 1999; Lindstrom et al. 1994), and soil organic carbon (Bowman and Anderson 2002). Active nitrogen and carbon pools increased with long-term enrollment in the CRP (Baer et al. 2000).

Despite all, the effectiveness of the program has been questioned because of the large costs and extensive staff required to conduct the program (Wu et al. 1997). The program has been criticized for its cost ineffectiveness in achieving soil conservation goals (Young et al. 1994). Renewal of the program requires a large capital input, and causes significant impact on the agriculture, the environment and the economy. Therefore, it is important to quantify the benefits of the CRP in reducing soil erosion and to develop appropriate soil and crop management practices to maintain these benefits. Such evaluation will help the Farm Service Agency to select lands for future CRP enrollments. Furthermore, the Environmental Benefit Index (EBI) method is believed to be subjective. Offers for CRP are ranked according to this index, which represents factors based on the relative environmental benefits for the land offered (USDA Farm Service Agency 2003b)(more on this index is given in section 1.7). Calculations of the EBI are manually executed in a complex procedure. Therefore, manipulating large amounts of data and the complicated manual calculations of EBI is cumbersome and errors are inevitable. An automated evaluation method is needed to ensure the enrollment of the most susceptible land to erosion, minimize the time of EBI calculations and reduce the manual handling of spatial data. This automated method of CRP evaluation will also produce results that can assist in decision making regarding the continuation of the program.

## 1.5 GOAL STATEMENT AND OBJECTIVES

The primary goal of this research is to evaluate the potential environmental impact of the Conservation Reserve Program (CRP) in Texas County, Oklahoma. A related goal is to identify priority areas for future CRP enrollment. A geospatial database was developed to achieve the objectives of this research which include:

1. Evaluating the impacts of CRP on soil loss and water quality.
2. Determining the relative sources of sediments, nitrogen and phosphorus.
3. Delineating suitable areas for future CRP enrollment.
4. Evaluating the ecological benefits of CRP.

## 1.6 STUDY AREA

Texas County is located in the Panhandle of Oklahoma (Figure 1.1). Soil erosion rates in the county increased with increase in the land cultivated during the 1970s. Much of this cultivation was discontinued, and most of the land was retired and allowed to naturally restore itself to rangeland (Brooks and Emel 1995). The county ranks first in the state of Oklahoma for its enrollment in the Conservation Reserve Program. Studies showed that changes in land use and vegetative cover due to CRP altered the quality of soil and water (Baer et al. 2000; Wu et al. 1997). Texas County CRP acreage was estimated at 218,000 acres in July 2003, whereas the CRP acreage of Oklahoma in the same time period was about 1.02 million acres (USDA Farm Service Agency 2003a).

Texas County, in the central part of the panhandle of Oklahoma, is bounded by the state of Kansas on the north and the state of Texas on the south. Cimarron County, Oklahoma bounds Texas County from the west and Beaver County from the east. The county boundary lines form a rectangle 97 km long and 55 Km wide. Texas County lies within the sub-humid region of the Central Great Plains. Physiographically, it consists of a flat plain, of which approximately 25% has been dissected and eroded by the North Canadian River and its tributaries (Fitzpatrick and Boatright 1930). The county consists of gently undulating upland plains, eroded, rough breaks and narrow flood plains along streams (USDA Soil Conservation Service 1961).

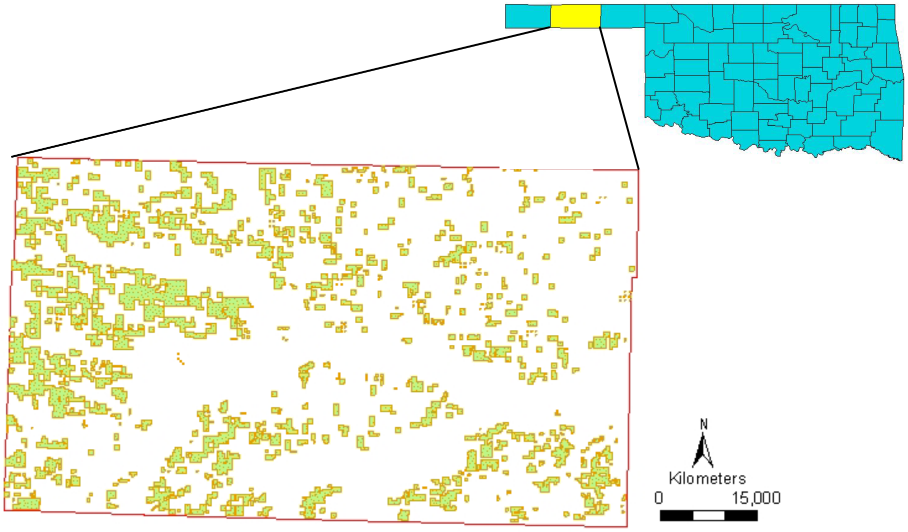

Figure 1.1: Spatial distribution of CRP tracts in Texas County, Oklahoma.

Geologically, the county consists of a Tertiary geological formation extending eastward from the Rocky Mountains. It is believed that rivers deposited this material during and immediately following the uplift of the Rockies. The plains have an elevation of approximately 1150 m above sea level along the western boundary of the county and slope very uniformly to the eastern boundary where the elevation is approximately 792 m (Figure 1.2). The drainage is controlled by the Beaver River, which flows northeastward from a point near the southwestern corner nearly to the center of the county, then eastward into Beaver County (USDA Soil Conservation Service 1961). The Beaver River's main tributaries are 1) Coldwater and 2) Palo Duro Creeks (Figure 1.2) (Fitzpatrick and Boatright 1930).

The climate of Texas County is semiarid and is subject to sudden changes in temperature. The average annual temperature is 13.2 °C and the average daily range in temperature is 0.6 °C. However, extreme high temperatures up to 40.5 °C might occur. The annual average relative humidity is 61%, and the average annual precipitation is about 432 mm. A very slight increase in the average annual rainfall occurs from northwest to southeast across the county (USDA Soil Conservation Service 1961; Fitzpatrick and Boatright 1930). Figure 1.3 is the soil map from the State Soil Geographic Database in Texas County represented by the State map unit identification number (MUID). More details on the soil map units are available in chapter three.

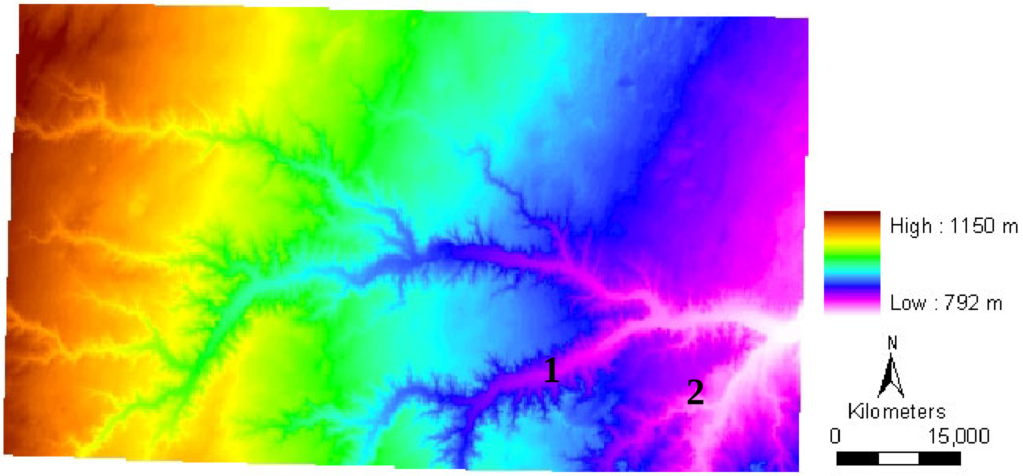

Figure 1.2: The digital elevation model of Texas County (1-Coldwater Creek, 2-Palo Duro Creek) (Source: USGS)

With very few exceptions the soils have developed from the Tertiary geological formation. This formation consists of beds of sands, clays, conglomerates, impure limestone, fine stratified sandstones, and various types of gravel. The predominant soil has been classified as members of the Richfield series (OK011) with 34.1% of the total soil surface area.

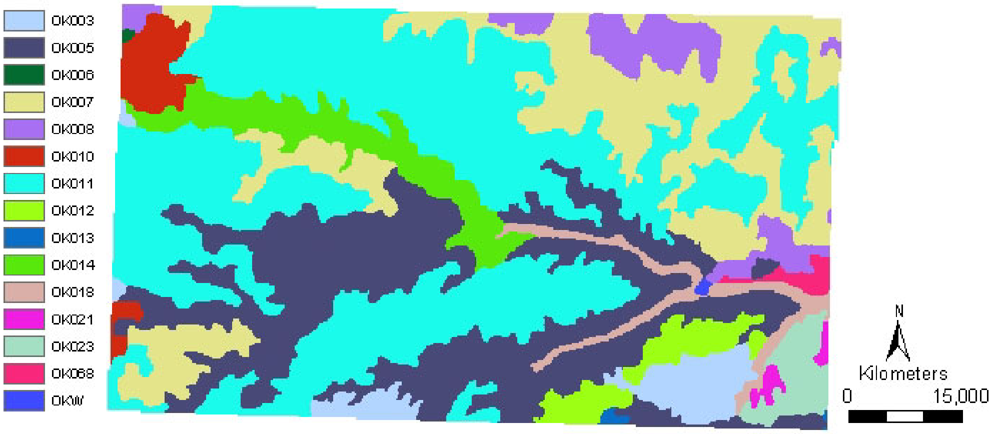

Figure 1.3: Soil types in Texas County (Source: USDA Natural Resources Conservation Service).

These soils may have at one time covered the entire county but have since been eroded along the stream valleys. The Richfield series consists of deep, dark clayey soils that are well drained. The surface soil (up to 15 cm) is silt loam or clay underlined by compact clay. The silty surface layer of soil is vulnerable to erosion more than the clayey subsurface layers. Other soil series include Dalhart series, Vona series, Ulysses series, and Berthoud series (USDA Soil Conservation Service 1961; Fitzpatrick and Boatright 1930).

Farming the land in Texas County goes back to 1880. The main crops were wheat, grain sorghum, and broomcorn. With the increasing prices of wheat more land was taken out of grass and put into wheat in the same period of introducing farming machinery. The conservation activities in Texas County date back to the 1940s. The cultivated acreage in 1954 was two-thirds of the agricultural land and the rest was in grass (USDA Soil Conservation Service 1961). Wheat and grain are the primary crops in Texas County today. Wheat is grown on heavy soils and sorghum is grown on sandy soils. The major crops grown in Texas County include (USDA National Agricultural Statistics Service 2002); all wheat (84,982 hectare), corn (34,398 hectare), sorghum (31,565 hectare), irrigated wheat (25,495 hectare), all hay (24,685 hectare), alfalfa (2,832 hectare), and soybean (1,416 hectare). The geographic distribution and proportions of major land covers are shown in Figures 1.4 and 1.5. Table 1.1 shows the proportions of land covers in Texas County and the Beaver River Watershed. In most places in Texas County, the soils require practices to minimize erosion and to maintain high fertility.

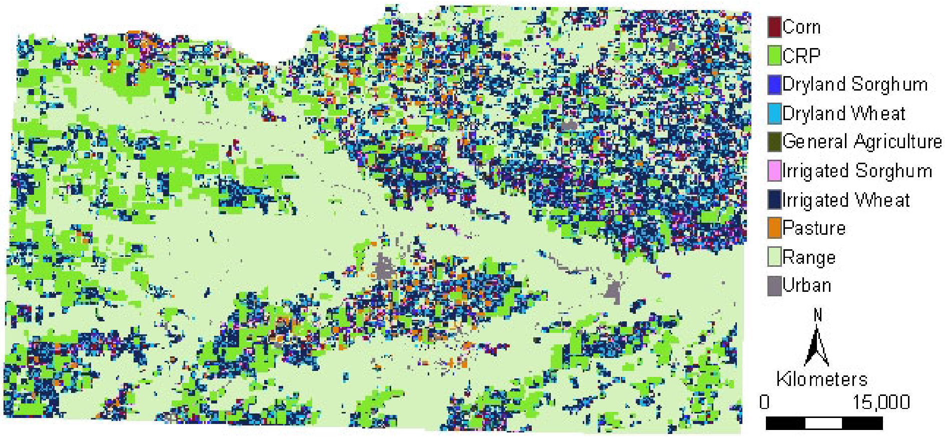

Figure 1.4: Land use land covers of Texas County within Bear River watershed (Source: USGS National Land Cover Database).

The most common practices adopted in Texas County include crop residue, crop rotation, stubble mulching, and contour farming (USDA Soil Conservation Service 1961). Rangelands are not suitable for cultivation and because of the overgrazing and drought periods, most of the rangelands are low in productivity (USDA Soil Conservation Service 1961).

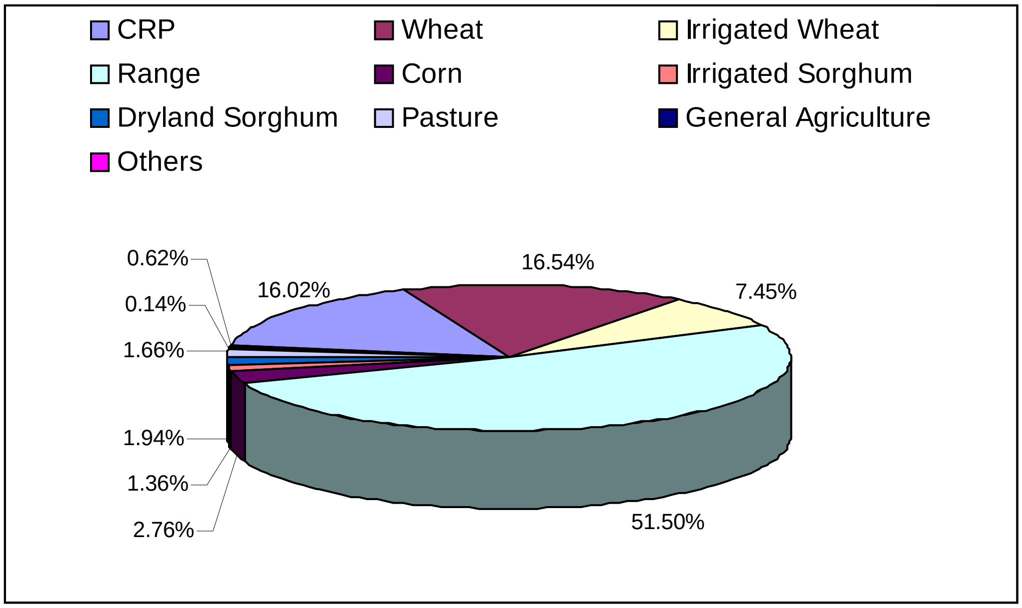

Figure 1.5: Pie-chart showing the proportions of each land cover in Texas County (Source: USDA National Agricultural Statistics Service 2002).

Texas County falls within the boundaries of the Beaver River Watershed (hydrologic unit 11100101), in the central high plains. More precisely, the watershed extends over four states Oklahoma, Kansas, Texas, and New Mexico (Figure 1.6). SWAT does not model areas bounded by political boundaries but by naturally delineated watersheds; otherwise calibration and outputs will not be valid. The boundaries of all subbasins in the watershed must be naturally delineated and not terminated by political boundaries (Texas County boundaries). Therefore, the whole watershed was modeled and fully calibrated. Since this research project focuses on evaluating the CRP in Texas County, the model outputs were clipped out for the county area only.

Table 1.1: The percentages of each land cover in Beaver River watershed and Texas County (Source: USDA National Agricultural Statistics Service 2002).

| Land cover | Watershed (%) | Texas (%) |
|---|---|---|
| CRP | 4.05 | 16.02 |
| Wheat | 18.44 | 16.54 |
| Irrigated Wheat | 8.28 | 7.44 |
| Range | 52.79 | 51.49 |
| Corn | 6.05 | 2.76 |
| Irrigated Sorghum | 2.99 | 1.36 |
| Dryland Sorghum | 4.26 | 1.94 |
| Pasture | 1.72 | 1.65 |
| General Agriculture | 0.58 | 0.14 |
| Others | 0.84 | 0.62 |

The watershed runs west-east. The main outlet, at subbasin number 52, is near Beaver City east of the watershed (Figure 1.6). The watershed lies within a semi-arid climate region with an average precipitation range between about 305 mm in Union County, New Mexico and 508 mm in Beaver County, Oklahoma (Oregon Climate

Service 2000). The minimum elevation in the watershed is 724 m and the maximum is 2654 m with more than 90% of the watershed area is less than 1435 m. There are 45 soil units defined by STATSGO in the watershed but 15 of them dominate the watershed with more than 80% of the total area.

The land use land cover of the watershed consists of five major categories: range 52.79%, irrigated wheat 8.28, dryland wheat 18.44%, irrigated sorghum 2.99%, dryland sorghum 4.26, corn 6.05%, pasture 1.72%, general agriculture 0.58 and CRP 4.05 (USDA National Agricultural Statistics Service 2002). General agriculture is defined as areas used for the production of crops that are temporarily barren or with sparse vegetative cover as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage. Other land covers including bare rock, quarries, wetlands, forest, etc composed less than 1%. These minor land covers were removed from the model after the hydrologic response units have been defined. Upon the HRUs definition, land covers with large area gain more.

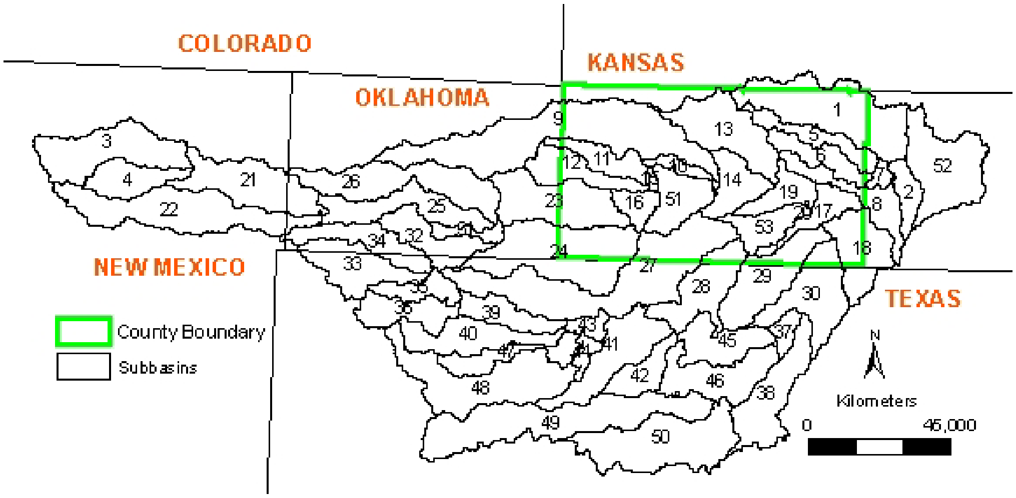

Figure 1.6: Location map of Beaver River Watershed.

Since Texas County is located in a semi-arid region it is worth discussing the different environmental characteristics of such areas. Agnew and Anderson (1992) summarized the definitions of drylands on different basis: climatic, geomorphic, biogeographic and pedologic. Climate in Texas County can be classified semi-arid according to the 1979 UNESCO classification scheme (Pilgrim et al. 1988). The UNESCO classification divisions were based on moisture indices, and other environmental parameters including soil, relief and vegetation. The four zones are:

| | |
|---|---|
| a. Hyper-arid | ($P/PET<0.03$) |
| b. Arid | ($0.03< P/PET<0.20$) |
| c. Semi-arid | ($0.2< P/PET<0.50$) |
| d. Subhumid | ($0.50< P/PET$) |

Where P is mean annual precipitation and ETP is potential evapotranspiration calculated using the Penman formula. Evaporation and evapotranspiration form the major water losses from the land surface due to the high temperatures, sparse vegetation and relatively high wind speed. Soil development is usually slower than the rates of soil erosion. Spatial variability of precipitation can dominate the water balance of large watersheds in dry climate regions (Arnold et al. 1998). Vegetation is sparsely distributed mainly in response to water availability. This low density of vegetation cover accelerates the processes of water and wind erosion of topsoil. Agricultural activities disturb the soil surface and make it more susceptible to both processes of erosion; water and wind.

The arid and semiarid climatic regions in the United States are characterized by large extremes in the hydrological components (Hernandez and Miller 2000) including:

a) low annual precipitation but high-intensity storms with significant spatial variability, b) high potential evaporation, c) low annual runoff but short-term high volume runoff, and d) runoff losses in ephemeral channels (Branson et al. 1981). Furthermore, these regions are susceptible to erosion. Therefore, hydrologic models must account adequately for these factors in assessing the impact of the environmental changes on the landscape (Hernandez and Miller 2000). Vegetation cover represents one of the most powerful factors influencing the runoff regime and consequently the transport of nutrients and soil removal. Semi-arid regions are characterized by unevenly distributed, seasonal and sporadic rain bursts that are mostly lost through surface runoff especially in high slope areas (El-Awar et al. 2001). Such rain events can be destructive and cause floods that may destroy lives and infrastructure. Most importantly, rainfall causes sever erosion in highlands and sediment accumulations in lowlands (El-Awar et al. 2001).

## 1.7 CRP ENROLLMENT

The conservation reserve program provides technical and financial assistance to eligible farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. The program provides assistance to farmers and ranchers in complying with Federal, State, and tribal environmental laws, and encourages environmental enhancement. The program is funded through the Commodity Credit Corporation (CCC). The USDA issued $1.6 billion in annual Conservation Reserve Program (CRP) payments to producers as annual rental payments earned for the fiscal year 2003. This amount of money does not include payments for 2 million acres enrolled under the most recent CRP sign-up 26, which was held from May 5 to June 13, 2003. Producers received an average of $47.62 per acre (USDA FSA 2003a).

The CRP is administered by the Farm Service Agency, with NRCS providing technical land eligibility determinations, Environmental Benefit Index Scoring, and conservation planning (USDA Natural Resources and Conservation Service 2002). The Commodity Credit Corporation (CCC) makes annual rental payments based on the agriculture rental value of the land, and it provides cost-share assistance for up to 50 percent of the participant's costs in establishing approved conservation practices (USDA NRCS 2002). In addition to NRCS, technical support functions are also provided by:

-USDA's Cooperative State Research, Education, and Extension Service;

-State forestry agencies;

-Local soil and water conservation districts; and

-Private sector providers of technical assistance.

To be eligible for placement in CRP, land must be either: 1) cropland (including field margins) that is planted or considered planted to an agricultural commodity four of the previous six crop years 1996 through 2001, and which is physically and legally capable of being planted in a normal manner to an agricultural commodity; or 2) marginal pasture land.

In addition to the eligible land requirements, cropland must meet one of the following criteria (USDA Farm Service Agency 2003b):

1. Have a weighted average erosion index of 8 or higher;

2. Expiring CRP acreage;

3. Water Bank Program acreage that expired 2000 through 2002, or

4. Located in a national or state CRP conservation priority area.

Also, the land must be eligible and suitable for any of the following conservation practices: riparian buffers, wildlife habitat buffers, wetland buffers, filter strips, wetland restoration, grass waterways, shelterbelts, living snow fences, contour grass strips, salt tolerant vegetation; and shallow water areas for wildlife. Land within an Environmental Protection Agency (EPA)-designated public wellhead area may also be eligible for enrollment on a continuous basis (USDA FSA 2003b).

Offers for CRP are ranked according to the Environmental Benefits Index (EBI). The Farm Service Agency collects data for each of the EBI factors based on the relative environmental benefits for the land offered. Each eligible offer is ranked in comparison to all other offers and selections made from that ranking. A decision on the EBI cutoff is made after the sign-up ends. Those who have met previous sign-up EBI thresholds are not guaranteed a contract under the following sign-up. Producers can avoid the highly competitive EBI process under the general sign-up by enrolling the most environmentally desirable land under CRP's continuous sign-up program. Under the continuous sign-up, relatively small amounts of land serving much larger areas, such as filter strips, riparian buffers and grass waterways, can be enrolled at any time (USDA Farm Service Agency 2003b).

CRP is a highly competitive program. While the U.S. has over 350 million acres of cropland, the maximum CRP enrollment authority is 39.2 million acres (USDA FSA

2003c). As such, the demand to enroll land in CRP is greater than the amount that FSA can accept. Eligible croplands are rated according to the (EBI) score. The EBI score has developed over time. The EBI for sign-up 26 (USDA FSA 2003b) is composed of six environmental factors:

- Wildlife habitat benefits resulting from covers on contract acreage;
- Water quality benefits from reduced erosion, runoff, and leaching;
- On-farm benefits from reduced erosion;
- Benefits that will likely endure beyond the contract period;
- Air quality benefits from reduced wind erosion; and
- Cost

Oklahoma enrollment in the CRP is ranked 11th in the nation. As of July 2003 there were 1,022,756 (34,117,275 statewide) acres enrolled in the program, and 218,304 acres in Texas County. In September 2003 35,929 acres were expired from the State's program compared to 668,887 acres nationwide. In the sign-up 26 (CRP enrollment number 26) 43,945 acres were accepted to be enrolled in the State's program compared to 1,995,189 acres nationwide. No new enrollments occurred for Texas County in the sign-up 26 (USDA Farm Service Agency 2003a).

# Chapter 2 DATA AND METHODS

A GIS-based modeling approach was adopted in this study to evaluate the soil erosion potential in CRP sites. Geospatial data pertaining to Texas County were collected and a GIS database was developed using ArcView and Arc GIS software.

Several preprocessing operations were performed on the GIS data. The data were georeferenced into the same coordinate system (Universal Transverse Mercator NAD83). The croplands in the National Land Cover Database map were broken down into more detailed categories (wheat, corn and sorghum) based on crop statistics. The CRP reference map was incorporated with the land use land cover to be used in modeling the soil erosion as the post CRP scenario. The weather data were downloaded from the National Climate Data Center and processed into the proper format for SWAT model.

The AVSWAT (ArcView SWAT) interface, an ArcView extension for SWAT model, generates model inputs from the available GIS data (Di Luzio et al. 2002a; Arnold et al. 1998). These data are processed within ArcView and converted to a form usable by the model. The data of elevation, soils and land use were used to generate the input files. Observed data for calibration process were incorporated. Use of basin scale model like SWAT needs great amount of time, skills and cost for acquiring input data, running the model and analyzing the results. Because watersheds significantly vary in space and time, GIS is an efficient method of collecting, storing and retrieving input data required for simulation models. Therefore, AVSWAT has been developed at the Blackland Research Center integrating the SWAT and ArcView along with Spatial Analyst. The export of data from GIS to SWAT model and the return of results for display are accomplished by

Avenue routines. Figure 2.1 is a flow chart showing the methodology adopted in evaluating the CRP in Texas County.

## 2.1 DATA

Extensive amounts of data were required to create the input files for modeling. Data necessary for this study included topographic information, land use information, soil data, climate records, agricultural management data and stream gage records. These data were obtained from public agencies including the USGS and County Extension Offices, and via personal communications. The data required to run SWAT are of two types: spatial and non-spatial. Table 2.1 shows the required GIS data and sources.

Table 2.1: Model input GIS data sources.

| Data | Resolution/scale | Source | Description |
|---|---|---|---|
| Digital elevation model (DEM) | 30 m | United States Geological Survey | Elevation |
| Land use (1992 NLCD) | 30 m | USGS-National Land Cover Database | Land use land cover categories |
| CRP map | 200 m | Natural Resources Conservation Service | The spatial distribution of the CRP sites in Texas County. |
| Soil (STATSGO) | 1:250000 | USDA-Natural Resources Conservation Service | Soil physical properties e.g. texture, bulk density, etc. |

### 2.1.1 Spatial data

A. Topographic data

Topographic data are required for delineation of the watershed and its subbasins and generation of other data. The United Sates Geological Survey (USGS) database known as Digital Elevation Model (DEM) describes the surface of the terrain as

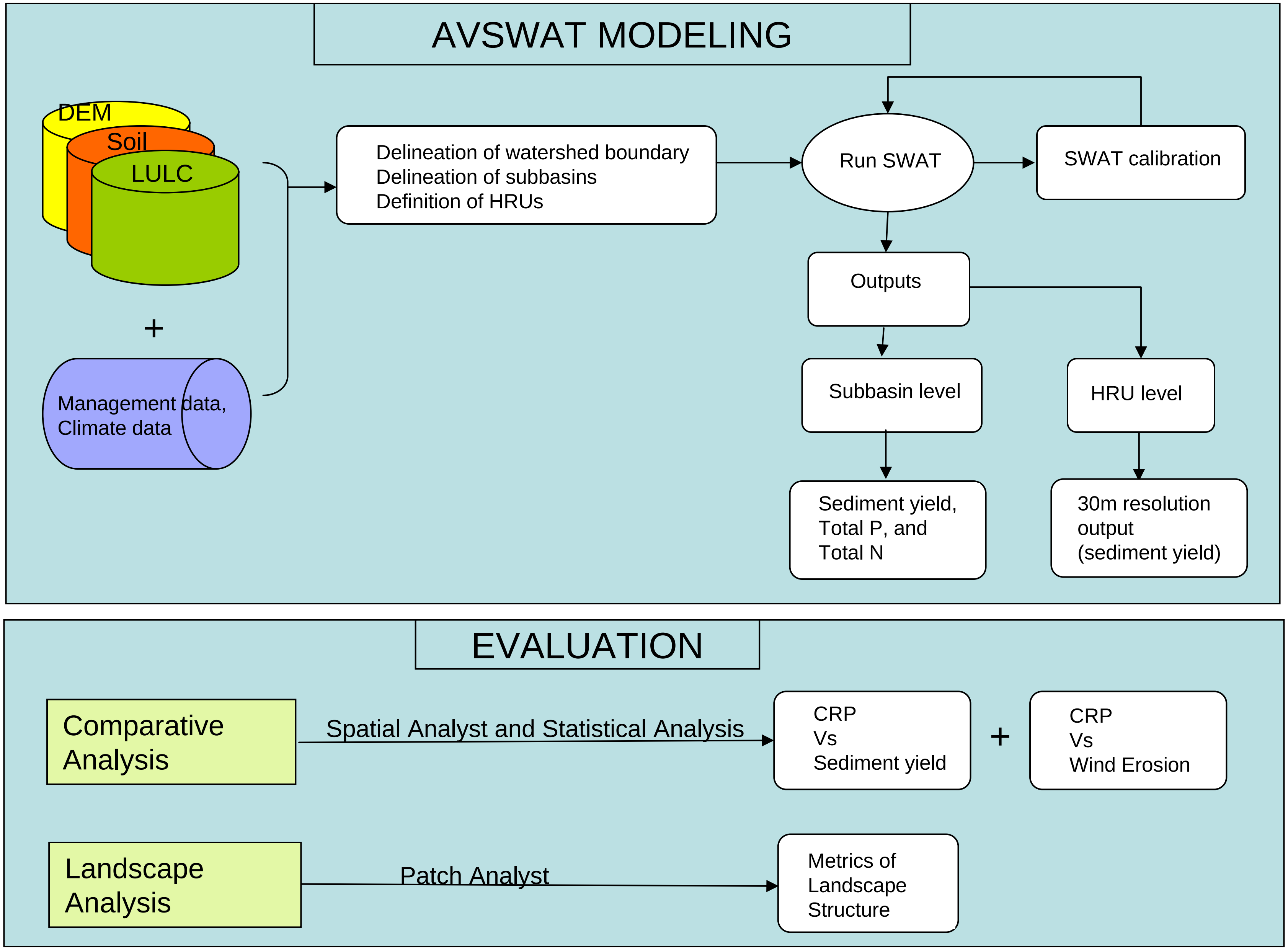

Figure 2.1: Flow chart of methodology used to evaluate CRP in Texas County.

a topographical database. DEM is a digital record of terrain elevations for ground positions at regularly spaced horizontal intervals that is derived from USGS maps. The digital elevation model is a fundamental input of spatially distributed models, such as SWAT. The DEM was used to define topography for SWAT. A DEM can provide the primary spatial information on elevation, slope and aspect of catchments in the modeling process. The high resolution of the DEM (30 m) allowed detailed delineation of sub-basins within the watershed. The DEM is also used to derive parameters such as slope and slope length factors used in the Modified Universal Soil Loss Equation (MUSLE). Since the Beaver River Basin is much bigger than Texas County the DEM was mosaicked from tens of USGS quads downloaded from the website www.mapmart.com. These DEMs were in different map units (foot and meter) and different resolutions (10 and 30 m). The DEM used in the study was 30 m resolution.

### B. Land use land cover (LULC)

Land cover is considered the most important GIS data used in SWAT because it can change spatially and temporally over a short time period. LULC affect surface erosion, water runoff, and ET (evapotranspiration) in a watershed. There is more than one source of LULC available to use. The least detailed and easiest data to use with SWAT is USGS LULC data (available at http://edc.usgs.gov/products/landcover/lulc.html). These data are available nationwide in 1:250,000 scale but no longer supported and maintained. Dates of the USGS LULC range from the late 1970s to the early 1980s. The second set of LULC is available from Gap Analysis Program (available at http://www.gap.uidaho.edu/About/Overview/GapDescription/default.htm#Products). It is available in 30 m resolution. The USGS and EPA (Environmental Protection Agency) have released 1992 NLCD (National Land Cover Database) nationwide in 30 m resolution. The latter set of data has been used in the SWAT model. The NLCD was derived from the early to mid-1990s Landsat Thematic Mapper satellite data. It is a 21-class land cover classification scheme applied consistently over the United States. The LULC categories are quite different from one set of data to another because the purpose of developing each is different.

Since this study is investigating the difference in soil loss pre- and post-CRP the land use land cover for the two time periods were required. The land cover map was enhanced by classifying broad land cover classes (row crop and small grains) into more detailed land covers; irrigated wheat, dryland wheat, irrigated, corn, sorghum, and dryland sorghum. The classification process was implemented in a GIS environment using spatial analyst based on the State's agricultural statistics. The area of each crop was obtained from the State's annual agricultural statistics. This map was used for modeling the watershed as the pre-CRP scenario. The CRP tracts mapped by the Natural Resources and Conservation Service were incorporated, using GIS spatial analyst, into the NLCD map and used as the post-CRP scenario. In other words, both scenarios are the same except for the CRP. This approach allows for determining the impacts of CRP on soil loss. Within the Beaver River Basin, the land use distribution is about 40% agriculture, 52.79% range, 1.72% pasture and 2% others. The proportion of each land use category is shown in table 2.2. USDA Statewide Agricultural Statistics were summarized for each county within the Beaver River Basin and used to proportion each crop type.

Table 2.2: Comparison of areal proportions of land use land covers between Beaver River watershed and Texas County.

| Land cover | Watershed (%) | Texas County (%) |
|---|---|---|
| CRP | 4.05 | 16.02 |
| Wheat | 18.44 | 16.54 |
| Irrigated Wheat | 8.28 | 7.44 |
| Range | 52.79 | 51.49 |
| Corn | 6.05 | 2.76 |
| Irrigated Sorghum | 2.99 | 1.36 |
| Dryland Sorghum | 4.26 | 1.94 |
| Pasture | 1.72 | 1.65 |
| General Agriculture | 0.58 | 0.14 |
| Others | 0.84 | 0.62 |

### C. Soil data

State Soil Geographic Database (STATSGO) is the only available GIS coverage for soils nationwide, which were developed by the Natural Resource Conservation Service (NRCS). STATSGO are the default soil data used with SWAT. The scale of this soil data is 1:250,000. Each map unit (association) consists of more than one soil series. Some STATSGO soils were made up of as many as twenty SSURGO soil series (USDA NRCS 1994). An associated Map Unit Interpretations Record (MUIR) database contains the properties and distribution of soils in each map unit. Information for each association is contained in a table that summarizes values for each soil series within that association. Relational soil physical properties include texture, bulk density, available water capacity, saturated conductivity, soil albedo, and organic carbon for up to ten soil layers. The soil series contains data on each unique soil layer. Data for each layer includes: depth of layer, depth of root zone, bulk density, available water capacity, organic carbon, clay content, sand content, USLE K factor, texture and other information. The soils database describes the surface and upper subsurface of a watershed and is used to determine a water budget for the soil profile, daily runoff, and erosion. The SWAT model uses information about each soil horizon e.g. thickness, texture, water holding capacity, etc.

SSURGO (Soil Survey Geographic Database) is far more detailed soil data that is not available for all areas in the United States. SSURGO is derived from the NRCS county-level soil survey, and is the most accurate soil data available (USDA SCS 1995). SSURGO is not available yet for Texas County. However, to use SSURGO in SWAT special processing and manipulations are needed before incorporating the data. Experts (Storm and White 2003) claimed no major differences on modeling soil loss using either soil data set. Another soil database is the Map Information Assembly and Display Systems (MIADS) data set developed by the Natural Resource Conservation Service. The categories are less detailed than those in the National Land Use Land Cover and the resolution is coarser (200 m).

In addition to the abovementioned spatial data, a digitized stream network of the watershed was used to help in delineation of subbasins. Its purpose was to help SWAT define stream locations correctly in flat topography.

### 2.1.2 Non-spatial data

SWAT model needs a variety of non-spatial data. Table 2.3 lists the data required non-spatial data and its format for SWAT (Di Luzio et al. 2002b).

Table 2.3: Tabular model input data.

| File description | Source (if applicable) |
|---|---|
| Location table for USGS stream flow gages | USGS |
| Location table for rain gages | NCDC |
| Precipitation data table | NCDC |
| Location table of temperature gages | NCDC |
| Temperature data tables | NCDC |
| Location of weather stations used to create custom generator data sets | NCDC |
| Subbasin outlet location table i.e. stream gauges location | USGS |
| Management data | County Extension Office |

A. Climate data:

SWAT can simulate weather data using a database of weather stations across the United States. But essentially rainfall and temperature data are important for calibration and more accurate outputs. Climate data were gathered from monitoring sites located within, or near, the Beaver River Watershed. Because of the spatial and temporal variability of precipitation, multiple climate stations with long period of records (40 years) were selected for this study. All of the stations used had time periods where data were missing. Big gaps in a station’s record were filled with data from the nearest station. In simpler cases a macro (see appendix) was used to estimate missing data. Each subbasin is assigned the nearest climate station. The weather data were obtained from the National Climate Data Center (NCDC). Figure 2.2 shows the weather stations used to simulate the weather data for SWAT. The climate stations include Boise City, Range, Clayton, Stratford, Spearman, Goodwell, Guymon, and Grenville.

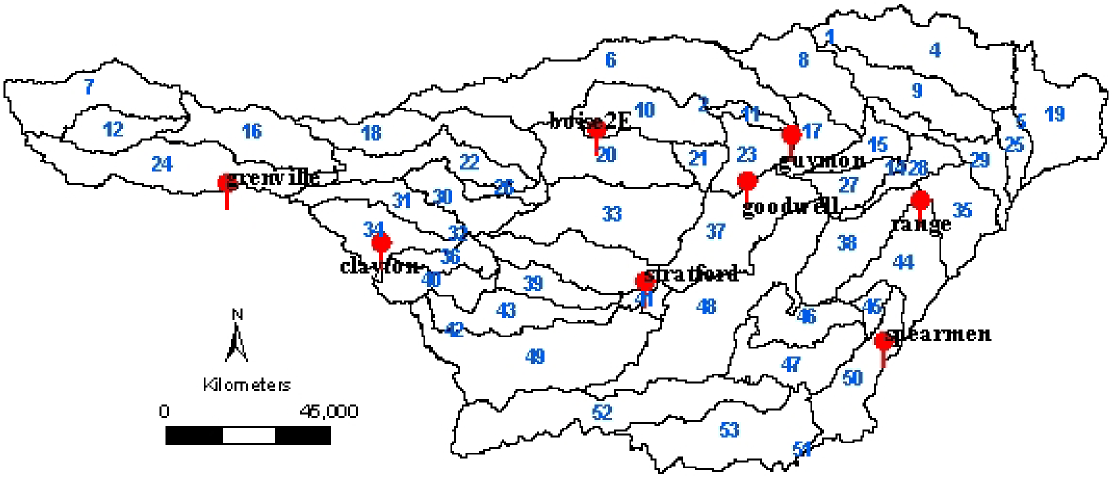

Figure 2.2: Climate stations used in SWAT modeling of Beaver River watershed.

B. Management data:

SWAT defines management practices as a series of individual operations. These operations can be defined by date or as a fraction of the total heat units required by the crop. The latter is the default. Heat units are predictor of harvest dates of crops. It is used by researchers for prediction of the timing of plant development stages such as flowering. SWAT requires a fraction of potential heat units to be specified. Fraction of potential heat units equal to heat units accumulated at a specific operation divided by potential heat units for the crop. Heat units are accumulated when the average daily temperature exceeds the base temperature of the crop. The base temperature is the minimum temperature required by the plant to grow. The amount of heat units accumulated each day is equal to the average daily temperature units minus the base temperature of the plant. Heat units do not accumulate until plant growth begins (White 2001). Management data include types of crops, tillage practices, fertilizer application, irrigation, dates of plantation and harvest. All management data were collected from six County Extension Agents in the area of the watershed. The counties are Beaver, Texas and Cimarron in Oklahoma, Union County in New Mexico, and Dallam, Hansford and Sherman in Texas. The default SWAT managements were used for all other land covers such as forest and urban. Management scenarios for each land cover are given in appendix.

Range and pasture were set up as a cattle grazing operation (Table 2.4). High grazing rates reduce land cover and expose ground to climatic conditions and therefore induce more soil loss. Grazing does not have a significant impact on soluble phosphorus loading (White 2001).

Table 2.4: Pasture/range grazing data.

| Parameter | Value |
|---|---|
| Stocking rate (AU/acre) | 0.067 |
| Cows with calves/ha | 0.14 |
| Biomass consumption (kg/day/ha) | 1.87 |
| Biomass trampled daily (kg/ha) | 1.87 |
| Manure deposited daily (kg/day) | 0.58 |
| CN for pasture/range | Fair |

Soil phosphorus content for agricultural areas were estimated using observed soil test data. Soil phosphorus content of unmanaged areas was based on SWAT computer simulation. County extension agents provided soil test data. Area weighted soil test phosphorus was calculated for each subbasin. Soil test phosphorus influence soluble and sediment-bound phosphorus loading. The purpose of STP is to estimate the amount of soil P available for crop production, and to make accurate fertilizer recommendations.

Table 2.5 shows the average STP (soil test phosphorus) by county. Sol_labp is the soluble P concentration in the surface layer (mg/kg). The default value of sol_labp is 20 mg/kg. Soluble P sets the amount of P in SWAT's various pools. If STP value represents both pools (sol_labp and sol_actp) then the STP = 2.5 sol_labp. The sol_actp is the amount of P stored in the active mineral phosphorus pool(kg P/ha).

Table 2.5: STP and labile P values for each county within the boundaries of Beaver River watershed in 2004 (Source: County Extension Offices).

| County | STP (lb/acre) | Labile P (mg/kg) |
|---|---|---|
| Beaver | 44 | 8.8 |
| Texas | 59 | 11.8 |
| Cimarron | 64 | 12.8 |
| Union | 50 | 10 |
| Dallam | 80 | 16 |
| Sherman | 75 | 15 |
| Hansford | 60 | 12 |

Mineral labile P in solution (mg/kg) = STP (lb/acre)/5. The STP is modified in the SWAT .chm file.

C. Observed data for calibration:

The first step in a traditional watershed model calibration is to break the measured stream flow time series into calibration and validation periods. In the calibration period, model inputs are allowed to vary across the basin until acceptable fit to measured flow at the basin outlet is obtained. The model is then run using the same input parameters for the validation period and goodness-to-fit is determined (Arnold et al. 2000).

The USGS maintains records for numerous gage and monitoring stations throughout the country. Two gage stations within the Beaver River Basin were identified for this study: Guymon gage station near Guymon and Beaver River near Beaver (Figure 2.3). Data for these gages were obtained via the USGS website. Stream gage data for Guymon gage station (1980 to 1992) and for Beaver River gage station (1989 to 1999) were used for calibration and validation. For the simulations, actual weather data from 1960-1998 were used.

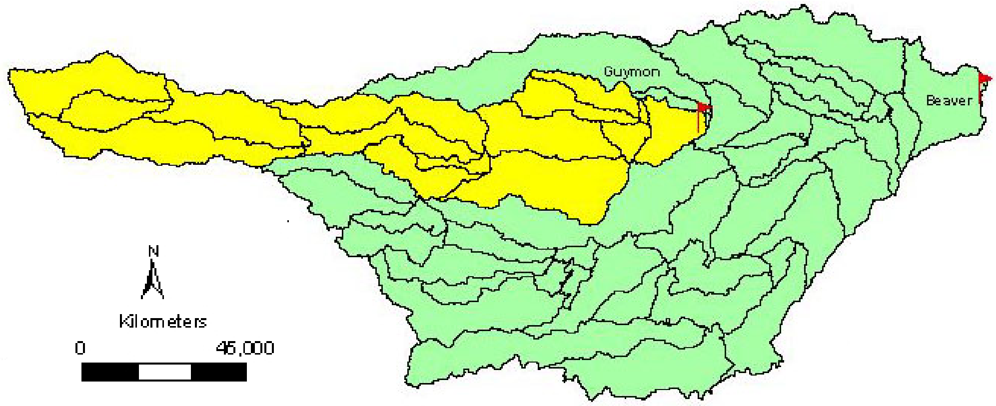

Figure 2.3: USGS gage stations used for calibrating SWAT model.

## 2.2 SWAT MODEL

SWAT is a watershed scale model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds over long periods of time. SWAT is a physically based model that uses readily available input data (Di Luzio et al. 2002b) and is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without an excessive investment of time or money. The model has been validated for numerous basins throughout the U.S. (Arnold et al. 1999) and has been applied worldwide.

A single subbasin can be divided into areas with the same soils and land use. Areas with a unique soil and land use combination are defined as Hydrologic Response Units (HRU). The derivation of HRUs is based either on the dominant land use category and soil type in the subbasin or on a predetermined threshold for both variables. In the first approach, one HRU is created for each subbasin, because only the dominant soil type and dominant land use land cover were considered. The second approach creates multiple HRUs within the same subbasin because more than one soil type and more than one land cover are captured. Subdividing the watershed into HRUs enables the model to reflect differences in hydrologic conditions for different land covers and soils. This increases the accuracy of variables of prediction. Processes within an HRU are calculated independently, and the aggregated total for a subbasin is the sum of all the HRUs it contains. Runoff, for example, is predicted separately for each HRU and routed to obtain the total runoff for the watershed. Erosion and sediment yield is estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). While the USLE uses rainfall as an indicator of erosive energy, MUSLE uses the amount of runoff to simulate erosion and sediment yield. SWAT allows the user to define management practices taking place in every HRU. The user may define the beginning and the ending of the growing season, specify timing and amounts of fertilizer, pesticide and irrigation applications as well as timing of tillage operations. At the end of the growing season, the biomass may be removed from the HRU as yield or placed on the surface as residue. There is no limit to the number of years of different management operations specified in a rotation, a change in management practices from one year to the next.

The climate of a watershed provides the moisture and energy inputs, which control the water balance and determine the relative importance of the different components of the hydrologic cycle. The climatic variables required by SWAT consist of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. The model allows values for daily precipitation and maximum/minimum air temperatures to be input from records of observed data or generated during the simulation. The model always generates solar radiation, wind speed and relative humidity.

## 2.3 SIMULATION PROCEDURE

### 2.3.1 Data Preparation

The first task was to have all GIS data in the same coordinate system. This will allow all layers be overlaid for future operations. Each of the data sets (DEM, LULC, soil, streams, and boundaries) was projected into the Universal Transverse Mercator system with the North American Datum of 1983 (UTM83). The complete specifications of the coordinate system are found in table 2.6.

The DEM for the watershed was mosaicked from USGS quads downloaded via the Internet. State Soil Geographic Database (STATSGO) for the watershed was downloaded also from USGS website. Since the watershed extends over four States: Kansas, Oklahoma, Texas and New Mexico, STATSGO of the four States were merged and clipped to the watershed boundary and re-projected into the above mentioned coordinate system. The National Land Use Land Cover also was available from the USGS website. And it was mosaicked and clipped in Arc GIS. This layer was further classified into the different crop types that grow in the watershed. The weather data were processed in *Excel* spreadsheet to conform to the format used by SWAT.

Table 2.6: Coordinate system specifications.

| Projection | UTM |
|---|---|
| Zone | 14 |
| Datum | NAD83 |
| Reference latitude | 00 |
| Central meridian | -99 |
| False easting | 500,000 |
| False northing | 0 |
| Spheroid | GRS1980 |
| Scale factor | 0.9996 |

In AVSWAT the slope for HRUs are assumed to be the same within the subbasin. On the ground different land use covers tend to locate on different slopes. Forests, for example, occupy areas of steep slopes while agricultural lands tend to occupy flatter surfaces. To enhance the predictions from SWAT model the slope of each land use land cover has been incorporated into the model. Soil phosphorus test data were also included into the model.

### 2.3.2 Watershed Delineation

Watershed delineation was performed using the AVSWAT interface. The 30 m DEM was imported in AVSWAT. The stream network layer also was imported and draped over the DEM to maintain flow paths. Next, internally drained areas were identified within the DEM and filled to prevent any unwanted holes. This process took a long time because of the size and resolution of the DEM. Internally drained depressions (sinks) are groups of cells of equal elevations in which all neighboring cells are higher in elevation. GIS is able to determine flow direction and networks by comparing elevations of the DEM. Sinks are problematic because they create disjointed streams.  ArcView and Arc Info have functions to remove these sinks. The next step in the process was defining the stream network, which uses the accumulation grid to set up the paths. Setting a threshold area sets the amount of water that accumulates in the grid, and then defines the stream. Then the outlets are defined at every stream intersection. Because model output is only available at subbasin outlets, additional outlets were added at points of interest such as gage stations.

AVSWAT then delineates watershed boundary based on flow accumulation and a user specified threshold value (minimum size). The appropriate level of subdividing a watershed is difficult to determine. A broad characterization can be provided by using the subdivision level that is similar to the digitized stream network defined from USGS 7.5-min quadrangles as a minimal subdivision level (Bingner et al.1997). Mamillapalli et al. (1996) showed that as the number of subbasins increases better accuracy is obtained. However, they do not specify the best threshold area that gives the desired accuracy. Jha et al. (2002) recommended a 3% threshold area of the watershed total area to better predict sediment yield. This latter approach has produced 53 subbasins for Beaver River watershed. Figure 2.4 shows the spatial distribution of the watershed subbasins.

Once the watershed boundary was delineated, automated routines within AVSWAT were used to generate stream and hydrologic characteristics. AVSWAT generated the average slope and slope length for each subbasin from the DEM. Flow path and channel characteristics were also calculated.

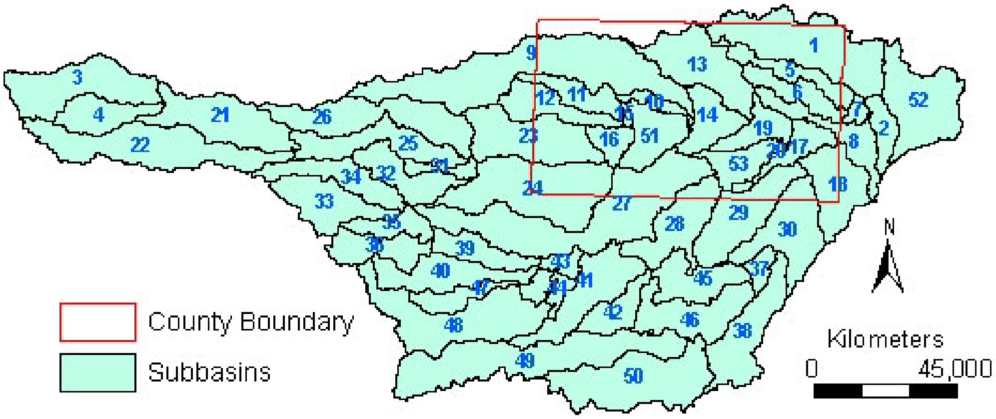

Figure 2.4: Subbasins of the Beaver River watershed.

### 2.3.3 HRU Definition

The STATSGO soil GIS layer and LULC were clipped with the delineated watershed boundary using ArcView. Soil data (STATSGO) and the land use land cover were linked to the model database. The two sets of data were overlaid to produce the hydrologic response units. Once the operation of overlay was completed, the AVSWAT tool was used to compute the HRUs for each of the subbasin. The land use and soil thresholds were set to 1% and 5% respectively. These thresholds defined 1,027 hydrologic response units. These thresholds determine the minimum percentage of any land cover and soil in a subbasin that will compose an HRU. A higher number of HRUs in a subbasin allows the model to capture more spatial detail. The area of HRUs ranged between 0.03-434.13 km$^2$ with an average of 24.16 km$^2$. This range indicates significant variability in the area. Figure 2.5 shows the area of HRUs in the watershed.

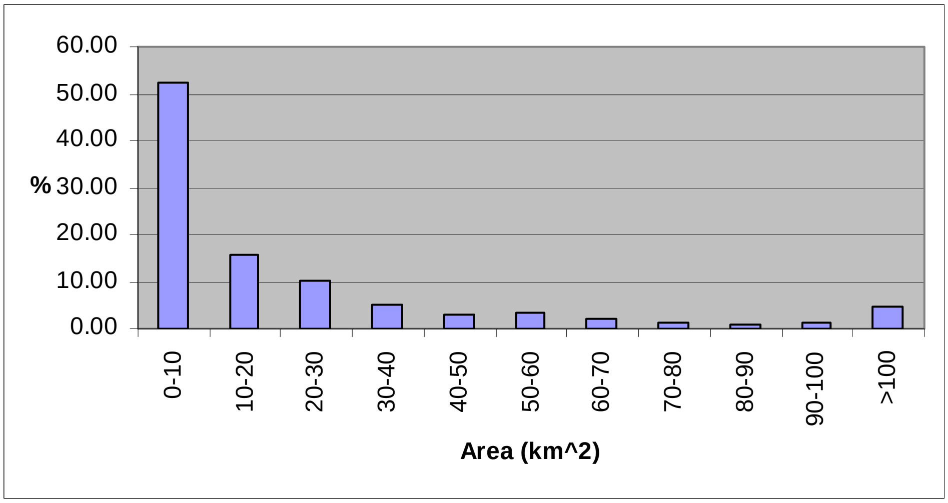

Figure 2.5: Histogram of hydrologic response units (HRU) sizes in Beaver River watershed.

### 2.3.4 Calibration

The Beaver River Watershed was calibrated using data from two stream gages; Guymon gage station and Beaver River near Beaver. These gages were used to calibrate the hydrologic component of the model. The USGS HYSEP sliding interval method (Sloto and Crouse 1996) was used to separate the baseflow from the surface runoff. Three methods were used for evaluating the model predictions during calibration period:

a. Relative error: RE= [(Predicted-Observed)/Observed]*100

b. Linear regression: regression line slopes and R square values near unity indicate a close relationship between predicted and measured yields.

c. The Nash-Sutcliffe coefficient of Efficiency (COE): the COE measures the comparison of the actual fit to the line of perfect fit (the 1:1 line) and measures how well the measured and simulated flows correspond. Negative COE values indicate that the predicted value is less than the arithmetic mean of the data set. More details on calibration are found in chapter 3.

## 2.4 FUTURE CRP ENROLLMENTS

A combination of GIS input data and predictions of SWAT were used to map the hot spots for future enrollment in the CRP. SWAT predicts sediment yield on hydrological response units (HRU) within each subbasin. Sediment yield from HRUs is adjusted to slope from GIS data. Cells with sediment yield greater than 10 tons/acre/year were considered priority areas for soil conservation and must enroll in the CRP.

## 2.5 STATISTICAL AND SPATIAL ANALYSIS

Statistical analyses data were derived from the various levels of outputs derived by SWAT (subbasin level, HRU level, and cell level). The main goal of the analyses was to find the relationship between sediment yield and land cover (CRP), soil type and slope. Interrelationships between land covers, soil types and slopes were also determined. Both scenarios pre- and post-CRP were statistically analyzed and quantitative association of CRP and sediment yield was calculated using the subbasins level data.

## 2.6 WIND EROSION

Wind erosion analysis was carried out using the equation of wind erodibility index. Data of wind erosion were obtained from the SSURGO database. The relationship between CRP and wind erosion was analyzed using spatial analyst in Arc GIS. The wind erodibility index (WEI) was calculated using the formula:

$$\text{Wind Erodibility Index} = C*I/T$$

C: wind erosion factor,
I: soil erodibility index
T: soil loss tolerance

## 2.7 PATCH ANALYSIS

The ArcView extension Patch Analyst was used to determine the changes in landscape structure due to the introduction of CRP in Texas County. Different metrics of landscape structure were measured pre- and post-CRP in Texas County. These metrics were analyzed in the light of creating better wildlife habitat in Texas County.

## 2.8 ASSUMPTIONS AND LIMITATIONS

Model limitation may be the result of data used in the model, model inadequacies, or using the model in situations for which it was not developed. It should be stated that the uncertainty in modeling nonpoint sources of sediment and agricultural nutrients is high relative to the point source modeling. The erosion of sediment and agricultural chemicals is influenced by both spatial and temporal variability. This is due in part to the error and uncertainty in spatial/temporal databases, which arises from both the characterization and measurement of natural events. Errors in the modeling process, in terms of parameter estimates and representation of properties and processes, further contribute to uncertainty. This uncertainty implies that modeling results need to have limitations placed on the conclusions that are derived. However, the main modeling limitations pertaining to this work include:

1. Weather is the driving force for hydrologic models. Few weather stations are used in modeling. These data are applied at a very large watershed. These stations may not represent the entire area, which may reflect on the model predictions. Rainfall can be quite variable, especially in the spring and summer when convective thunderstorms produce precipitation with a high degree of spatial variability. It may rain heavily at a

weather station, but be dry a short distance away. This limitation, among others, cautions us against using model output on daily or monthly basis.

2. The soil data used by the SWAT model is very generic. The STATSGO database is a very general classification of soil types.

3. Some land covers are not represented in the model. This is due to the removal of minor land covers when deriving the HRUs (1% threshold).

4. A single management scenario was applied uniformly to each particular land cover. Simulations assume that every land cover is managed exactly the same all over the watershed. However, management may vary by field, not by crop as was assumed. The amount of fertilizer applied, for example, varies from one place to another, especially in such a large watershed. Unfortunately, SWAT cannot handle different scenarios within the same model.

5. All HRUs within the same subbasin are assumed to be identical except their land cover soil types.

6. The runoff data must be separated into base flow and stream flow, by ancillary techniques outside the SWAT model.

7. It is difficult to determine the amount of sediment eroded from the streambed. Therefore, it is assumed that all sediments delivered out of the watershed are from hillslopes.

8. No single point sources were included in the model due to lack of required data for modeling. Potential point sources include animal feedlots and hog farms. Data from these point sources could be significant.

9. There are cases where CRP tracts are still in use for crop production. In other cases CRP tracts are enrolled although they do not meet the CRP enrollment criteria. These practices lead to underestimation of the CRP advantages and limit the benefits of the program.

10. GIS extensions (e.g. Xtools, spatial tools, etc) are necessary to help AVSWAT accomplish the process of simulation properly.

11. The computer used for this project limited delineating of higher number of subbaisns (more than 53). The model operations would be more time-consuming if the delineated number of subbaisns were higher. However, the thresholds for the land use land cover and soil were set to low levels (1% and 5% respectively) in order to compensate for the low number of subbasins.

# Chapter 3 RESULTS AND DISCUSSION

This chapter presents SWAT model calibration and data analysis. Outputs of sediment yield, phosphorus and nitrogen from AVSWAT were processed, analyzed and discussed. Statistical analyses were conducted to quantify the relationship between sediment yield and different factors that govern soil loss (land use land cover, soil, and slope). The relationship of CRP with wind erosion was addressed based on data from the SSURG database. In addition, the impact of CRP on landscape structure was determined by measuring different landscape metrics in GIS.

## 3.1. HYDROLOGIC CALIBRATION

### 3.1.1 Introduction

In general, the object of calibration is to minimize the difference between observed and simulated data. The act of calibration standardizes a model and improves its accuracy. Calibration is a process by which model parameters are adjusted to more accurately simulate observed data. Many models are developed for specific environmental conditions and are, by definition, calibrated to those conditions. Such models usually are not useful outside of their particular environment. Calibration is in a sense customizing a generic model. During calibration, the tunable parameters are adjusted so that the model fits available data. This is typically performed manually by increasing or decreasing parameter values, running the model, and analyzing the errors (Santhi et al. 2001; Peterson and Hamlett 1997). After calibration, the model must be validated against observed data (i.e. comparing outputs from calibrated model with observed data from the same period of time). Validation is a confirmation that the model is predicting values similar to observed data.

The SWAT model was developed to be applicable over a wide range of environmental conditions in the United States (Arnold et al. 1999). However, differences exist in site conditions that cannot be accounted for in any model. Therefore, calibration of the SWAT model is needed to minimize uncertainty.

The parameters that can be adjusted for hydrologic calibration include:

A. Surface runoff:

1. The curve number (CN2 in management file):

The curve number is used in a runoff rating curve developed by the USDA-NRCS to specify the amount of runoff that occurs due to rainfall, based on vegetation and surface soil. The higher the curve number, the more the runoff. The curve number can be adjusted for each land cover in the database. The management file has to be re-written every time the CN is adjusted before running the model.

2. The soil available water capacity (SOL_AWC in soil file):

This factor specifies the fraction of water stored in soil lost back to the atmosphere. Increasing the AWC will reduce the surface runoff, but can add to the baseflow. The AWC can not be adjusted by more than 0.04.

3. The soil evaporation compensation factor (ESCO in basin or hydrologic response unit file):

This factor specifies whether the deeper soil layers should be weighted to control soil water evaporation. The range is 0.01-1.0, and the default value is 0.95. ESCO is adjusted in dry climates to reflect more moisture storage in deeper soil layers. As the ESCO is reduced the model is able to extract more of the evaporative demand from lower levels.

B. Baseflow:

1. The shallow aquifer re-evaporation (Revap) coefficient (GW_REVAP in groundwater file):

It is the movement of water from the shallow aquifer to the overlying unsaturated zone (root zone). The higher the value of GW_REVAP, the lower the baseflow.

2. Shallow aquifer storage for re-evaporation (REVAPMN in groundwater file):

The threshold depth of water in the shallow aquifer for “revap” to occur (i.e. deep percolation loss). If reduced, it decreases the surface runoff. The min value is 0. The higher the value of REVAPMN the higher the baseflow.

3. Shallow aquifer storage for groundwater flow (GWQMN in groundwater file):

The threshold depth of water in the shallow aquifer required for return flow to occur. The lower the value is the higher the base flow.

Table 3.1 shows how much each hydrologic component is sensitive to changes in the abovementioned parameters. Surface flow, for example, is highly sensitive to changes in values of curve number and available water capacity. On the other hand, baseflow has low sensitivity to the same parameters but high sensitivity to other parameters such as shallow aquifer storage for groundwater flow.

Table 3.1: Sensitivity of SWAT parameters.

| Parameter | Total flow | Surface flow | Base flow |
|---|---|---|---|
| Curve number | High | High | Low |
| Soil available water capacity | High | High | Low |
| Shallow aquifer re-evaporation coefficient | Medium | Low | High |
| Shallow aquifer storage for re-evaporation | Medium | Low | High |
| Shallow aquifer storage for groundwater flow | Medium | Low | High |

### 3.1.2 Baseflow Separation:

Stream flow is composed of two main sources, surface runoff and groundwater. The latter is known as baseflow. For this study the SWAT model was calibrated for observed surface runoff and baseflow. The data from the U.S. Geologic Survey gage stations represent the stream total flow. The USGS HYSEP sliding interval method (Sloto and Crouse 1996) was used to separate the baseflow from the surface run off. The duration of surface runoff is calculated using the formula:

$$N = A^{0.2}$$

Where N is the number of days after which surface runoff ceases and A is the drainage area in square miles. The interval 2N used for hydrological separations is the odd integer between 3 and 11 nearest to 2N. This interval was adjusted to provide acceptable baseflow values. The sliding-interval method assigns the minimum value of stream flow measurements within the selected interval for the day being considered. The discharge at that point is assigned to the median day in the interval. The process continues for all days in the record as the interval moves along (in parallel). The results indicate that approximately 12.5% of the flow is baseflow according to the data from the Guymon gage station, while is approximately 27% according to data from the Beaver River gage station. Figure 3.1 is an example of baseflow separation.

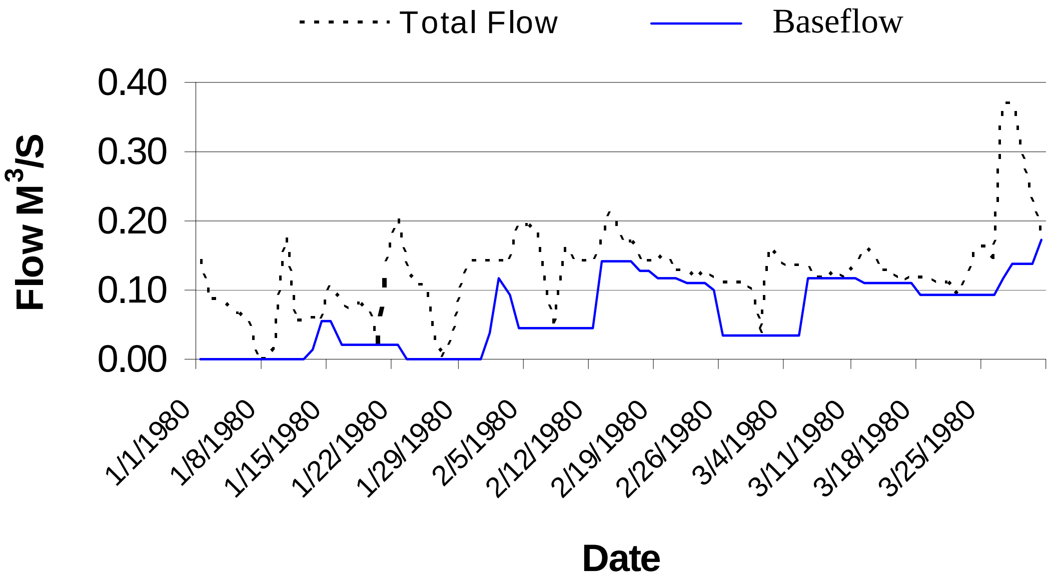

Figure 3.1: Example of baseflow separation in Guymon gage station.

### 3.1.3 Observed Stream Flow and Calibration

The SWAT model was calibrated for Beaver River Basin using observed stream data from two USGS gage stations: Guymon gage station and Beaver River gage station (Figure 3.2). These gages were used to calibrate the hydrologic component of the model. Each gage station has a different period of record (Table 3.2). The model was calibrated for total flow, surface flow and baseflow. Because the purpose of this study is to estimate soil loss, more emphasis was put on calibrating the surface runoff than other types of flow. The surface runoff is the main factor in soil erosion; moreover the contribution of the groundwater in the study area to the stream flow is very small.

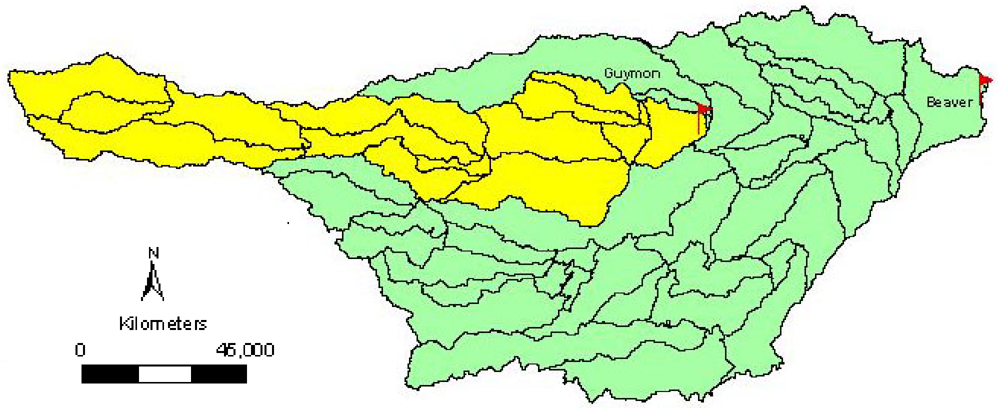

Figure 3.2: USGS stream gage stations used to calibrate the SWAT model (subbasins in yellow are upstream Guymon gage station).

Table 3.2: Period of record at USGS stream gage stations used to calibrate the SWAT model.

| Name of gage station | USGS stream gage number | Time period |
|---|---|---|
| Guymon near Guymon | 07232900 | 1980-1992 |
| Beaver River near Beaver | 07234000 | 1989-1999 |

### 3.1.4 Model Calibration

There are several statistical measures that can be used to assess goodness of fit of a given model and to compare the performance of a suite of models. These statistical measures are used as indicators of the extent to which model predictions match observation. There are two main categories of goodness of fit measures (StatSoft 2004), which are (a) residual-based, and (b) statistical association-based. Residual-based measures such as the mean bias, the sum of square errors, mean of square errors, and root mean square errors provide quantitative estimates of the deviation of model predictions from observations. On the other hand, measures of statistical association such as the correlation coefficient (*r*), the Nash-Sutcliffe coefficient of efficiency (*COE*) and the coefficient of determination ($R^2$) provide quantitative estimates of the statistical covariation**.** Three methods were used to evaluate the performance of SWAT model:

A. Relative error

Relative error is a measure of a model's ability to simulate a measured value such as surface runoff. With this technique the lower the relative error, the better the fit, with zero representing perfect simulation of observed data.

Relative error % = [(observed – simulated)/ observed]*100

B. Linear regression ($R^2$)

The value is an indicator of strength of relationship between the observed and simulated values. Regression line slopes and $R^2$ values near unity indicate a close relationship between predicted and measured yields.

C. The Nash-Sutcliffe Coefficient of Efficiency (COE)

The COE (Nash and Sutcliffe 1971) measures the comparison of the actual fit to the line of perfect fit (the 1:1 line) and measures how well the measured and simulated flows correspond. COE indicates the model's ability to describe the probability distribution of the observed results. Negative COE values indicate that the predicted value is less than the arithmetic mean of the data set.

$$COE = 1 - [(\sum(O-P)^2/\sum(O-O_{av})^2], \text{ where}$$

O is the observed value

P is the predicted value

$O_{av}$ is the average of observed value

D. Graphical methods

Graphical methods used in conjunction with statistical measures can aid in assessing model performance. Time series plots of measured and simulated data are used to assess model performance.

$R^2$ values tend to be higher than Nash-Sutcliffe values. $R^2$ and COE provide a better indication of the accuracy of the predicted to measured values than the relative error. If the simulated surface runoff is within 15% of the observed surface runoff then the relative error is acceptable. However, higher relative errors were reported in many studies. If COE and $R^2$ are greater than 0.50 and 0.60 then the statistical measures are acceptable and simulated values are valid (Santhi et al. 2001).

Bednarz (2000) found that measured and predicted total monthly flows compare reasonably well with $R^2$ range between 0.44 and 0.49. Others calibrated SWAT models to $R^2$ of 0.65 (Arnold et al., 2000), 0.55 (Peterson and Hamlett, 1997) and COE of 0.58 (Spruill et al. 2000).

## Beaver River near Beaver

This gage station is located at the main outlet of the watershed. The record (1989-1999) from this station was split into two periods. The time period 1989-94 was used for calibration and the time period 1995-1999 was used for validation.

Gage data:

| | |
|---|---|
| Location: | Beaver River at Beaver, OK (USGS 07234000) |
| Hydrologic Unit Code: | 11100102 |
| Latitude: | 36°49'20" |
| Longitude: | 100°31'08" |

Adjustments to several parameters were necessary to calibrate the model. The curve number (CN), SOL_AWC, ESCO and other groundwater parameters were adjusted to match observed data with predicted data (Table 3.3). Measured and predicted average monthly flows compare reasonably well with 12% and 10% difference for total and surface runoff respectively (Table 3.4). SWAT over prediction of flow is most probably due to spatial variability of rainfall which was not reflected in measured weather data. Figures 3.3 shows the SWAT model predicted stream flows plotted against observed flows. $R^2$, which indicates how well predictions match against observations, was estimated at 0.61. The calibration data set produced COE of 0.55. Figure 3.4 shows a reasonable visual agreement between observed and predicted flows. The relative errors of stream, surface and baseflow for the validation period are given in table 3.4. Model validation for the period (1995-99) produced relative errors of 3% and 12% for the total stream flow and surface runoff. The validation data set produced $R^2$ equal to 0.66 and COE of 0.53 for the monthly total stream flow and 0.68 $R^2$ and 0.58 CEO for the surface runoff.

Table 3.3: SWAT input variables for Beaver River Watershed (Beaver River gage station).

| Variable | Calibration value |
|---|---|
| CN | -4 |
| Soil Available Water capacity Adjustment (%) | 0.20 |
| Soil Evaporation Compensation Factor (ESCO) | 0.80 |
| Minimum shallow Aquifer Storage for GW flows (GWQMN) | 50mm |
| Min. shallow Aquifer Storage for Re-evaporation (inches) (REVAPMN) | 0.30 |
| Shallow Aquifer Re-evaporation Coefficient (GW_REVAP) | 0.40 |

Table 3.4: Beaver River (USGS stream gage 07234000) calibration average monthly flow and relative differences (all units are in $m^3/s$).

| | Calibration (1989-1994) | Validation (1995-1999) |
|---|---|---|
| | Relative error % | Relative error % |
| Flow | 12 | 3 |
| Surface runoff | 10 | 12 |
| Base flow | 0 | 15 |

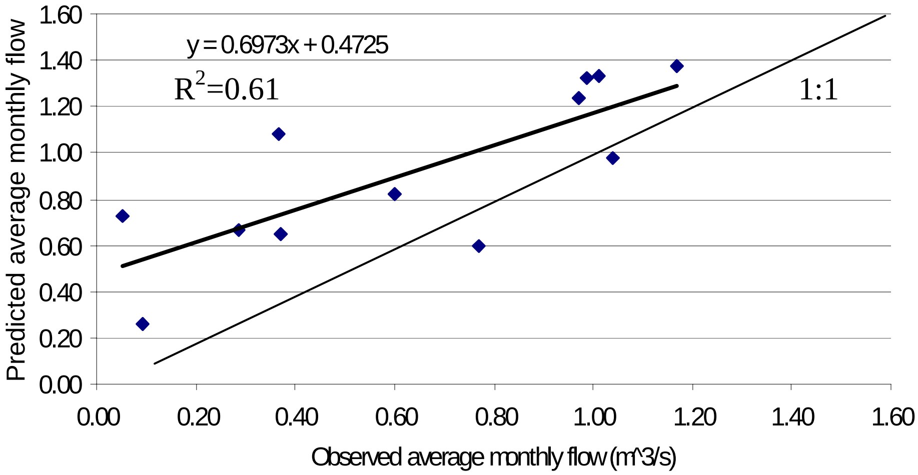

Figure 3.3: Beaver River observed vs predicted average monthly stream flow (Beaver gage station 1989-1994).

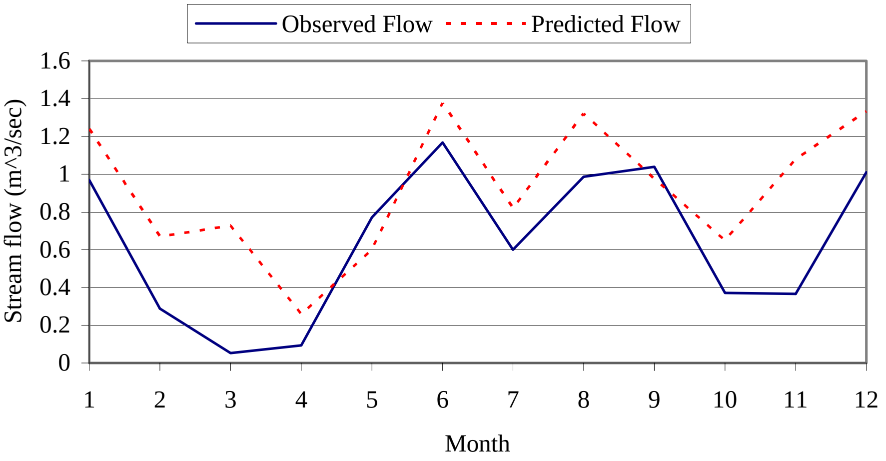

Figure 3.4: Stream flow (time-series) of predicted and observed average monthly data from Beaver River gage station (1989-1994).

## Guymon near Guymon

The record (1980-1992) from this station was split into two periods. The simulation period 1980 through 1988 was used for calibration and the time period 1989-1992 was used for validation. This gage station encompasses 15 sub-basins: 3,4,11,12,15,16,21,22, 23,24,25,26,31,32 and 51 (Figure 3.2).

Gage data:

| | |
|---|---|
| Location: | Texas County, Oklahoma |
| Hydrologic Unit Code: | 11100103 |
| Latitude: | 36°34'19" |
| Longitude: | 101°22'52" NAD27 |

Adjustments to several parameters were necessary to calibrate the model on Guymon gage station stream flow data. The curve number (CN), SOL_AWC, ESCO and other groundwater parameters were adjusted to match observed data as much as possible (Table 3.5). The average monthly total stream flow and surface runoff were over predicted within 9 % and 14% of the observed flow respectively (Table 3.6). Table 3.6 reports the relative errors of hydrological components for the validation period. Monthly predicted and observed values of total flow and surface runoff are compared in figures 3.5 and 3.6. Good agreement was found between observed and predicted monthly flow. The calibration data set produced an $R^2$ of 0.65 and COE (coefficient of efficiency) of 0.64.

Table 3.5: SWAT input variables for Beaver Watershed (Guymon gage station)

| Variable | Calibration Value |
|---|---|
| Runoff curve number adjustment (CN) | -3 |
| Soil Available Water capacity Adjustment (SOL_AWC)(%) | 0.20 |
| Minimum shallow Aquifer Storage for GW flows (GWQMN) | 50 mm |
| Min. shallow Aquifer Storage for Re-evaporation (inches) (REVAPMN) | 0.30 |
| Shallow Aquifer Re-evaporation Coefficient (GW_REVAP) | 0.40 |

The validation process for the period (1989-1992) produced relative errors of 21% and 22% for the total stream flow and surface runoff respectively. The validation data set produced $R^2$ equal to 0.62 and CEO equal to 0.59 for the stream flow. For the surface runoff $R^2$ was 0.63 and CEO was 0.61.

Table 3.6: Guymon gage station (US Geographic survey stream gage 07232900) calibration average monthly flow and relative differences (all units in $m^3/s$).

| | Calibration (1980-1988) | Validation (1989-1990) |
|---|---|---|
| | Relative error % | Relative error % |
| Flow | 9 | 21 |
| Surface runoff | 14 | 22 |
| Base flow | 0 | -40 |

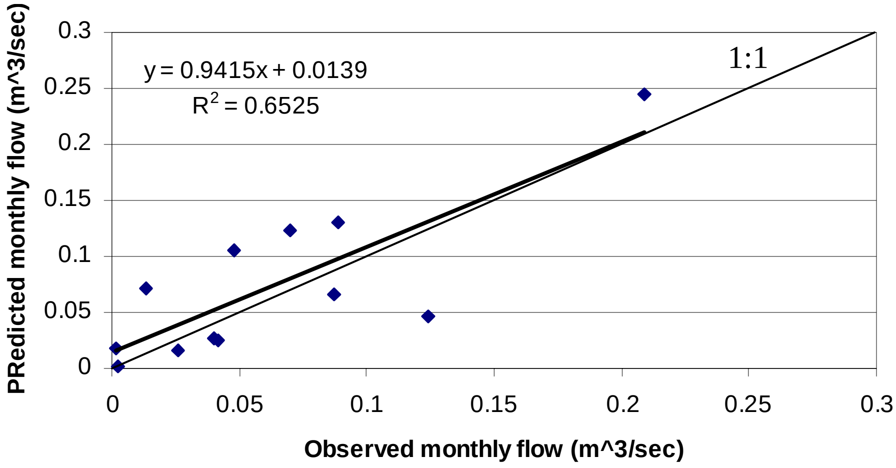

Figure 3.5: Beaver River (Guymon gage station) observed vs predicted average monthly total stream flow (1980-88).

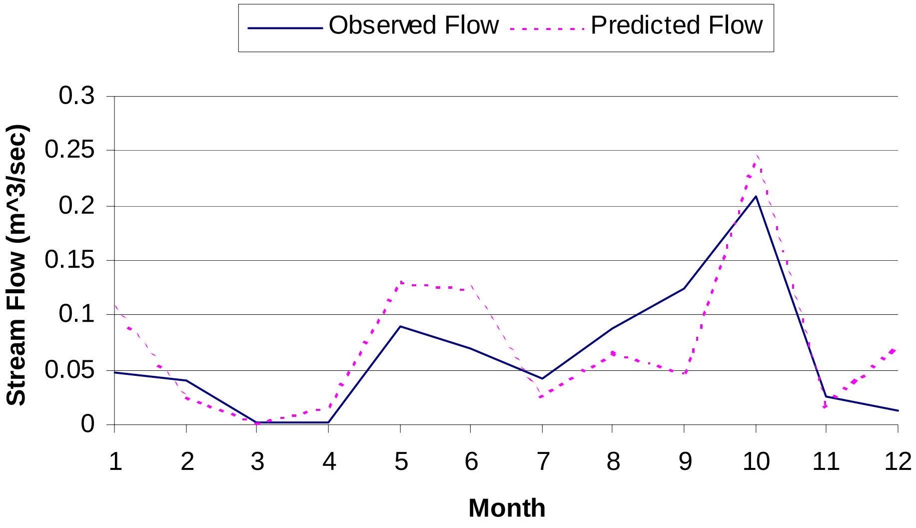

Figure 3.6: Beaver River observed and predicted average monthly total stream flow (time-series) (Guymon gage station).

### 3.1.5 Calibration Results and Model Performance

SWAT was calibrated for the flow at two stream gages: Guymon near Guymon and Beaver River near Beaver. The results of calibration are shown in table 3.7.

Table 3.7: Average monthly stream flow calibration results.

| | Relative Error % | | $R^2$ | | Nash-Sutcliffe Coefficient | |
|---|---|---|---|---|---|---|
| | Calibration | Validation | Calibration | Validation | Calibration | Validation |
| Guymon | 9 | 21 | 0.65 | 0.62 | 0.64 | 0.59 |
| Beaver | 12 | 3 | 0.61 | 0.66 | 0.55 | 0.53 |

SWAT is known to do better in wet conditions than in dry conditions (Mamillapalli et al. 1996). Mamillapalli et al. (1996) reported higher coefficient of efficiency (higher accuracy) for periods of wet conditions than those of dry conditions in the same watershed. The poor prediction of stream flow can be explained by the fact that all of the parameters must be balanced and may not be uniformly applicable across the basin. The results also illustrate that a calibrated model does not necessarily mean it is correct. The model could over predict surface runoff but still predict an accurate yearly total flow because baseflow or some other parameter is being over predicted or under predicted. This can greatly affect the calibration results but it does not have an impact on the model's ability to compare loadings from different management practices. Predictions of management scenarios are valid because climate factors remain constant under all management scenarios.

Discrepancies in data may be due to any one or more of several reasons:

1. The gage stations might not represent the watershed: at times, the monitoring data would show a large runoff event while the model had not predicted one or vice versa.
2. In some cases the climate data did not record a precipitation event, thus a runoff event was not simulated, but, the monitoring data shows a large runoff event. If the surface flow observed although precipitation is not recorded, the watershed is large so precipitation occurs somewhere the weather stations did not record the precipitation events. Over and under prediction of stream flow (low values of $R^2$) is most likely due to spatial variability of rainfall, which was not reflected in measured weather data.
3. The area of the watershed: there are noted discrepancies between the drainage area reported by the USGS and the actual area of the watershed derived by the AVSWAT interface. The area of the Beaver River watershed derived by AVSWAT was 3.20% smaller than the USGS reported area.  In the calibration process we might compare predictions from a watershed that is larger or smaller from that of the observed data.

## 3.2 SEDIMENT YIELD

Erosion in the SWAT model is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith in 1978. In MUSLE the rainfall energy factor is replaced by a runoff factor. Runoff is a function of the existing soil moisture and rainfall energy. This modification improves the prediction of sediment yield, eliminates the need for delivery ratios and allows the prediction of soil loss from a single storm event. Delivery ratio is the ratio of sediment yield at any point along the channel divided by the gross erosion in the entire watershed (Neitsch et al. 2002). The rainfall factor in USLE represents energy used in detachment only, but the runoff factor represents energy used in sediment detachment and transportation.

### **The Modified Universal Soil Loss Equation (MUSLE)**

The Modified Universal Soil Loss Equation (MUSLE) is expressed as

$$Y = 11.8\,(Q_{surf}*q_{peak}*A_{hru})^{0.56}*K*C*P*LS*CFRG, \quad \text{where}$$

$Y$ = sediment yield (metric tons)

$Q_{surf}$ = the surface runoff volume ($m^{3/ha}$)

$q_{peak}$ = the peak runoff rate for the subbasin ($m^3/s$)

$A_{hru}$ = area of the HRU (ha)

K = the USLE soil erodibility factor

C = the USLE cover and management factor

P = the USLE support practice factor

LS = the USLE topographic factor

CFRG = the coarse fragment factor

Q is more related to the detachment process and q defines sediment transport (Williams and Berndt 1977). Q is predicted with a water yield model (Williams and LaSeur 1976) based on the Soil Conservation Service (SCS) runoff curve number technique (USDA-ASC 1972) and a soil moisture index accounting procedure. Peak-flow rate is predicted from a flow-volume (runoff) relationship (Williams and Berndt 1977). It is the maximum flow rate that occurs with a given rainfall event. It is an indicator of the erosive power of a storm.

### Soil erodibility factor (K-factor)

Soils erode differently when all other factors are the same. This is caused by the variation in soil properties such as texture and composition. Soil erodibility is defined as the soil loss ratio of soil loss from a specified soil to the soil loss from a unit plot (Wischmeier and Smith 1978). A unit plot is 22.1 m (72.6 ft) long and 9% uniform slope, in continuous fallow, tilled up and down the slope. A continuous fallow is a land that has been tilled and kept free of vegetation for more than two years (Neitsch et al. 2002). The unit of K is (ton acre hr)/(acre ft-ton inch). The more the silt content in soil the more the soil is erodible (Wischmeier and Smith 1978).

### Cover and land management factor (C-factor)

C-factor is defined as the ratio of soil loss from land cropped under specific management conditions to the soil loss from clean-tilled, continuous fallow. The plant canopy reduces the energy of the free falling water drops and consequently diminishes soil erosion. The reduction in rainfall energy is determined by the height and density of the canopy. The residue on the soil surface is more effective than the canopy cover. Residue intercepts raindrops near the surface and drops regain no fall velocity. Because residue reduces runoff flow, its velocity and transport capacity are reduced too. The crop management factor, C, is evaluated for all days when runoff occurs using the equation

$C = \exp((-0.2231 - CVM) \exp(-0.00115\ CV) + CVM$, where CV is the soil cover (above ground biomass + residue in kg/ha) and the value of CVM is estimated from the equation $CVM = 1.463 \ln(CVA) + 0.1034$, the values for CVA for each crop is determined from tables prepared by Wischmeier and Smith (1978) (Arnold et al. 1998).

### Support practice factor (P-factor)

P-factor is the ratio of soil loss with a specific support practice to the corresponding loss from up-down slope land. Support practices include tillage, stripcropping and terrace systems (Neitsch et al. 2002). Contour tillage provides good protection against erosion from storms of low to moderate intensity but little or no protection against occasion severe storms. Contouring is most effective on slopes of 3-8%. Stripcropping is a practice in which contoured strips of sod are alternated with equal-width strips of row crop or small grain. Terraces are a series of horizontal ridges made in a hillside. Terraces divide the slope of the hill into segments equal to the horizontal terrace interval.

Topographic factor (LS-factor)

LS is the ratio of soil loss per unit area from a field slope to that from a 22.1m length of uniform 9% slope under the same conditions. The LS factor is computed with the equation (Wischmeier and Smith 1978) $LS = (\lambda/221.)^{\Im}(65.41\ S^2+4.565\ S+0.065)$

The exponent $\Im$ varies with slope and is computed using the equation

$\Im = 0.6\ (1-\exp(-35.835\ S))$, S is the slope value.

Coarse fragment factor (CFRG-factor)

The CFRG factor is calculated by the equation $CFRG = \exp(-0.053.rock)$, where rock is the percent rock in the first soil layer.

### 3.2.1 Spatial Variation of Sediment Yield

It was expected that the CRP would reduce the soil loss into watershed tributaries and streams. The rationale behind this assumption comes from the role of a good land cover in alleviating the detachment of soil particles which prohibit the particles from being transported with surface runoff into streams. The second reason is that grasslands are not disturbed by human activities such as cultivation. In other words, human interference is absent to disturb the topsoil layer. Since lands under CRP are planted with grass and not agriculturally active for several years, the sediment yield will be minimal.

Figure 3.7 shows predicted (40 years simulation) sediment yield in Texas County for the pre-CRP scenario. The sediment yield ranges between 0.04 and 0.70 tons/ha/year. The highest sediment yield was found in the southeastern corner of the county (subbasins 18, 30, 8 and 29). The lowest sediment yield was found in the northwestern corner and south of the county (subbasins 9, 11, 12, 27 and 28). Figure 3.8 shows the sediment yield post-CRP. The map shows a slight reduction in sediment yield. The highest amount of sediment yield was 0.52 t/ha (subbasin 18) and the lowest was 0.02 t/ha (subbasins 27 and 28). The spatial distribution of sediment yield was similar in both scenarios except for the amount. The reductions in sediment yield ranges between zero (subbasin 20) and 68% (subbasin 15) (Figure 3.9). The overall average reduction in sediment yield for the county was about 32.60%. Figure 3.10 is a plot of sediment yield from both scenarios. The graph shows a slight but observed reduction in sediment yield due to CRP. The correlation coefficient between the sediment yield in the two scenarios was 0.91 and found to be significant at $\alpha$ =0.01. This means that subbasins with high/low sediment yield in the pre-CRP scenario have high/low sediment yield in the post-CRP scenario. There was a good agreement in spatial distribution of runoff with areas of high and low sediment yield (Figure 3.11); subbasins of high surface runoff correlate with subbasins of high sediment yield in the county.

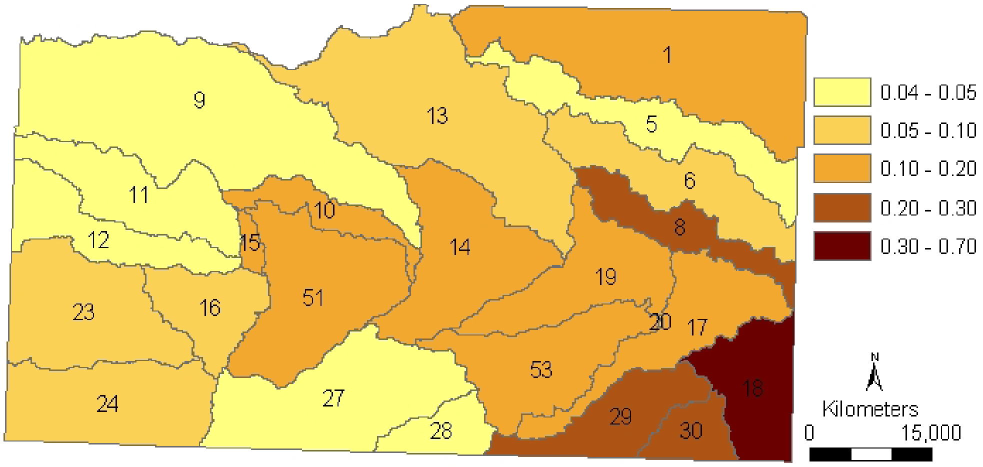

Figure 3.7: Pre-CRP yearly average sediment yield (tons/ha/year) of Texas County within the Beaver River watershed from SWAT simulation (40 years).

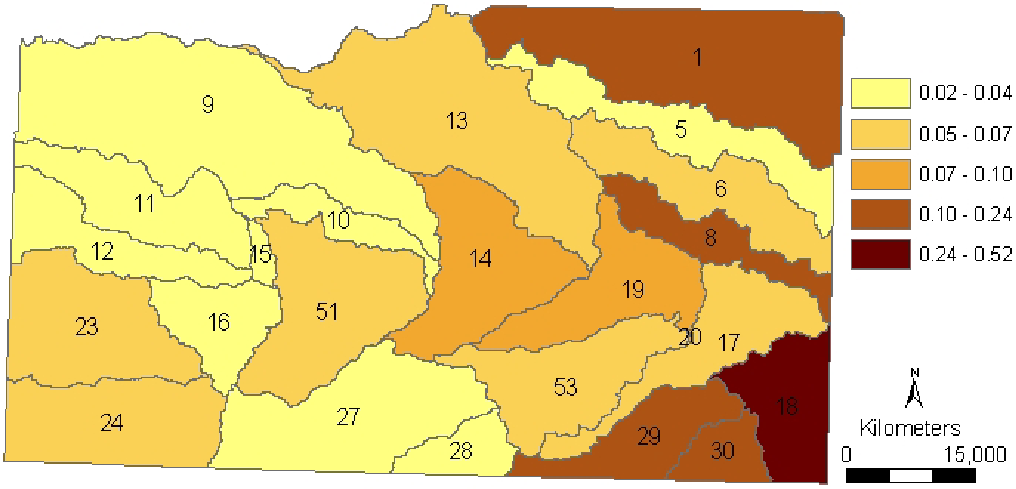

Figure 3.8: Post-CRP yearly average sediment yield (tons/ha/year) of Texas County within the Beaver River watershed from SWAT simulations (40 years).

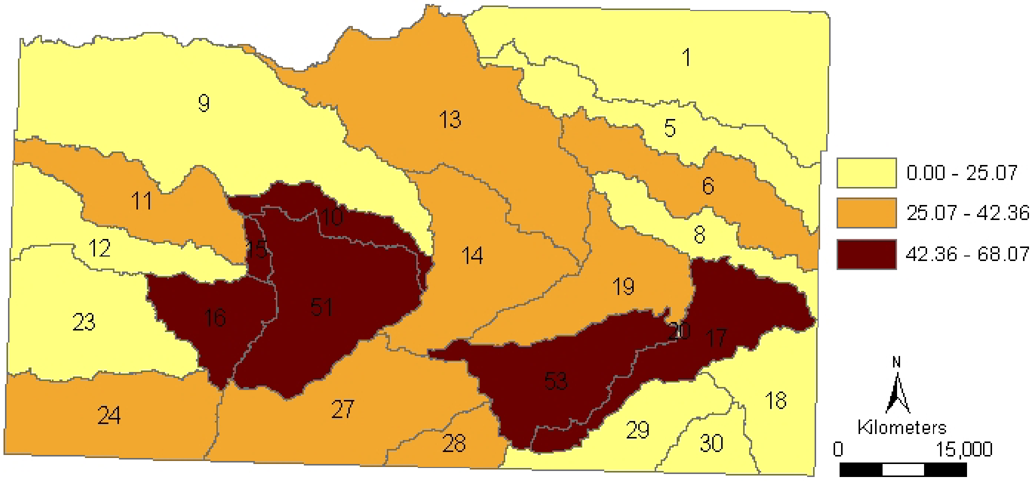

Figure 3.9: Reduction in sediment yield (%) of Texas County within the Beaver River watershed from SWAT simulations (40 years).

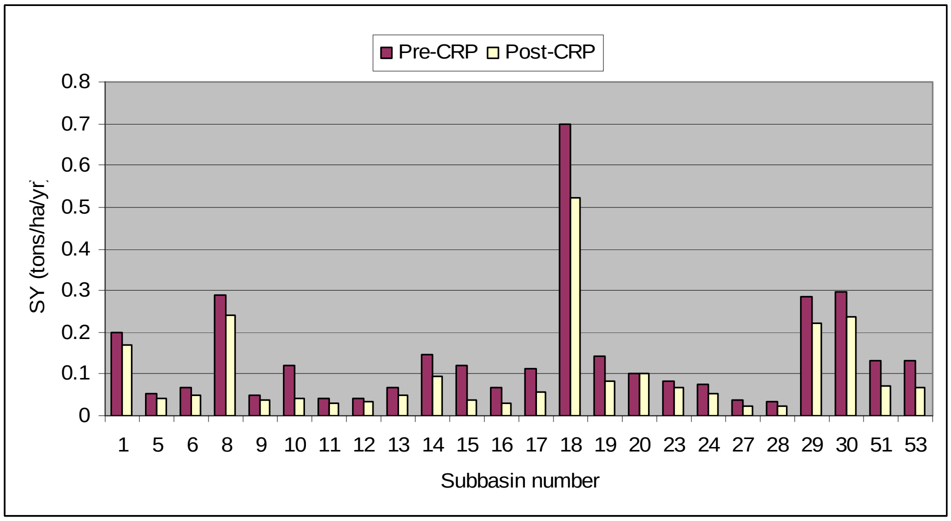

Figure 3.10: Comparison of sediment yield (40 years of SWAT simulation) for pre- and post-CRP time periods in Texas County within the Beaver River watershed (SY=sediment yield).

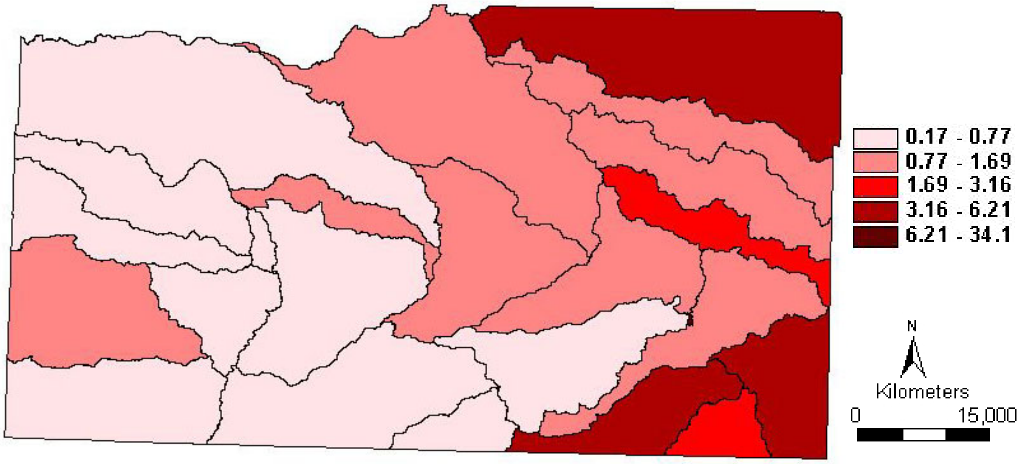

Figure 3.11: Spatial distribution of post-CRP surface runoff ($m^3$) (40 years of SWAT simulation) in Texas County within the Beaver River watershed.

### 3.2.2 Sediment Yield by Land Use Land Cover

Each land use land cover modeled by SWAT yielded different amounts of sediments. The differences are due to the land cover characteristics, soil type, topography, and other factors. The total contribution of each land cover is dependent on its characteristics, management practices and total coverage area. Based on simulation, wheat was highest in sediment yield with an average of 12.60 and 5.60 tons/ha/year for dryland and irrigated wheat respectively (Table 3.8). General agriculture was the second highest land use yield sediment with 2.40 tons/ha/year. General agriculture is defined as areas used for the production of crops that are temporarily barren or with sparse vegetative cover as a result of being tilled in a management practice that incorporates prescribed alternation between cropping and tillage. The CRP yields only 0.06 tons/ha/year.

Table 3.8: Average sediment yield for each land use based on 40 years of simulation.

| Land use | Average sediment yield (tons/ha/year) |
|---|---|
| Dryland wheat | 12.60 |
| Irrigated wheat | 5.90 |
| General agriculture | 2.40 |
| Irrig. Sorghum | 0.10 |
| Dryland Sorghum | 0.10 |
| Corn | 0.25 |
| Commercial | 0.04 |
| CRP | 0.06 |
| Range | 0.001 |
| Pasture | 0.001 |

The large numbers above (for wheat) shows that the sediment yield is caused by rainfall events taking place in periods of no or little vegetation cover. The rainfall season in Texas County runs from June to December (Haan et al., 1994) (Figure 3.12). In summer time, when no wheat is grown and the soil is bare, the strong and short rain events detach and transport soil particles more strongly and effectively. In winter time the rainfall is more continuous and lighter (lower energy) producing lesser sediment yield.

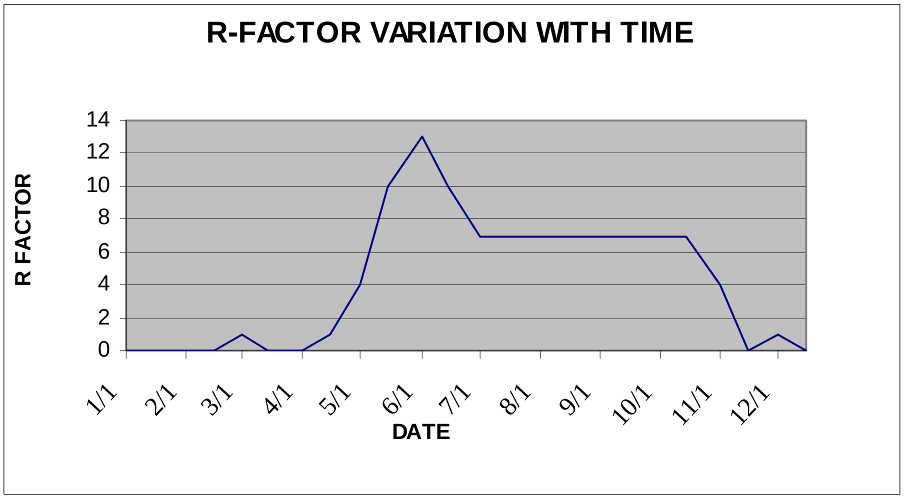

Figure 3.12: Seasonal distribution of rainfall in Texas County (Source: Haan et al. 1994).

Row crops (corn or sorghum) are grown in summer time, which protects the topsoil from erosion during strong precipitation events.

Figures 3.13 and 3.14 show the sediment yield (and nutrients loading) by land cover. Wheat was responsible for about 75% of the sediment yield in the county. General agriculture, corn and sorghum accounted for about 10.72%, 7.91% and 5.0% of the sediment yield respectively.

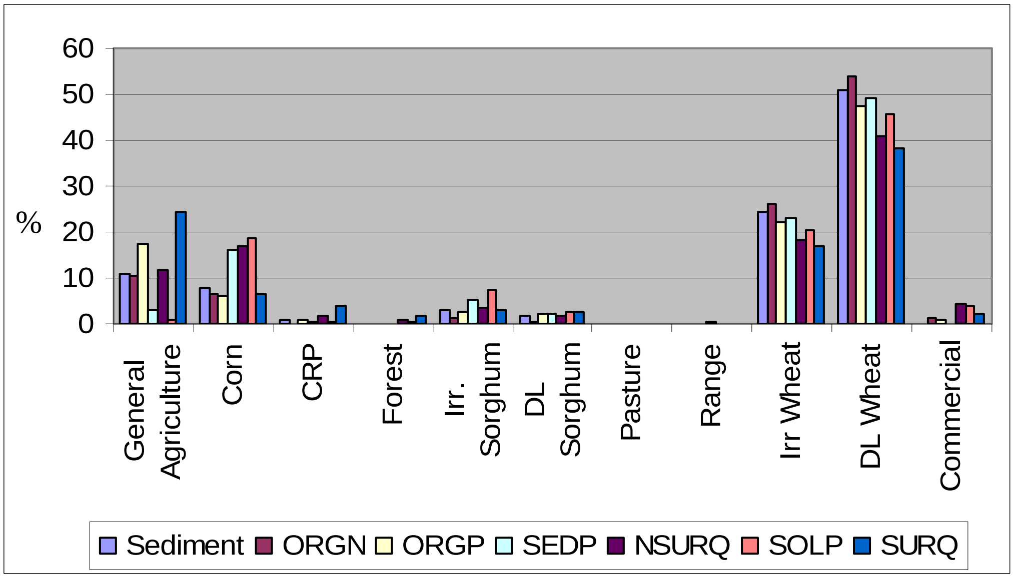

Figure 3.13: SWAT predicted land cover sediment and nutrient comparisons derived from 40-year simulation in Texas County within the Beaver River watershed.

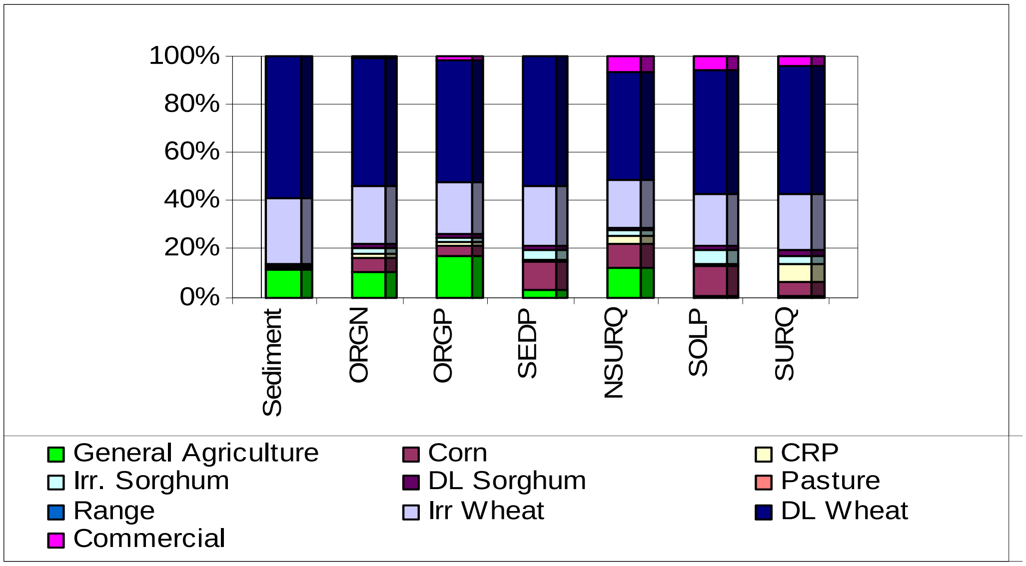

Figure 3.14: Relative contribution of each land cover to the total county load in Texas County within the Beaver River watershed derived from a 40-year simulation.

### 3.2.3 CRP and Sediment Yield

Figure 3.15 shows the distribution of CRP tracts in Texas County in relation to watershed subbasins. The map shows that CRP tracts are dense in the northwest and western portions of the county. In other areas CRP tracts are clustered in small patches or dispersed. Figures 3.16 and 3.17 and table 3.9 show the total area under CRP in each subbasin. The area of CRP ranges between 168 and 15800 hectares with an average of 3500 hectares. Subbasin number 9 contains the highest area under CRP with about 15,850 hectares, the next three subbasins with high CRP area include subbasins 13, 11, and 23 with 7550 hectare, 7350 hectare, and 7300 hectare respectively. The subbasins 15, 28, 30, and 16 contain less than 1000 hectare of CRP area. The sediment yield is highest from subbasins 18 (0.523 t/ha/year), 30 (0.295 t/ha/year), 29 (0.284 t/ha/year) and 8 (0.289 t/h/year).

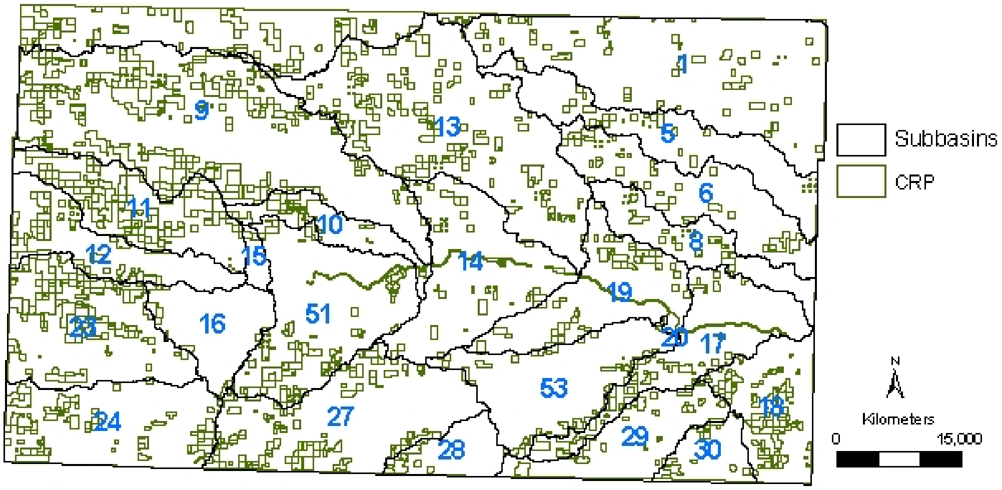

Figure 3.15: CRP tracts and subbasins of Texas County within the Beaver River watershed.

All of these subbasins have a low area under CRP with less than 1600 hectares, except subbasin number 18, which contains a larger CRP area. In addition to soil characteristics, the high amount of sediment yield in subbasin 18 is most probably due to high average slopes in this subbasin compared to other subbasins. On the other end of the spectrum, the area under CRP is highest in subbasins 9, 13, 11 and 23. All these subbasins yield low sediment (less than 0.065 tons/ha/year). An exception is subbasin number 23, which gives a relatively higher value (0.131 tons/ha/year) probably due to higher slope. Based on this we can conclude that the CRP area is closely related to sediment yield. The higher the area of CRP in any subbasin the lower the sediment yield is found.

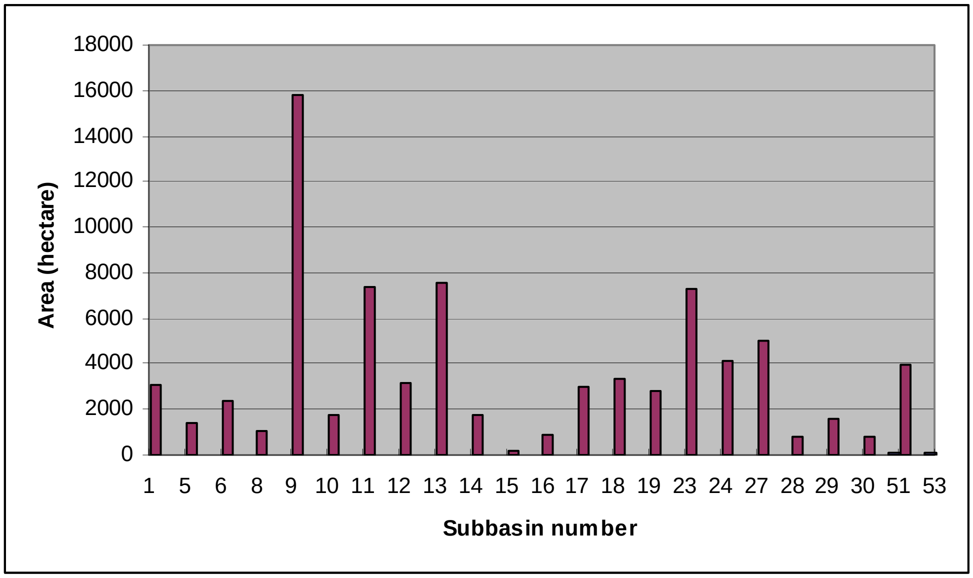

Figure 3.16: Area of CRP tracts in subbasins of Texas County within the Beaver River watershed.

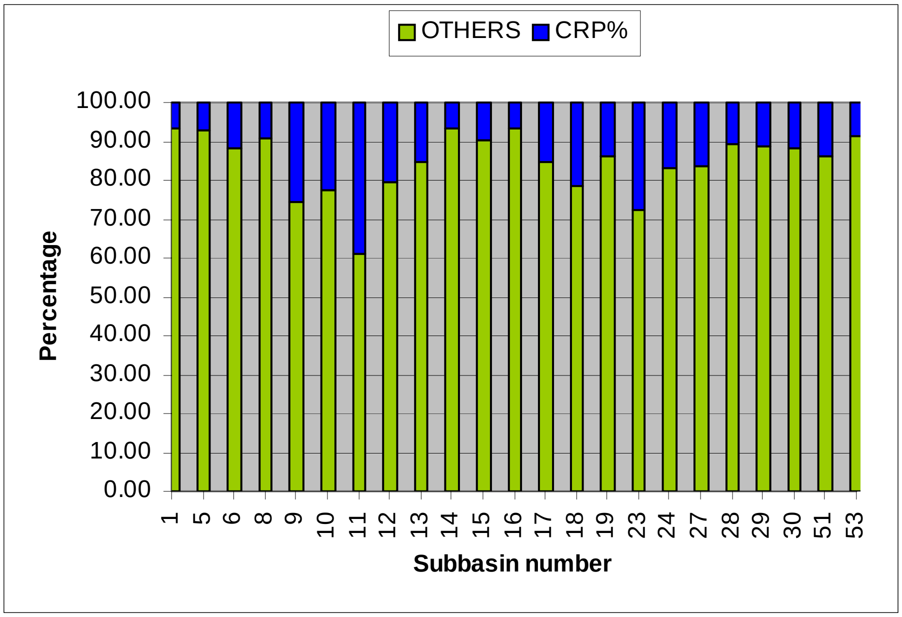

Figure 3.17: The area of CRP as a proportion of subbasin total area in Texas County within the Beaver River watershed.

Figure 3.18 is a plot of CRP area and mean slope against sediment yield for each subbasin. This figure summarizes the general conclusion that the higher the area under CRP the lower is the sediment yield. This is observed in subbasins 9 and 11 where higher CRP corresponds with suppressed sediment yields (0.036 and 0.029 tons/ha/year respectively). Other subbasins (30, 23, and 13) show similar trend. Table 3.9 shows the percentages of reduction in sediment yield pre- and post-CRP as compared to the percentage of CRP area in each subbasin. The relationship between both variables is nonlinear, which is a reflection of the multiple factors that influence soil loss. There are cases where the reduction in sediment yield is greater than 50% (subbasins 10, 15 and 16) but the CRP area is significantly less. There are also rare instances where reduction is less than the proportion of CRP area. Generally, subbasins with high sediment yield (30, 29 and 8) have closer relationship with CRP area than subbasins with lower sediment yield.

The reduction in sediment yield depends on what crop and how much area of cropland CRP has replaced. If the replaced crop was wheat, the reduction in sediment yield will be higher than if the replaced crop was corn or sorghum. This is because the rate of sediment yield from wheat is much higher than that from corn or sorghum, as illustrated earlier in table 3.8.

Table 3.9: Comparison of area and density of CRP, and sediment yield (SYLD) in each subbasin (tons/ha/yr).

| *Subbasin* | *CRP-area (Ha)* | *CRP% of subbasin area* | *SYLD* | *% Reduction* |
|---|---|---|---|---|
| 1 | 3100 | 6.64 | 0.170 | 13.82 |
| 5 | 1400 | 7.22 | 0.040 | 24.14 |
| 6 | 2350 | 11.57 | 0.048 | 29.17 |
| 8 | 1100 | 9.07 | 0.241 | 16.74 |
| 9 | 15850 | 25.83 | 0.036 | 24.42 |
| 10 | 1800 | 22.52 | 0.042 | 65.00 |
| 11 | 7350 | 38.75 | 0.029 | 29.55 |
| 12 | 3100 | 20.39 | 0.032 | 19.70 |
| 13 | 7550 | 15.19 | 0.048 | 30.43 |
| 14 | 1750 | 6.72 | 0.094 | 35.17 |
| 15 | 168 | 9.53 | 0.038 | 68.07 |
| 16 | 850 | 6.78 | 0.030 | 55.22 |
| 17 | 3000 | 15.60 | 0.058 | 49.12 |
| 18 | 3350 | 21.29 | 0.523 | 25.09 |
| 19 | 2800 | 13.99 | 0.083 | 42.36 |
| 23 | 7300 | 27.94 | 0.066 | 21.08 |
| 24 | 4150 | 16.90 | 0.054 | 28.00 |
| 27 | 5000 | 16.20 | 0.023 | 34.45 |
| 28 | 750 | 10.70 | 0.023 | 33.53 |
| 29 | 1550 | 11.06 | 0.221 | 22.19 |
| 30 | 750 | 11.66 | 0.235 | 20.29 |
| 51 | 4000 | 13.96 | 0.071 | 45.38 |
| 53 | 1900 | 8.85 | 0.066 | 49.62 |

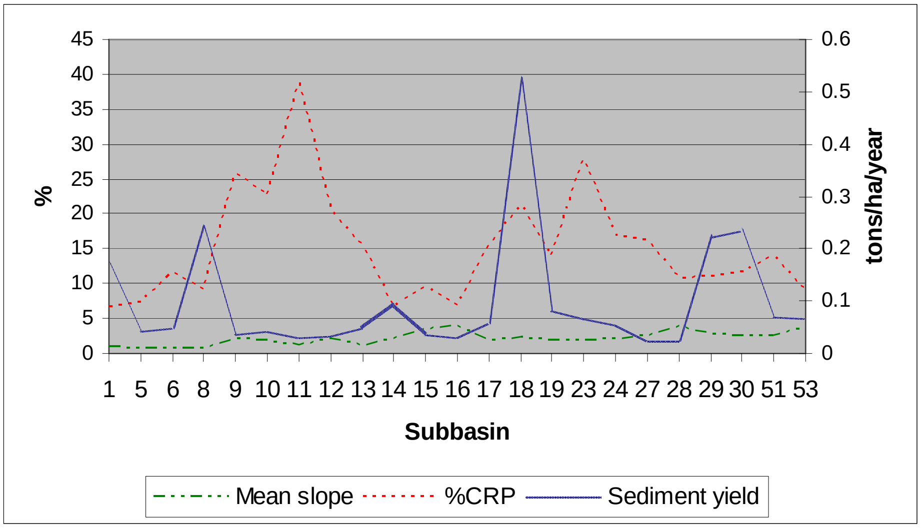

Figure 3.18: Sediment yield versus CRP area and density.

Visual interpretation of the figures 3.19 and 3.20 show that, both sediment yield and CRP area have the same trendlines. The trendlines of sediment yield and CRP area run east-west (x-axis in green color) and north-south (y-axis in blue color) of the county. The higher end of the trendline for sediment yield is on the eastern and southern sides, which is opposite to the CRP area. This arrangement proves again the conclusion of higher area CRP association with lower sediment yields.

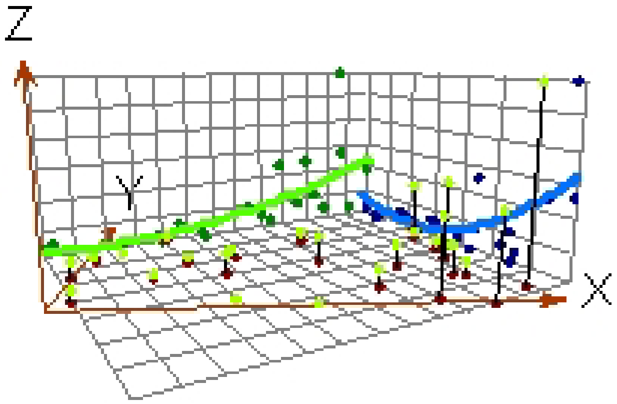

Figure 3.19: Trendlines of sediment yield in Texas County within the Beaver River watershed.

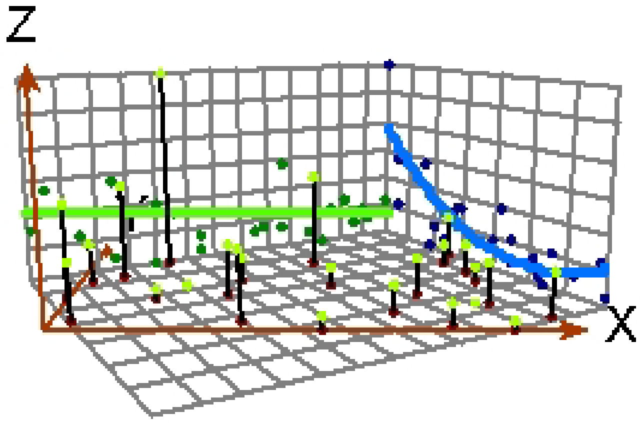

Figure 3.20: Trendlines of CRP area in Texas County within the Beaver River watershed.

## 3.3 FUTURE CRP ENROLLMENT

### 3.3.1 Soil Tolerance

Soil loss tolerance (T) was used as a cut-off value for future CRP enrollment. This value may vary from one area to another depending on cost of soil conservation. Soil loss tolerance most commonly defined as “the maximum rate of annual soil erosion that may occur and still permit a high level of crop productivity to be obtained economically and indefinitely” (Wischmeier and Smith 1978). Sheet and rill erosion in the United States averaged at 6.70 tons per hectare per year in 2001 (NRCS 2001). A maximum soil loss tolerance in most agricultural soils of the United States is considered to be about 11.0 tons per hectare per year (Institute of Applied Sciences 2003). This value has been selected for several reasons:

1. Soil losses in excess of this value affect the maintenance, cost, and effectiveness of water control structures (like ponds) and other structures affected by sediment such as dams.

2. Excessive surface erosion is accompanied by gully formation in many places, causing added problems to tillage operations and to sedimentation of ditches, streams, and waterways.

3. Plant nutrients are lost; the average value of nitrogen and phosphorus in a ton of soil is about $5-$10. Plant nutrient losses of more than $10 per acre per year are considered excessive. If nutrient loss is a primary consideration (such as in lands planted in cash crops), maximum soil loss tolerance could be as low as 1-2 tons per acre per year (Institute of Applied Sciences 2003).

The impact of soil erosion on a given soil type depends on the type and depth of soil. Deep uniform, and stone free topsoil materials show higher tolerance limit than shallow and previously eroded soils (Ontario Ministry of Agriculture and Food 2003).

### 3.3.2 Cell-Based Mapping of Sediment Yield

The EBI (environmental benefit index) reflects compromises between science and policy considerations. The EBI was developed not only to maximize the potential benefits from the CRP, but to meet the demands of diverse consumer groups, the needs of farmers, and the realities of implementing a massive conservation program (Ribaudo 1989). The criteria and procedure of evaluating the applications for the Conservation Reserve Program is subjective to some extent. Based on many environmental factors (see section 1.7) and personnel skills, enrollment in the program is not absolutely objective. Using objective-based criteria that evaluate all CRP enrollments is essential. Mapping areas vulnerable to soil degradation using SWAT provides acceptable and more accurate criteria.

Of all outputs calculated by SWAT, the data pertaining to hydrologic response units are most valuable simply because it represents the smallest unit in the watershed and because it takes into consideration variations in land cover and soil, which are critical factors in soil erosion assessment. In addition to these factors slope was also used in mapping target areas.

The sediment yield from SWAT can directly be mapped on a subbasin level only. The output from a subbasin is an aggregation of the hydrologic response units, which are unique combinations of land covers and soil types, within that subbasin. SWAT assumes a uniform slope across each subbasin. Slope varies significantly from one place to another, particularly in large subbasins. For better predictions from SWAT, the average slope of each land cover was derived from GIS data and incorporated into the model. Since AVSWAT does not provide location information of HRUs, it was necessary to approximate a cell-based sediment yield. The GIS data (slope, land use, and soil) were used in conjunction with HRU data to map the sediment yield on a 30 meter cell resolution. Although mapping sediment yield this way is not absolutely accurate, the results would be close to the actual world (White 2003).

Watershed land cover, soil and slope from GIS data were combined to approximate the unique combinations of the hydrologic response units. Sediment yields from HRU (unique land use land cover and soil) SWAT output were assigned to the same combinations (unique land use land cover and soil) in GIS data. If two or more HRUs had the same soil and land cover, an area-weighted average was performed. If a unique GIS combination of land use land cover and soil had no equivalent in HRU output (i.e. the soil is different), the average sediment yield for the land cover was assigned for that cell in

GIS data. The sediment yield from HRU was adjusted for each grid cell based on the slope from GIS data and the average HRU slope. The sediment yield adjustment was based on the equation (White et al. 2003):

$$E_g = E_o * (0.065+0.0456* S_o+0.006541* S_o^2)/(0.065+0.0456* S_g +0.006541* S_g^{2})$$

$E_g$ = grid cell erosion (metric tons/ha)
$E_o$ = HRU erosion rate (metric tons/ha)
$S_o$ = HRU slope in percent
$S_g$ = grid cell slope in percent

Figure 3.21 shows the results of cell-based erosion estimation. There is an increase in amounts of sediment yield when compared to sediment yields from subbasins. This is explained by the increase in channel erosion due to high cell resolution (FitzHugh and Mackay 2000). Most hot spots (10 tons/ha/year or more) are located in wheat fields. Three classes of soil loss have been created: 0-5 tons/ha/year, 5-10 tons/ha/year and greater than 10 tons/ha/year. The selection of the value 10 tons/ha is based on the average soil loss tolerance in the United States (11.0 tons/ha/year). Also, Morgan (1995) recommends that an appropriate boundary measure of soil loss over which agriculturists should be concerned is 10 tons/ha/year. Areas of high erosion hazard are concentrated in the northeastern part of the county where the area is highly cultivated with wheat. These areas of hotspots are also under low CRP enrollment. Eighty three percent of Texas County area has a sediment yield value less than 5 tons/ha/year (Table 3.10). Only 4.60% of the county area is under critical soil erosion conditions with more than 10 tons/ha/year.

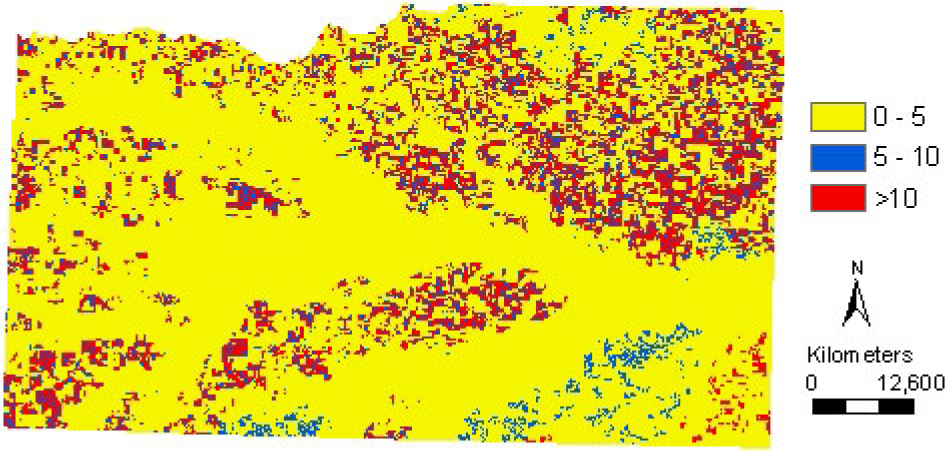

Figure 3.21: Post-CRP hot spots (tons/ha/year) extracted from HRU data in Texas County within the Beaver River watershed.

Table 3.10: The ordinal categories of soil erosion and proportions of each category.

| Range (tons/ha/year) | Erosion risk class | Proportion |
|---|---|---|
| 0-5 | Low | 83.20% |
| 5-10 | Moderate | 12.20% |
| >10 | High | 4.60% |

Areas with more or equal to 10 tons/ha/year sediment yield are most important to observe. If these areas are with less than 10 tons/ha soil tolerance (H_SY/L-T) (Figure 3.22), then they are classified as erosion sensitive areas. Values of soil loss tolerance were obtained from SSURGO database. Figure 3.22 shows a very small area of this class with no pattern of distribution. We can notice the large area of the class high sediment yield with high soil loss tolerance; it amounts to about 14% of the total area. Other major classes are areas of low sediment area with high soil tolerance 62% and areas of low sediment yield and low soil loss tolerance 16%.

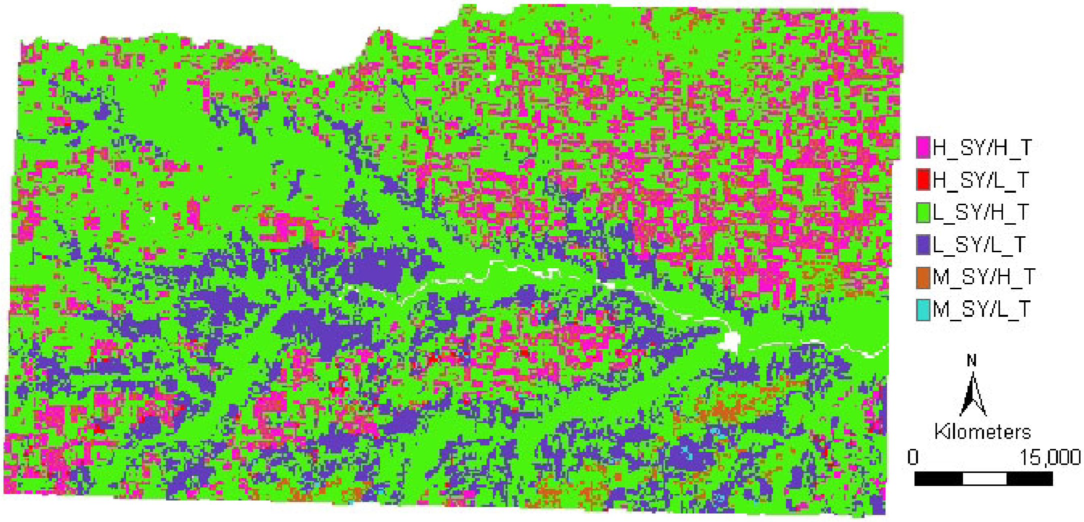

Figure 3.22: Relationship between sediment yield and soil loss tolerance in Texas County within the Beaver River watershed. (SY=sediment yield, T=soil loss tolerance, H=high, L=low)(Source of T values: SSURGO databse).

The mapped hotspots (Figure 3.21) will facilitate the decision making process of CRP enrollment. The Farm Service Agency can make use of such maps as decision support aids to target critical regions for CRP enrollments. Having such information in hand the applications for CRP enrollment can be evaluated easier and simpler. In the enrollment procedure the farm under consideration can be located on the map of hotspots to determine whether or not it falls within the desired category of soil loss. This map will also facilitate digital mapping of tracts enrolled in the program.

Table 3.11 reports the average sediment yield from each land cover from both scenarios pre- and post-CRP. The values of sediment yield from the pre-CRP scenario are higher than the post-CRP scenario, which agrees with data from the subbasins level.

Table 3.11: Average sediment yield by land cover from both scenarios. Averages derived from HRU data.

| Land use | Mean (tons/ha/yr) post-CRP |
|---|---|
| General Agriculture (AGRL) | 0.77 |
| Corn | 0.06 |
| CRP (CRPS) | 0.02 |
| Irrigated Sorghum (SGHY) | 0.03 |
| Pasture (PAST) | 0.00 |
| Range (RNGE) | 0.00 |
| Dryland Sorghum (GRSG) | 0.03 |
| Dryland Wheat (WWHT) | 3.22 |
| Commercial (UCOM) | 0.01 |
| Irrigated Wheat (SWHT) | 1.57 |

## 3.4 STATISTICAL ANALYSIS

### 3.4.1 Descriptive Statistics

The statistical analyses in this section are based on grid-based data. The grid-based data were derived from detailed GIS data and outputs from the hydrologic response units. It is an attempt to find interrelationships between sediment yield, soil, land use and slope. Other factors, including surface runoff and peak stream flow, need further work to be mapped on grid-cell bases.

Sediment Yield

Table 3.12 presents a statistical analysis of the sediment yield by land cover type. The four-letter code (in parenthesis) for each land cover is given by SWAT. From the table we can observe that wheat drives more sediments out of the agricultural fields than any other crop. The average sediment yield from wheat fields is about 2.40 tons/ha/year.

General agriculture comes second with 0.77 tons/ha/year. Average sediment yield from CRP is about 0.02 tons/ha/year. It is interesting to note that the order of crop sediment yield is the same when compared to the results from the hydrologic response units (Table 3.10). The amounts of sediment yield are different because the grid-based data were derived from 30 m cell GIS data and the hydrologic response units are much larger. The area of hydrologic response units in Texas County varies between 0.16 $km^2$ (grain sorghum) and 281 $km^2$ (range). Wheat shows largest variation in sediment yield (SD=4.08 and 1.93). CRP sites showed only a standard variation of 0.03. Figure 3.23 is a box-plot of mean sediment yield by land cover. The box-plot is a five-number description figure of data. It shows a measure of central location (the median), two measures of dispersion (the range and inter-quartile range), the skewness (from the orientation of the median relative to the quartiles) and potential outliers. The line inside the box indicates the median of the sediment yield distribution. If the median is positioned in the middle of the rectangle then the data is symmetrical, otherwise it is skewed. The upper and lower boundaries of the rectangle are the 75th and 25th percentile, respectively. The dotted lines drawn up and down the rectangle are the last values that are not outliers. The cross symbol in the plot indicates an outlier. Outliers are defined as those values that are one step away from the lower quartile and one step from the upper quartile. A step is 1.5 times interquartile range. As noticed in the figure, we can make conclusions from descriptive statistics for wheat and not for other crops. The figure shows that data of sediment yield by land cover are skewed. The range of data for irrigated wheat is lower than that of dryland wheat. The values of outliers are also higher for spring wheat than winter wheat.

Table 3.12: Statistical analyses of sediment yield by land cover type.

| Land use | Mean (tons/ha/yr) | SD | 95% CI of Mean |
|---|---|---|---|
| General Agriculture (AGRL) | 0.77 | 0.49 | 0.74 to 0.60 |
| Corn | 0.06 | 0.09 | 0.06 to 0.07 |
| CRP (CRPS) | 0.02 | 0.03 | 0.02 to 0.01 |
| Irrigated Sorghum (SGHY) | 0.03 | 0.03 | 0.03 to 0.03 |
| Pasture (PAST) | 0.00 | 0.00 | 0.00 to 0.00 |
| Range (RNGE) | 0.00 | 0.00 | 0.00 to 0.00 |
| Dryland Sorghum (GRSG) | 0.03 | 0.04 | 0.02 to 0.03 |
| Dryland Wheat (WWHT) | 3.22 | 4.08 | 3.11 to 3.34 |
| Commercial (UCOM) | 0.01 | 0.01 | 0.01 to 0.02 |
| Irrigated Wheat (SWHT) | 1.57 | 1.93 | 1.51 to 1.64 |

SD = standard deviation CI = confidence interval

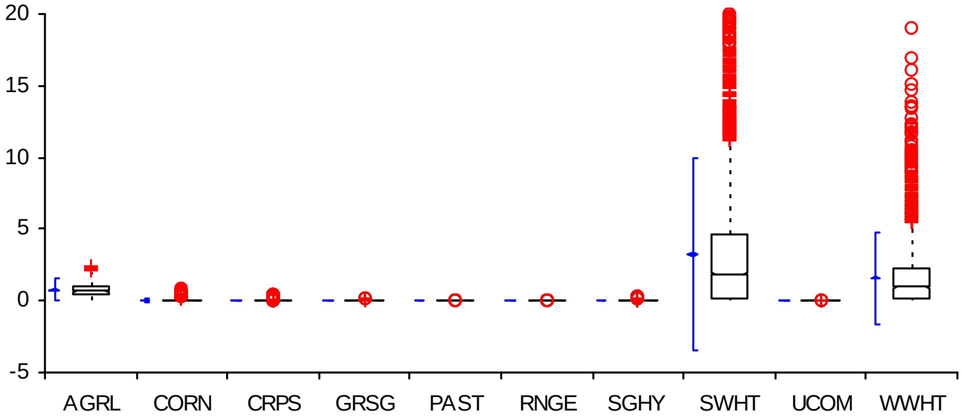

Figure 3.23: Sediment yield by land cover (tons/ha/year) in Texas County within the Beaver River watershed (AGRL=general agriculture, CORN=corn, CRPS=CRP, GRSG=irrigated sorghum, PAST=pasture, RNGE=range, SGHY=dryland sorghum, SWHT=dryland wheat, UCOM=commercial, WWHT=irrigated wheat).

Table 3.13 is a summary of statistics of sediment yield by soil type. The mean value is the average sediment yield (tons/ha/year) from cells in a specified soil type. The sediment yield is related to four major soil types; Dallam-Dalhart (OK006), Ulysses-

Darrouzett (OK013), Mansic (OK021) and Otero (OK023) with 5.63, 2.97, 2.26 and 1.19 tons/ha/year, respectively. The soil type Dallam-Dalhart shows the highest sediment yield (5.63 tons/ha/year), but its area is very small which means the limited existence of the soil in Texas County. On the other end, Tivoli-Pratt (OK068) shows the minimum mean sediment yield 0.001 tons/ha/year, but again its area is small compared to the coverage of other soil types. The associations Ulysses-Darrouzett (OK013), Mansic (OK021) and Otero (OK023) show high sediment yield with considerable areal coverage. Figure 3.24 is a box-plot of soil associations and sediment yield. The data is skewed and has a very wide range of values. Figure 3.25 shows the relationship between CRP and soil types in Texas County. Most CRP tracts are found in areas with the soil type Sherm (OK011) and the soil type Dalhart (OK007). CRP did not exist in areas with soil types such as Berthoud (OK005) and Sherm (OK012).

Table 3.13: Statistics of sediment yield (SY) by soil type.

| Soil type | % area | Mean SY | SD | 95% CI of Mean |
|---|---|---|---|---|
| OK003 (Conlen-Sunray) | 2.96 | 0.59 | 1.39 | 0.55 to 0.63 |
| OK005 (Berthoud) | 12.00 | 0.05 | 0.15 | 0.04 to 0.05 |
| OK006 (Dallam-Dalhart) | 0.40 | 5.63 | 4.16 | 3.95 to 7.31 |
| OK007 (Dalhart) | 13.50 | 0.73 | 1.62 | 0.67 to 0.79 |
| OK008 (Dalhart) | 4.65 | 0.39 | 0.96 | 0.35 to 0.43 |
| OK010 (Gruver-Dumas) | 1.60 | 0.75 | 1.68 | 0.68 to 0.82 |
| OK011 (Sherm) | 41.00 | 0.76 | 1.90 | 0.71 to 0.81 |
| OK012 (Sherm) | 1.29 | 0.60 | 1.25 | 0.54 to 0.65 |
| OK013 (Ulysses-Darouzett) | 10.00 | 2.98 | 6.08 | 2.60 to 3.34 |
| OK014 (Conlen-Vona) | 2.72 | 0.03 | 0.14 | 0.03 to 0.04 |
| OK018 (Lesho-Gracemore) | 3.51 | 0.05 | 0.19 | 0.04 to 0.06 |
| OK021 (Mansic) | 4.83 | 2.26 | 3.89 | 2.02 to 2.50 |
| OK023 (Otero) | 1.00 | 1.19 | 2.76 | 1.08 to 1.30 |
| OK068 (Tivoli-Pratt) | 0.52 | 0.01 | 0.00 | 0.00 to 0.00 |

SD = standard deviation CI = confidence interval

Table 3.14 contains the attributes of the major soil series in each map association. There are 14 soil associations in Texas County that have been modeled by SWAT. In STATSGO each map association (MUID) is an aggregation of many soil series. The dominant soil series in each soil association has been selected to represent that association for interpretation purposes of statistical analysis. For example, the soil series called SHERM compose about 55% of the soil association Sherm (OK011). Therefore, the characteristics of the soil series SHERM will be representing the soil characteristics of the soil association Sherm (OK011). The weighted average of the quantitative soil characteristics were calculated from all series and assigned to the soil association.

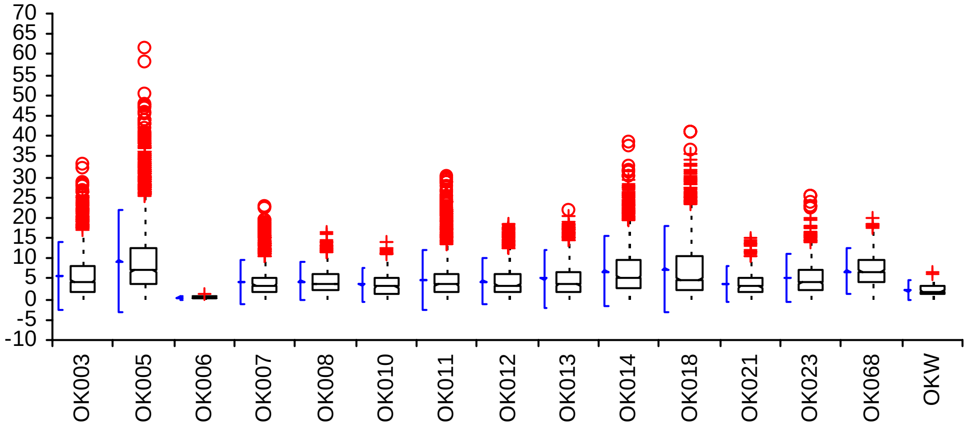

Figure 3.24: Box-plot shows the average sediment yield by soil type in Texas County within the Beaver River watershed.

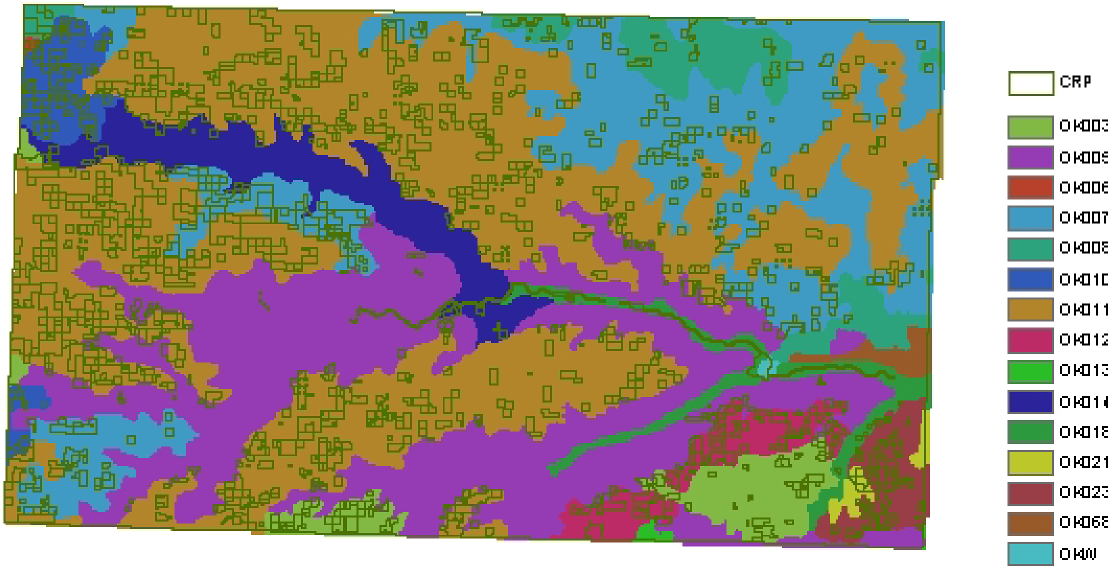

Figure 3.25: Distribution of CRP with soil types in Texas County.

In general, the characteristics of all soils in Texas County support the results obtained from the SWAT model. Most soils are classified as well drained with few classified as somewhat excessively drained. Another feature of soil is the surface water ponding. All soils have zero duration of surface water ponding in a normal year. The more are drained, the less surface runoff and consequently less soil loss. The association Lesho-Gracemore (OK018) is the only soil that shows occasional flooding and for a very brief time. If flooding happens it would occur during the period March-October. With the exception of the soils Gruver-Dumas (OK010), Ulysses-Darrouzett (OK013), Sherm (OK011) and Sherm (OK012), and Tivoli (OK068) all soils are classified in the hydrological group B which is characterized by moderate infiltration rates and moderate coarse textures. The major soil type Sherm (OK011), 40% of total area, is classified in the hydrologic group D that is characterized by very slow infiltration rates and the soils are clayey. Minor soil types are classified in hydrologic group C or hydrologic group A.

Table 3.14: Characteristics of STATSGO soil associations.

| MUID | Series name | Slope | Surface Texture | AF | AFD | Drainage | Hydrological Group |
|---|---|---|---|---|---|---|---|
| OK003 | CONLEN | 3-5 | L | NONE | | W | B |
| | SUNRAY | 0-3 | CL | NONE | | W | B |
| OK005 | BERTHOUD | 1-5 | CL | NONE | | W | B |
| OK006 | DALLAM | 0-1 | FSL | NONE | | W | B |
| | DALHART | 0-3 | LFS | NONE | | W | B |
| OK007 | DALHART | 1-3 | FSL | NONE | | W | B |
| OK008 | DALHART | 0-3 | LFS | NONE | | W | B |
| OK010 | GRUVER | 0-1 | L | NONE | | W | C |
| | DUMAS | 0-1 | L | NONE | | W | B |
| OK011 | SHERM | 0-1 | SICL | NONE | | W | D |
| OK012 | SHERM | 0-1 | SICL | NONE | | W | D |
| OK013 | ULYSSES | 0-3 | CL | NONE | | W | B |
| | DARROUZETT | 1-3 | SIL | NONE | | W | C |
| OK014 | CONLEN | 5-12 | CL | NONE | | W | B |
| | VONA | 0-3 | LFS | NONE | | W | B |
| OK014 | VONA | 8-20 | LFS | NONE | | W | B |
| | PASTURA | 5-12 | L | NONE | | W | D |
| OK018 | LESHO | 0-1 | SICL | OCCAS | V. BRIEF | SP | C |
| | GRACEMORE | 0-1 | LFS | OCCAS | V. BRIEF | SP | C |
| | LINCOLN | 0-1 | LFS | FREQ | V. BRIEF | SE | A |
| OK021 | MANSIC | 3 | CL | NONE | | W | B |
| OK023 | OTERO | 1 | LFS | NONE | | SE | B |
| OK068 | TIVOLI | 12 | FS | NONE | | E | A |
| | PRATT | 6 | LFS | NONE | | W | A |

Key:

MUID: soil association code

AF: annual flooding

AFD: duration of annual flooding

L: loam, S: sand, C: clay, SI: silt

W: well drained, P: poorly drained, SP: somewhat poorly drained, SE: somewhat excessively drained, E: excessively drained.

T value: soil loss tolerance

The former group is characterized by slow infiltration rates with moderately fine or fine textures, whereas group A has a high infiltration rates with deep soils that are well drained to excessively drained sands and gravels. Fine soil particles (less than 0.125 mm diameter) are primarily responsible for seal formation that retards infiltration, which increases runoff and the erosion potential. Large stable aggregates increase surface roughness, thus reducing potentials for runoff and water erosion (Unger 1999).

## Slope

The average slope percent in Texas County is about 6.10%. The slope ranges between 0 and 61.0%. Figure 3.26 shows the distribution of slope across Texas County. And it shows the non-normal distribution of slope and that it is skewed to the left.

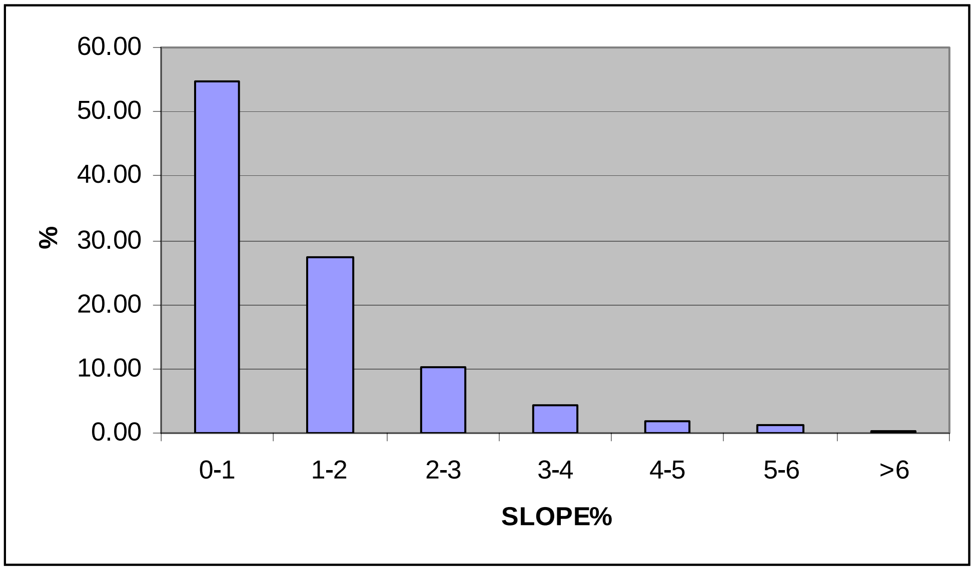

Figure 3.26: Distribution of slope (in percent) across Texas County.

### Slope and land use:

Table 3.15 shows that the average slope is highest in range areas. CRP ranks second among the land covers with an average slope percent of 5.20%. Wheat average slope is 3.94%. The data explains that CRP yields much less sediment than wheat, although its average slope is higher. Range areas also show high average slope (9.56%) but little sediment yield. Agricultural crops (wheat, corn and sorghum) show lower average slopes than CRP but higher sediment yield. The mean slopes of these crops are not surprising since the crops are expected to grow on flatter areas. These inverse relationships between sediment yield and slopes of land covers suggest the major role of management practices. Figure 3.27 shows the wide variation of slopes for the different land covers.

Table 3.15: Slope (percent) statistical analyses by land cover.

| Land use | % Area | Mean | SD | 95% CI of Mean | |
|---|---|---|---|---|---|
| General agriculture | 2.96 | 3.40 | 2.69 | 3.25 | 3.55 |
| Corn | 6.31 | 3.45 | 2.76 | 3.35 | 3.56 |
| CRP | 11.68 | 5.20 | 3.28 | 5.10 | 5.29 |
| Grain sorghum | 4.86 | 2.99 | 2.29 | 2.89 | 3.09 |
| Pasture | 4.35 | 4.37 | 3.64 | 4.19 | 4.54 |
| Range | 36.59 | 9.55 | 6.82 | 9.44 | 9.66 |
| Dry sorghum | 5.65 | 3.27 | 2.69 | 3.16 | 3.38 |
| Dryland Wheat | 11.57 | 4.19 | 3.10 | 4.10 | 4.28 |
| Urban | 6.99 | 4.93 | 4.25 | 4.77 | 5.09 |
| Irrigated wheat | 9.03 | 3.70 | 2.65 | 3.62 | 3.79 |

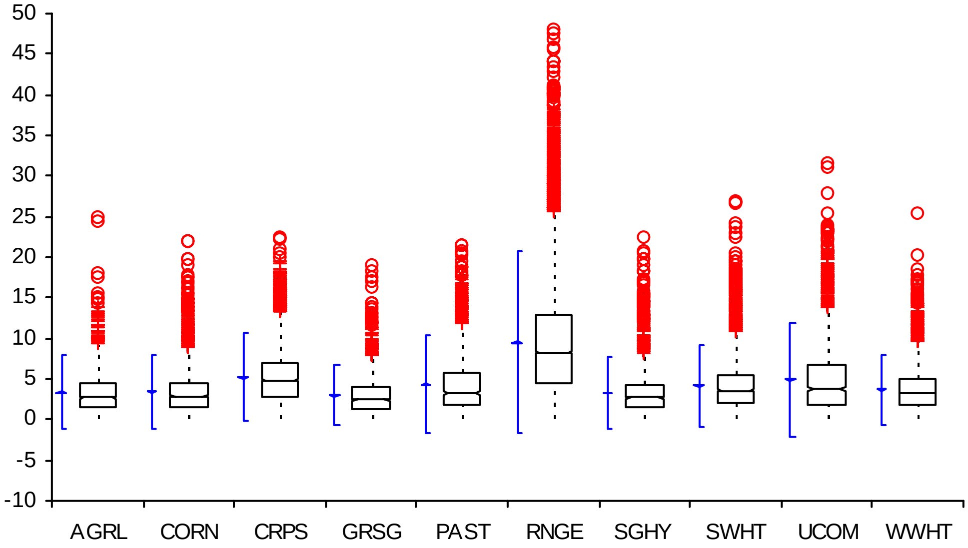

Figure 3.27: Box-plot shows the slope variation by land use in Texas County within the Beaver River watershed (AGRL=general agriculture, CORN=corn, CRPS=CRP, GRSG=irrigated sorghum, PAST=pasture, RNGE=range, SGHY=dryland sorghum, SWHT=dryland wheat, UCOM=commercial, WWHT=irrigated wheat).

### Slope and soil type

The soil Berthoud (OK005) shows the highest average slope 9.33% (Table 3.16). The average slope of soil Dallam-Dalhart (OK006) was the lowest amongst all soil types. This soil type showed a relatively high sediment yield (5.63 tons/ha/are) but again it does not cover a large area. The soil types Darrouzett (OK013), Mansic (OK021) and Otero (OK023) showing high sediment yield were associated with slopes in the range 3.75-5.15%. Other soil types Berthoud (OK005), Lesho-Gracemore (OK018), and Conlen-Vona (OK014) with no high sediment yield had high slopes. This confirms the interaction of the characteristics of land use, soil and topography. Sediment yield is a physical process resulting from many interrelated environmental factors. The variations in slope with soil type are depicted in Figure 3.28. This figure shows that all soil types have different slopes and vary in range. The figure also shows that slopes are not normally distributed for all soils.

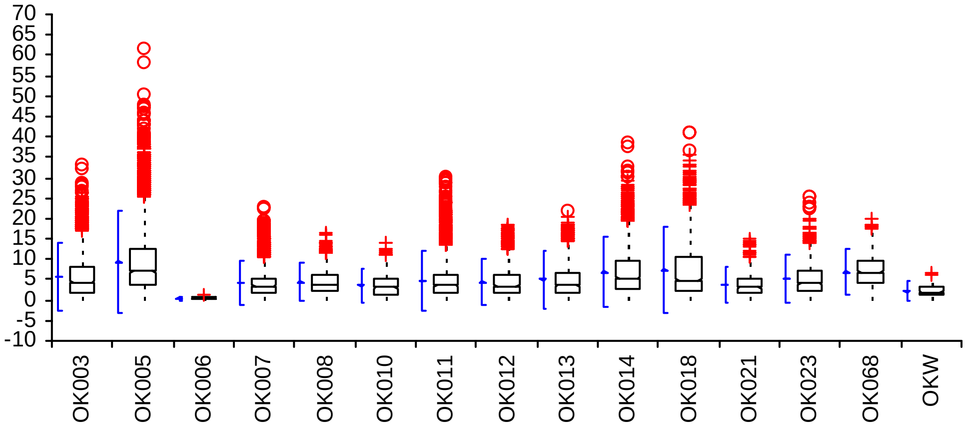

Figure 3.28: Box-plot shows the slope variation by soil type in Texas County within the Beaver River watershed.

Table 3.16: Slope statistical analyses by soil type.

| Soil Type | % Area | Mean | SD | 95% CI of Mean |
|---|---|---|---|---|
| OK003 (Conlen-Sunray) | 11.02 | 5.75 | 5.00 | 5.60- 5.90 |
| OK005 (Berthoud) | 21.23 | 9.33 | 7.50 | 9.17-9.49 |
| OK006 (Dallam-Dalhart) | 0.07 | 0.44 | 0.29 | 0.32-0.56 |
| OK007 (Dalhart) | 7.49 | 4.17 | 3.21 | 4.05-4.28 |
| OK008 (Dalhart) | 6.10 | 4.45 | 2.91 | 4.34-4.57 |
| OK010 (Gruver-Dumas) | 5.54 | 3.56 | 2.51 | 3.46-3.67 |
| OK011 (Sherm) | 12.54 | 4.77 | 4.41 | 4.65-4.89 |
| OK012 (Sherm) | 5.63 | 4.37 | 3.50 | 4.23-4.52 |
| OK013 (Ulysses-Darouzett) | 2.61 | 5.02 | 4.24 | 4.76-5.27 |
| OK014 (Conlen-Vona) | 10.59 | 6.93 | 5.33 | 6.77-7.09 |
| OK018 (Lesho-Gracemore) | 5.78 | 7.30 | 6.42 | 7.03-7.56 |
| OK021 (Mansic) | 2.56 | 3.76 | 2.57 | 3.60-3.92 |
| OK023 (Otero) | 6.69 | 5.16 | 3.62 | 5.01-5.29 |
| OK068 (Tivoli) | 2.15 | 6.90 | 3.53 | 6.66-7.13 |

Comparative Analysis of Sediment Yield

The following statistics were derived from data at the subbasins level. The average sediment yield for the pre-CRP scenario is about 3.06 tons/ha/year. The average sediment yield from subbasins in the post-CRP scenario is about 2.15 tons/ha/year (Table 3.17). The results show an overall reduction of 30% in sediment yield from Texas County after CRP is practiced.

Table 3.17: Statistical parameters for both scenarios pre and post-CRP.

| Scenario | No. of land covers | Mean (tons/ha/year) | Standard Deviation |
|---|---|---|---|
| Post-CRP | 10 | 2.15 | 4.13 |
| Pre-CRP | 9 | 3.06 | 6.14 |

### 3.4.2 Map Comparison and Areal Association

Areal association is the comparison of the spatial distributions of different variables (Taylor 1983). The purpose of map comparison is to find out common locations of two or more variables. Since we need to explain the spatial distribution of sediment yield in relation with CRP, a map of CRP area was compared visually to a sediment yield map. In general, if the relationship is not obvious, visual comparison of maps can be very unreliable and quantitative approaches to map comparison become necessary. Map comparison take visual comparison further step and tells us how much the two variables are areally associated by using statistical measures such as the coefficient of area. However, the most common approach to areal association is statistical correlation and regression.

Visual comparisons of maps can be useful in searching for relations between spatial distributions. However, quantitative approaches are much more reliable. Figure 3.29

shows the relationship of sediment yield and CRP area in its spatial form. The map represents the spatial distribution of the sediment yield with columnar representation of CRP areas in each subbasin. In general, the map indicates a considerable degree of areal association between the two variables.

The basic disadvantage of visual map comparison is that it involves subjective personal assumptions that may well vary between researchers. Inferences might be influenced by method of portraying variables. This technique is best when relationships between mapped variables is very strong. However, visual comparison does not specify the relative degree of the relationship between variables. Numerical assessments of areal association allow exact specification of the form of relations between variables (Taylor 1983).

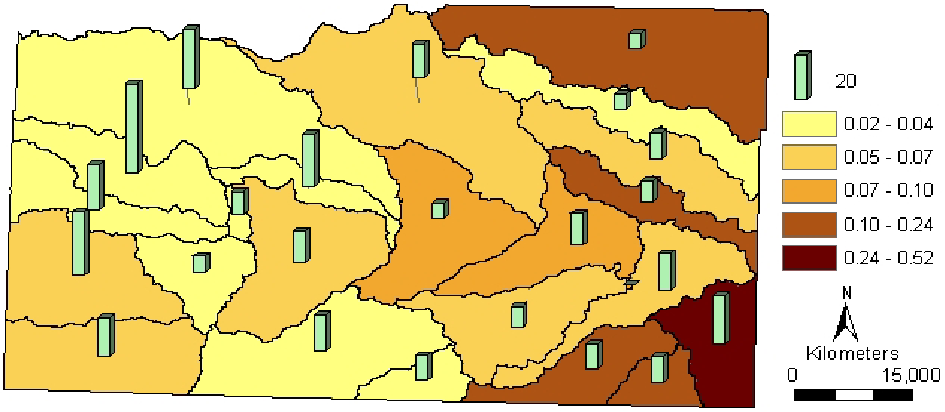

Figure 3.29: Visual comparison of the areal distribution of sediment yield and CRP tracts (columns) in Texas County within the Beaver River watershed.

### The Coefficient of Areal Correspondence

The coefficient of areal correspondence is a relative measure that relates the area of direct areal correspondence to that of possible correspondence (Taylor 1983). It is expressed as: $C_A = A \cap B / A \cup B$

$A \cap B$ is the area in which both variables are located together

$A \cup B$ is the area covered by either variable

The value of $C_A$ is 1 for complete correspondence and zero for no areal correspondence. To calculate the coefficient of areal correspondence we need to map areas of correspondence for both variables using statistical measures (mean and median) in combination with spatial analysis in Arc GIS. The GIS spatial analyses were employed to map areas of high sediment yield and examine its spatial association with area under CRP. The percentages of CRP in each subbasin were calculated (Table 3.18).

Normality and linearity tests revealed that the relationships of CRP and sediment yield are not linear (Figure 3.30). This is expected because of the nature of hydrochemical processes in any watershed (Nikolaids et al. 1998; Tong and Chen 2002). Using the median and mean of sediment yield, the subbasins were classified into three categories; high, medium or low depicting the subbasins with high, medium or low values of sediment yield (Figure 3.31). A similar procedure was used to classify the subbasins into three classes of CRP area; high, medium or low (Figure 3.32). Using Arc GIS the CRP and sediment yield maps were superimposed.

As shown in Figure 3.33, there were 12 subbasins that demonstrated the ideal association between CRP and sediment yield. Subbasins having high, medium or low sediment yield associate with subbasins of low, medium or high CRP area respectively because the relationship between sediment yield and CRP area is inversely proportional.

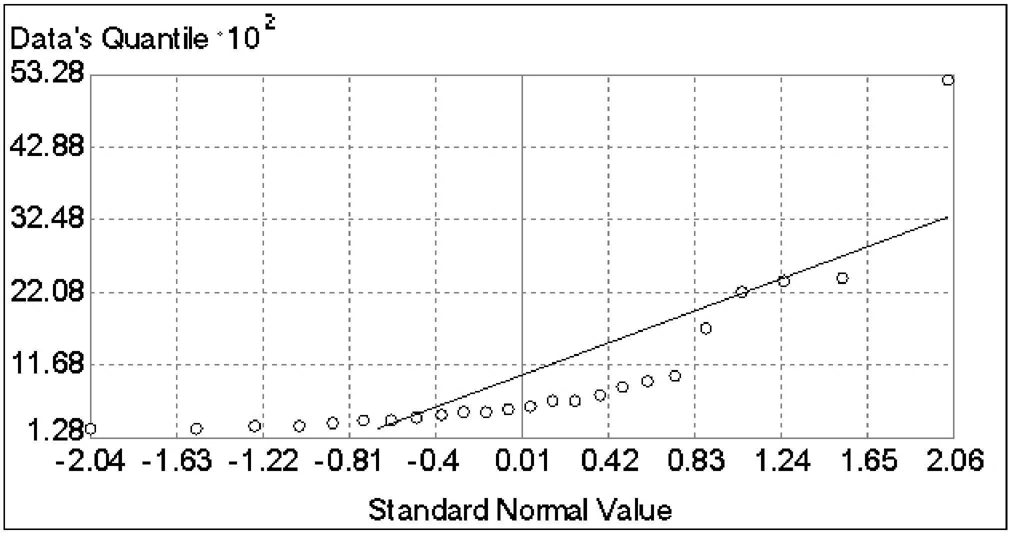

Figure 3.30: Nonlinear plot of sediment yield in Texas County within the Beaver River watershed.

Table 3.18: The percentages CRP area in subbasins within Texas County.

| *Subbasin* | *CRP% of subbasin area* |
|---|---|
| 1 | 6.64 |
| 5 | 7.22 |
| 6 | 11.57 |
| 8 | 9.07 |
| 9 | 25.83 |
| 10 | 22.52 |
| 11 | 38.75 |
| 12 | 20.39 |
| 13 | 15.19 |
| 14 | 6.72 |
| 15 | 9.53 |
| 16 | 6.78 |
| 17 | 15.60 |
| 18 | 21.29 |
| 19 | 13.99 |
| 23 | 27.94 |
| 24 | 16.90 |
| 27 | 16.20 |
| 28 | 10.70 |
| 29 | 11.06 |
| 30 | 11.66 |
| 51 | 13.96 |
| 53 | 8.85 |

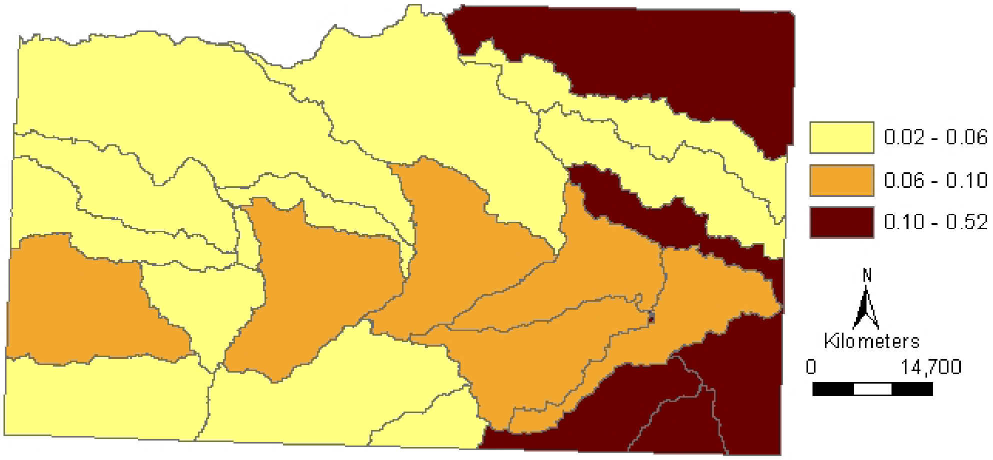

Figure 3.31: The categories of sediment yield: high, medium and low in Texas County within the Beaver River watershed.

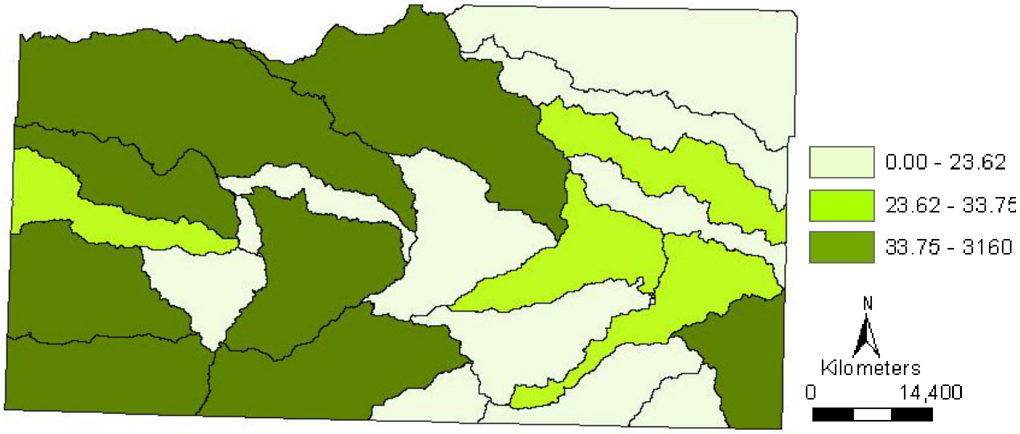

Figure 3.32: The categories of CRP area: high, medium and low in Texas County within the Beaver River watershed.

The output map (Figure 3.33) was used to calculate the areal correspondence ($C_A$). The areal correspondence for sediment yield and CRP area was 53%. The result indicates that positive associations of sediment yield and CRP area do exist in Texas County.

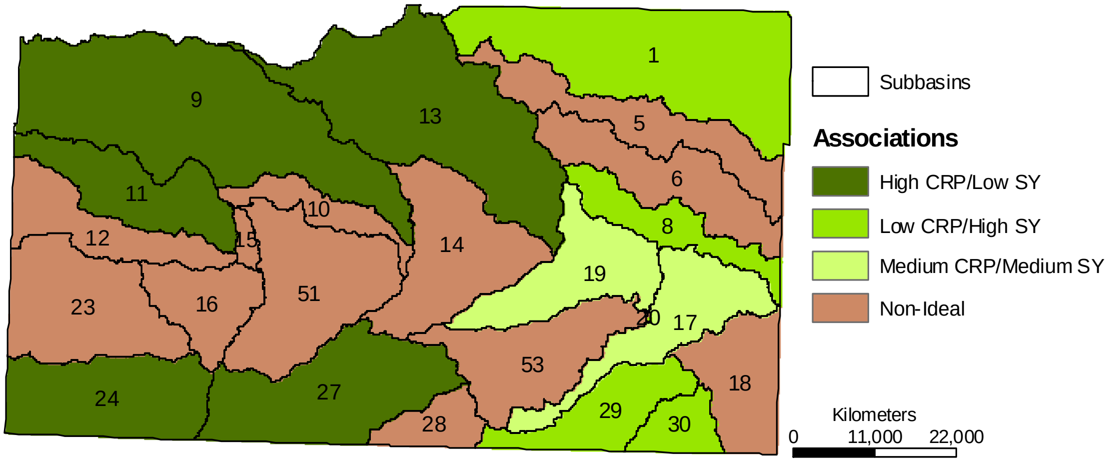

Figure 3.33: The ideal associations between CRP and sediment yield in Texas County within the Beaver River watershed..

## The Lorenz Curve

The Lorenz curve is a method of plotting two variables on a graph to illustrate the similarities in their areal distribution. Figure 3.34 is the Lorenz curve for CRP and sediment yield in Texas County. Deviations from the diagonal represent differences in the two distributions.

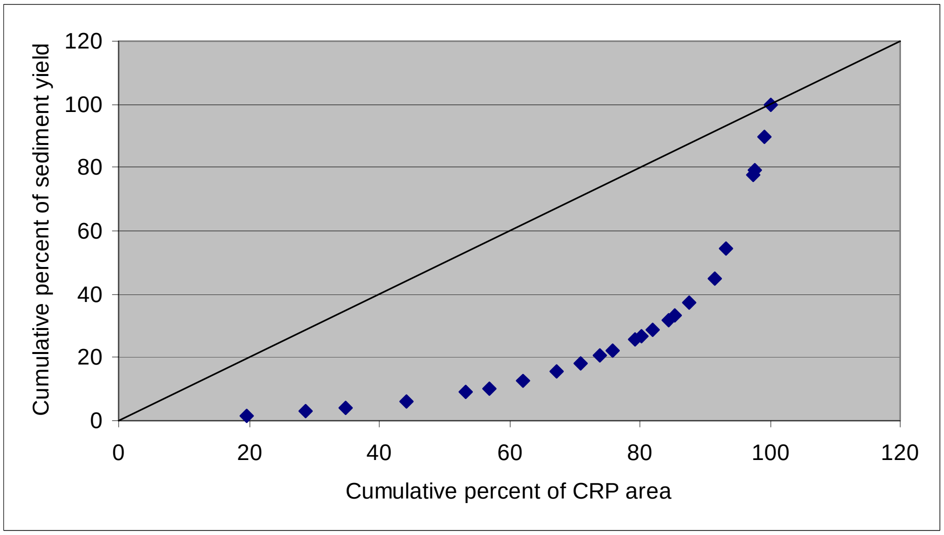

Figure 3.34: The Lorenz curve of sediment yield and CRP area in Texas County within the Beaver River watershed.

The index of dissimilarity $D_A$, is a measure of areal association derived from Lorenzo curve. $D_A$ is the maximum vertical distance between the diagonal and the curve (Taylor 1983). The value of $D_A$ is 1 for complete correspondence and zero for no areal correspondence. The formula for calculating $D_A$ is

$D_A = \sum |x_i - y_i|/2$

$D_A$ = maximum (cumulative percent of CRP - cumulative percent of sediment yield)

$x_i$ and $y_i$ are the uncumulated percentages for each variable.

The calculated dissimilarity index is equal to 53.40 for the variables sediment yield and area under CRP. The value $D_A$ indicates that CRP tracts are not localized in distribution.

### 3.4.3 Correlation and Regression

Correlation can be used to describe or predict linear relationships between two variables. The correlation between two variables reflects the degree to which the variables are related. Since data were tested and found not normally distributed, non-parametric statistical tests were used. Correlation of non-normally distributed variables can be computed using Spearman's correlation coefficient. Spearman correlation is based on ranking the two variables, and so makes no assumption about the distribution of the values. The degree of association is expressed by the correlation coefficient *r*.

Correlation analysis was conducted to test the relationship between sediment yield and CRP in Texas County. The calculations of *r* revealed that CRP area and sediment yield have good negative relationship with $r=-0.20$ at $\alpha=1\%$. The negative sign means an inverse relation between both variables. The greater the CRP area in a subbasin, the lower the sediment yield. Tong and Chen (2002) obtained similar results from the correlation of different land uses with water quality variables. They found that total nitrogen and total phosphorus were correlated with agriculture land use with *r* equal to 0.19 and 0.13 respectively.

Figure 3.35 is a scatter diagram of both variables. We can see that there is some sort of inverse linear relation between the two variables, although the data points are scattered around the line. This scatter of points is in part the result of the fact that any natural variable, such as land use, is one component of the complex real world. $R^2$ (0.04) is not significant at $\alpha = 1\%$, which is expected because the land use land cover (CRP) is only a minor variable among many variables that control the amount of sediment yield. Sediment yield is a function of soil, slope, runoff and land use.

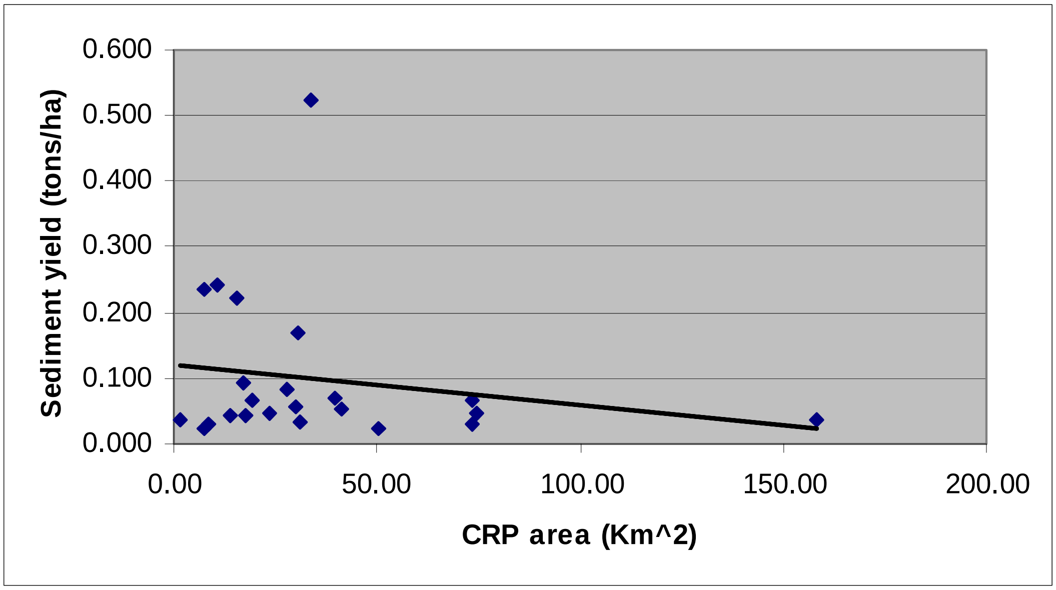

Figure 3.35: Scatter diagram of sediment yield and CRP area in Texas County within the Beaver River watershed.

A t-statistic for significance of the correlation coefficient *r* was computed to see if it was significant. The relationship between CRP area and sediment yield found to be not significant, equal to 0.172, at $\alpha = 1\%$. The significance of correlation depends upon the sample size (Rogerson 2001). Therefore, the matter of correlation is not absolute and is case dependent. If the available data were more than 24 observations (number of subbasins) the null hypothesis will be rejected. To answer the question: what is the relationship between CRP area and sediment yield a regression analysis was done. Linear regression allows the prediction of sediment yield, knowing the area of CRP. Sediment yield is the dependent variable and CRP area is the independent variable. The linear regression equation is

$$Y = 0.000006x + 0.120216$$

Y is the sediment yield and X is the CRP area. Using the equation we can predict the sediment yield knowing the area of CRP tracts in a subbasin.

## 3.5 CRP AND WIND EROSION

Generally, water erosion potential is lower than wind erosion potential in areas of the Southern Great Plains such as Texas County, but most water erosion occurs during occasional intense storms (Unger 1999). Soils in semi-arid portions of the southern Great Plains range from loamy sands to clay loams. The wind erosion potential often is high on dryland because of limited plant growth and failure to use conservation tillage that involves crop residue retention on the soil surface. A grass cover helps control wind erosion by reducing wind speed at the soil surface. Without such cover, erosion potential is affected by surface soil aggregate size and stability. Dry surface aggregates with greater than 0.84mm in diameter are generally considered nonerodible (Unger 1999). The wind erodibility index (WEI) is calculated using the formula:

$$\text{Wind Erodibility Index} = C*SEI/T$$

C: wind erosion factor,
SEI: soil erodibility index
T: soil loss tolerance

The major problem in Texas County is wind erosion, not the rill and sheet erosion. For Texas County wind erosion factor (C) is always a 100 and soil loss tolerance is 5 tons/acre (Sample 2003). The above equation does not account for vegetation cover. The wind erodibility index is based solely on soil characteristics. Figure 3.36 shows the soil erodibility index (SEI) mapped based on SSURGO database. Figure 3.37 is the WEI map using the above equation. Table 3.19 lists examples of the wind erodibility index for some soils series in Texas County.

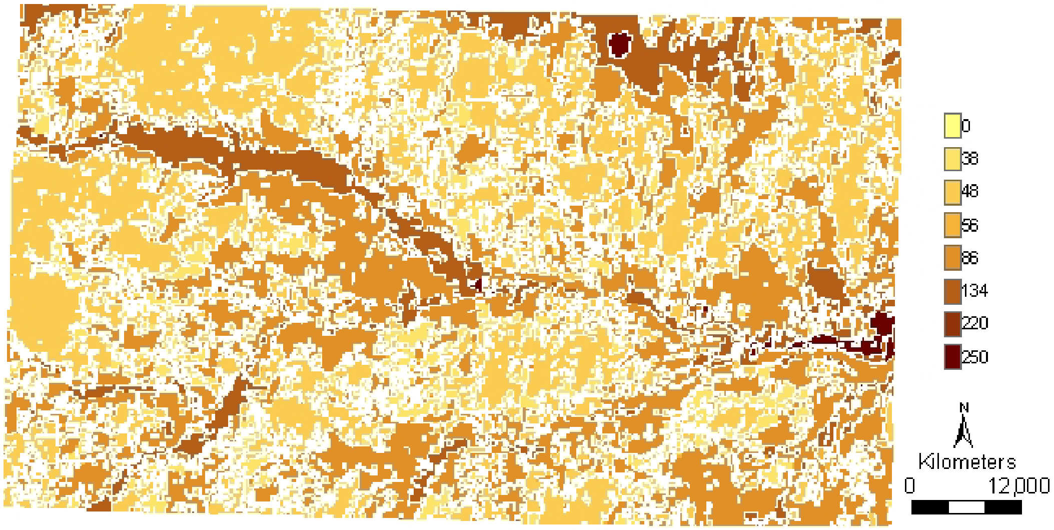

Figure 3.36: Map of soil erodibility index (SEI) in Texas County (tons/acre).

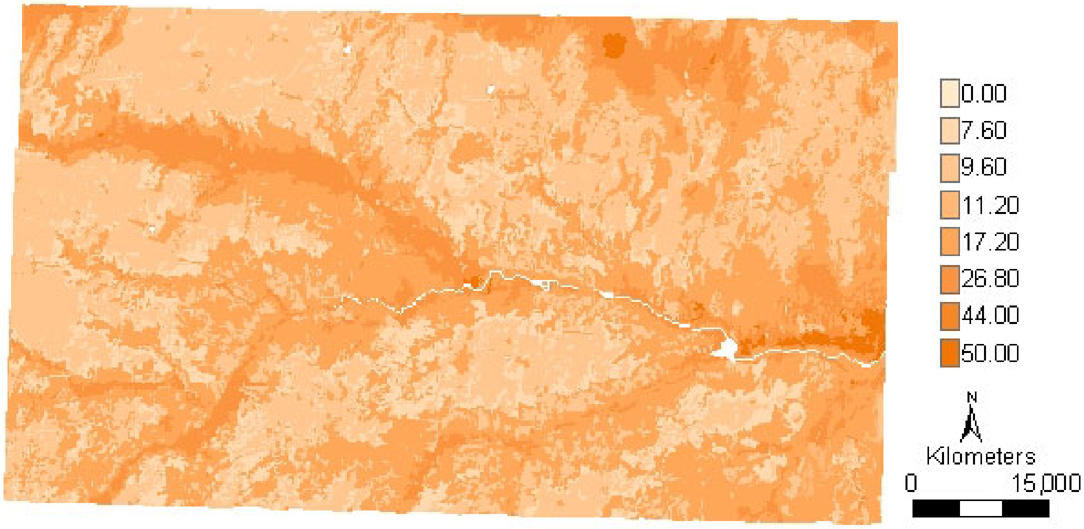

Figure 3.37: Map of wind erodibility index (WEI) in Texas County (tons/acre).

Table 3.19: Wind erodibility index of example soil series in Texas County.

| Series | Soil erodibility index | Wind erodibility index (tons/acre/yr) |
|---|---|---|
| Gruver, Sherm, Ulysses | 48 | 9.60 |
| Conlen, Berthoud, Dalhart, Lesho, Otero | 86 | 17.20 |
| Vona | 134 | 26.80 |

Figure 3.38 shows that the wind erodibility index ranges between 0 and 50 tons/acre/year. But two indices are most dominant in the county, 9.60 and 17.20 tons/acre/year with 38.68% and 38.57% of the total area respectively. Figure 3.39 displays the relationship between wind erodibility index and CRP in Texas County. Surprisingly the map shows that CRP does not exist in areas of high wind erodibility index (17.20 tons/acre/year) and more. It is rather found in areas of relatively low wind erodibility index. Comparing the WEI map with the LULC we find that the high values of WEI are in the rangeland and along the riparian areas.

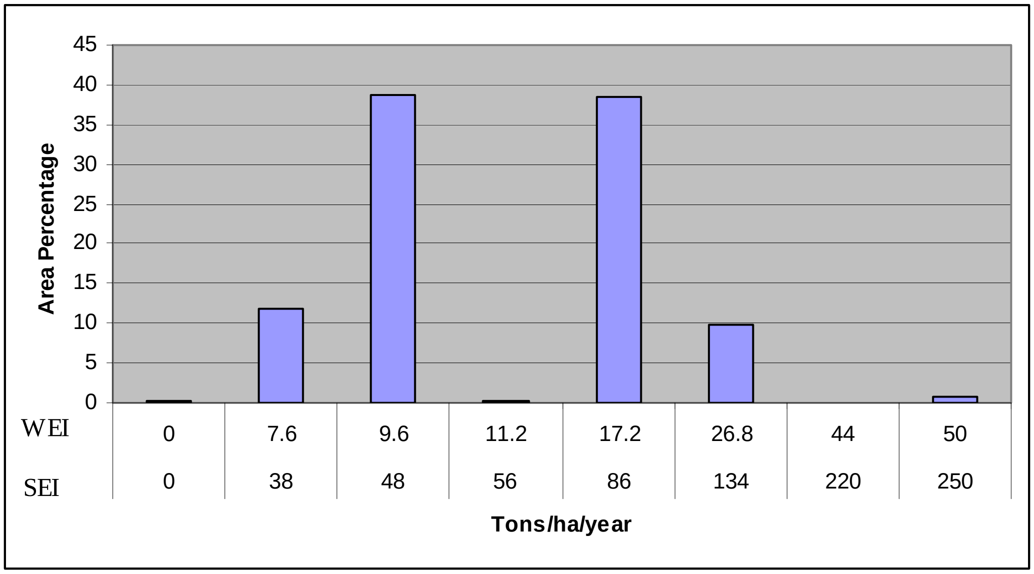

Figure 3.38: Wind erodibility index (WEI) and soil erodibility index (SEI) by area percent in Texas County.

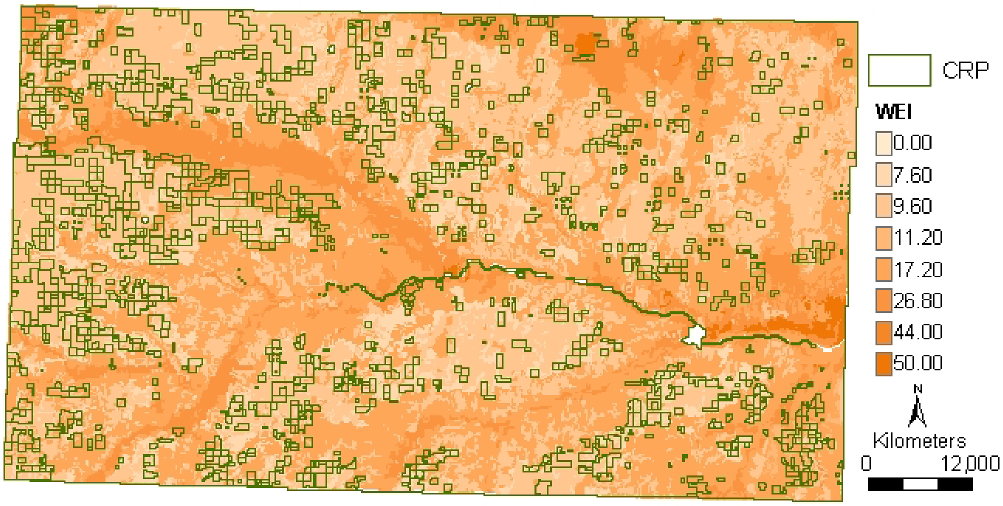

Figure 3.39: Relationship between wind erodibility index and CRP in Texas County.

## 3.6 WATER QUALITY

Today large quantities of fertilizers are applied to agricultural lands to meet the increase and need for food products. Changes in land use and increased application of fertilizers correlate strongly with the degradation of water quality. In the event of a major storm agricultural chemicals and sediments are transported in runoff and pollute drinking water resources. Water resource managers are responsible for maintaining water supplies and quality standards as the water demand increases and as land use changes (Perkins and Sophocleous 1999).

The U.S. Environmental Protection Agency (USEPA 1996) has identified eutrophication as the most ubiquitous water quality impairment in the United States. Eutrophication is a result of the over-discharge of nutrients by municipal, industrial and agricultural resources. Eutrophication restricts water use for fisheries, recreation, industry and municipalities through the increased growth of undesirable algae and aquatic weeds and the oxygen depletion caused by their death and decomposition (Yang et al. 1999). Nonpoint source pollution (NPS) arises from different diffuse sources that are normally associated with agricultural and human activities in a watershed. NPS pollutants such as nutrients, pesticides and sediments are transported from the land by atmospheric, surface water, and groundwater pathways (Nikolaidis, et al. 1998). NPS is difficult to control because its sources are attributed to a large area rather than to one particular discharge location. NPS nutrients, mainly nitrogen and phosphorus, are responsible for the eutrophication and reduced aesthetics of rivers and lakes (Nikolaidis, et al. 1998).

In agriculturally dominated watersheds, water quality is mainly affected by soil erosion and the resulting suspended sediment load. However, leaching of fertilizers is a key process, which derives solutes from agricultural fields (Mattikalli and Richards 1996). Thus, nitrogen, phosphorus and suspended sediment have been considered to be important parameters to portray the quality of surface water. The following sections deal with analyzing the relationship between water quality variables and sediment yield. Since there were no data with which to calibrate the nutrients all results were compared on a relative basis.

### 3.6.1 Phosphorus Loading

Phosphorus is required for many essential plant functions. The most important role is in energy storage and transfer. Energy obtained from photosynthesis and metabolism of carbohydrates is stored in phosphorus compounds for later use in growth and reproductive processes (Neitsch et al. 2002). Because of the time and expense involved in the field assessment of management impacts on P loss from agricultural watersheds, models often represent a more efficient and feasible means of evaluating management alternatives. SWAT provides estimates of runoff water quality to quantify the effects of different management practices in agricultural watersheds.

In Texas County the maximum phosphorus loading comes from subbasin numbers 18 and 20 for pre and post-CRP scenarios respectively (Figure 3.40 and Figure 3.41). The minimum phosphorus loading is 0.006 kg/ha/year (subbasin number 28) for the post-CRP scenario and about 0.012 kg/ha/year (subbasin number 8) for pre-CRP scenario. The spatial distribution of total phosphorus is closely similar to that of the sediment yield. Figure 3.42 depicts the changes in total phosphorus between pre- and post-CRP.

Dryland wheat is the crop that shows highest loadings of total phosphorus with an average of 3.33 kg/ha/year (Table 3.20). Pasture shows no phosphorus loadings but CRP shows 0.04 kg/ha/year. All subbasins show reduction in phosphorus loadings. Many of the subbasins show significant reduction with more than 50% namely; subbasins 12, 13, 20, 23 and 19.

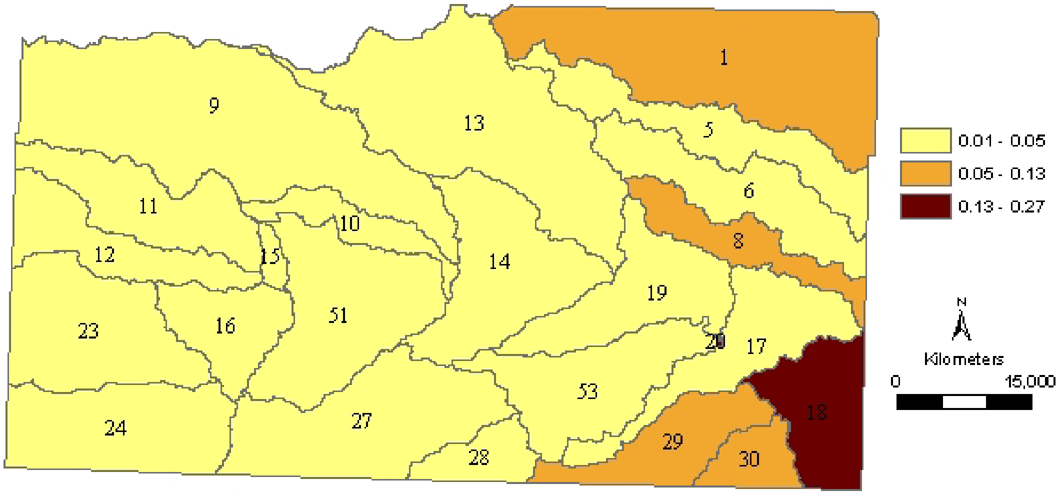

Figure 3.40: Pre-CRP average yearly total phosphorus (kg/ha) in Texas County within the Beaver River watershed from SWAT simulations (40 years).

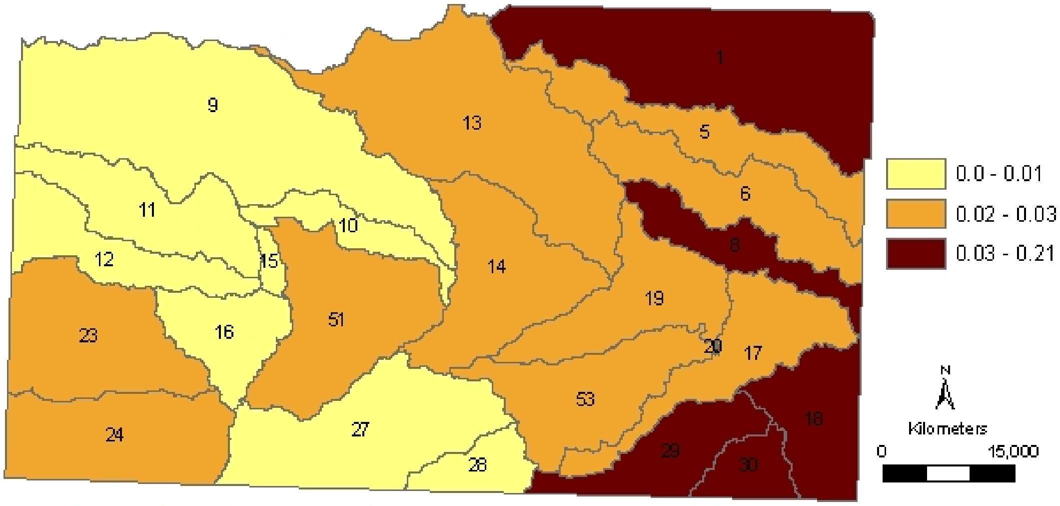

Figure 3.41: Post-CRP average yearly total phosphorus (kg/ha) in Texas County within the Beaver River watershed from SWAT simulations (40 years).

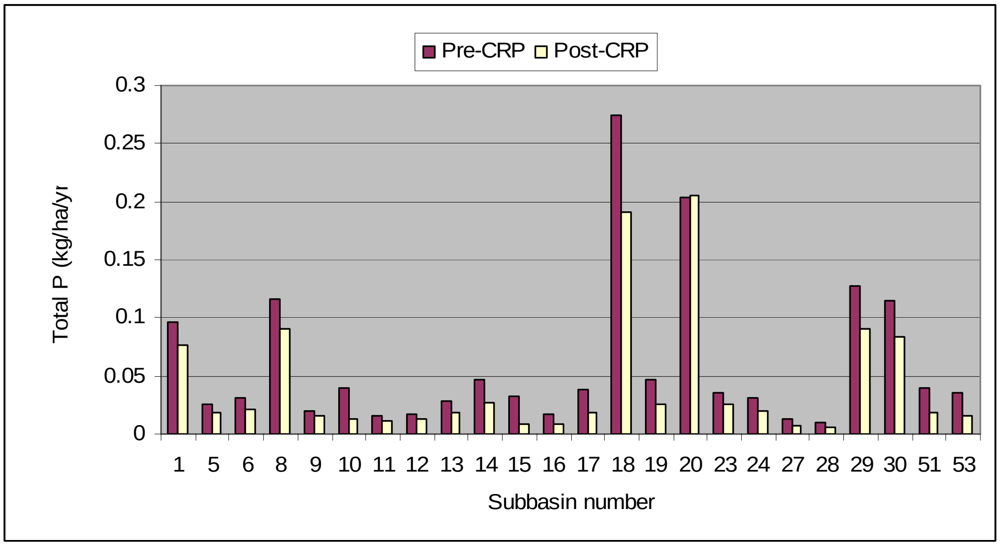

Figure 3.42: Change in total phosphorus in Texas County within the Beaver River watershed from SWAT simulations (40 years).

The percentages of reduction in total phosphorus show the same trend of sediment yield. Subbasins showing high percentage of reduction in sediment yield show high reduction in total phosphorus but not in the same proportions.

Table 3.20: Total phosphorus by land cover.

| Land cover | Total P kg/ha/yr |
|---|---|
| General Agriculture | 0.19 |
| Corn | 0.71 |
| CRP | 0.04 |
| Irr. Sorghum | 0.26 |
| DL Sorghum | 0.09 |
| Pasture | 0 |
| Range | 0.032 |
| Irr Wheat | 1.5 |
| DL Wheat | 3.33 |
| Commercial | 0.01 |

### 3.6.2 Nitrogen Loading

Plants require nitrogen more than any other essential element, excluding carbon, oxygen and hydrogen. There are three major forms of nitrogen in mineral soils: organic nitrogen associated with humus, mineral forms of nitrogen held by soil colloids, and mineral forms of nitrogen in solution (Neitsch et al. 2002). The spatial distribution of nitrogen loading follows the same spatial distribution of sediment yield. Figures 4.43 and 4.44 show the spatial distribution of total nitrogen pre- and post-CRP scenarios. The subbasin sources of minimum (0.012 and 0.018 kg/ha/year) and maximum (0.433 and 0.319 kg/ha) nitrogen loading are the same in both scenarios. Again the relationship between CRP area and reduction in nitrogen loading is nonlinear. Figure 3.45 shows the percentage of reduction in nitrogen loadings due to CRP. The loading by land cover (Table 3.21) is highest from wheat fields with an average of 0.80 kg/ha/year. CRP tracts deliver 0.05 kg/ha/year but range and pasture show no loading.

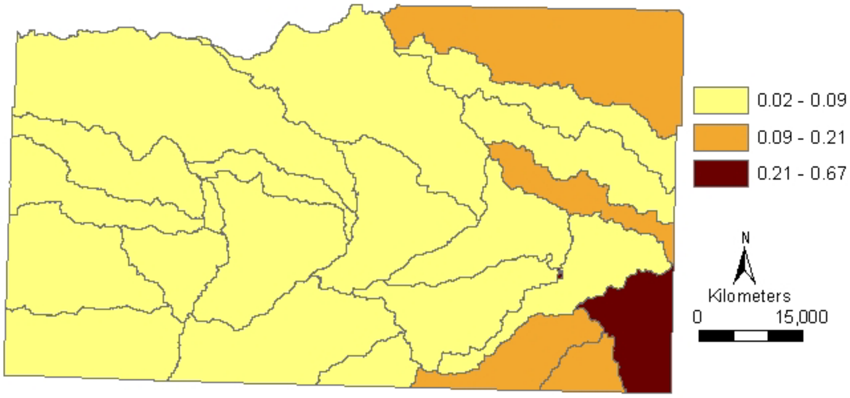

Figure 3.43: Pre-CRP average yearly total nitrogen (kg/ha/year) in Texas County within the Beaver River watershed from SWAT simulations (40 years).

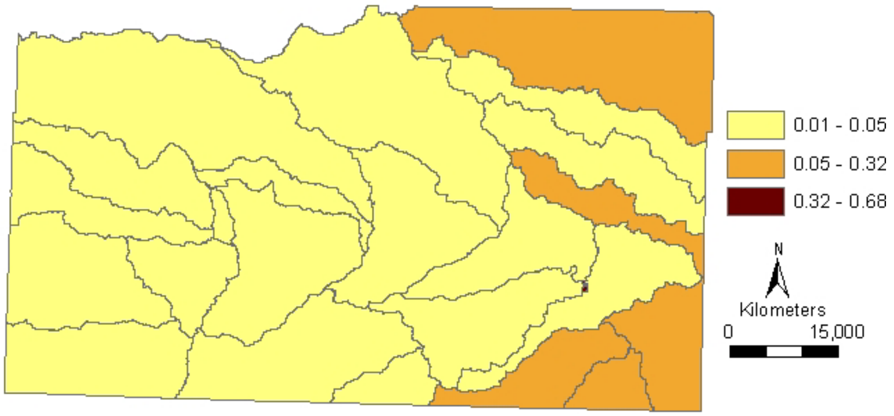

Figure 3.44: Post-CRP average yearly total nitrogen (kg/ha/year) in Texas County within the Beaver River watershed from SWAT simulations (40 years).

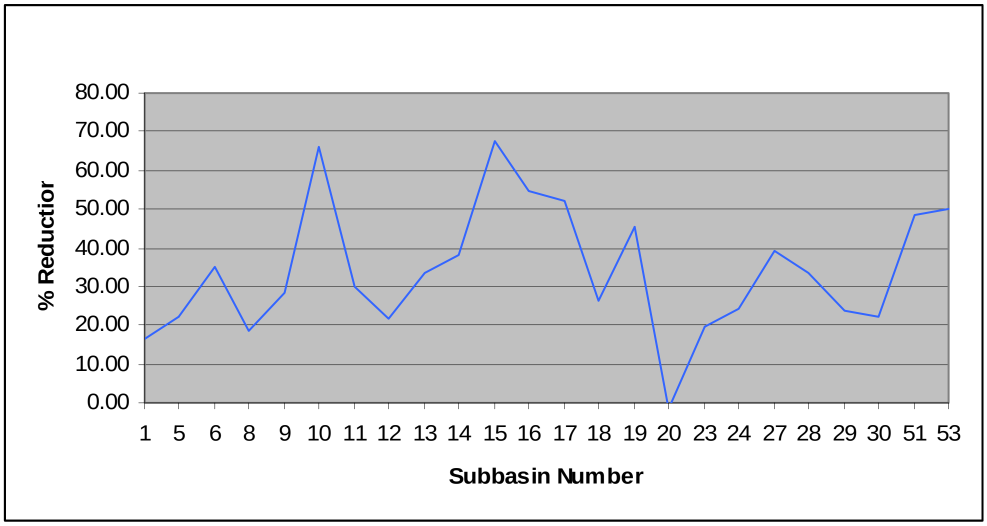

Figure 3.45: Percentage of reduction in total nitrogen between pre- and post-CRP Pre-CRP average yearly total nitrogen (kg/ha/year) in Texas County within the Beaver River watershed from SWAT simulations (40 years).

Table 3.22 and Figures 3.46 and 3.47 show the contribution of each land cover in percent toward the loading of several water quality elements. Wheat accounts for about

71% of the total phosphorus and about 54% of sediment-bound phosphorus. Sorghum and corn combined accounts for about 17% of the sediment-bound phosphorus.

Table 3.21: Total nitrate loadings by land cover.

| Land cover | Total N kg/ha/yr |
|---|---|
| General Agriculture | 0.21 |
| Corn | 0.18 |
| CRP | 0.05 |
| Irr. Sorghum | 0.05 |
| DL Sorghum | 0.02 |
| Pasture | 0.00 |
| Range | 0.00 |
| Irr Wheat | 0.34 |
| DL Wheat | 0.80 |
| Commercial | 0.12 |

Table 3.22: Nutrients by land cover in percentage.

| Land cover | ORGN | ORGP | SEDP | NSURQ | SOLP | SURQ |
|---|---|---|---|---|---|---|
| General Agriculture | 10.05 | 16.88 | 3.08 | 11.85 | 0.60 | 0.299 |
| Corn | 6.44 | 4.22 | 11.52 | 10.16 | 12.08 | 5.966 |
| CRP | 1.46 | 1.27 | 0.65 | 2.82 | 0.60 | 7.627 |
| Irr. Sorghum | 2.70 | 2.11 | 4.22 | 2.82 | 6.04 | 3.322 |
| DL Sorghum | 1.11 | 1.27 | 1.46 | 1.13 | 2.11 | 2.085 |
| Pasture | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.011 |
| Range | 0.06 | 0.00 | 0.52 | 0.00 | 0.00 | 0.143 |
| Irr Wheat | 23.98 | 21.94 | 24.34 | 19.30 | 21.15 | 23.02 |
| DL Wheat | 53.36 | 50.63 | 54.04 | 45.15 | 51.36 | 53.25 |
| Commercial | 0.83 | 1.69 | 0.16 | 6.77 | 6.04 | 4.277 |

Nitrate, soluble phosphorus and organic nitrogen are also closely associated with wheat fields. Wheat also contributes to about 77% of the total nitrogen and about the same amount for the organic nitrogen. But only contribute about 64.50% of the nitrogen transports with surface runoff. Corn and sorghum accounted for 13.70% and 6.70% of the total phosphorus. But they accounted for only 8.0% and 2.40% of the total nitrogen.

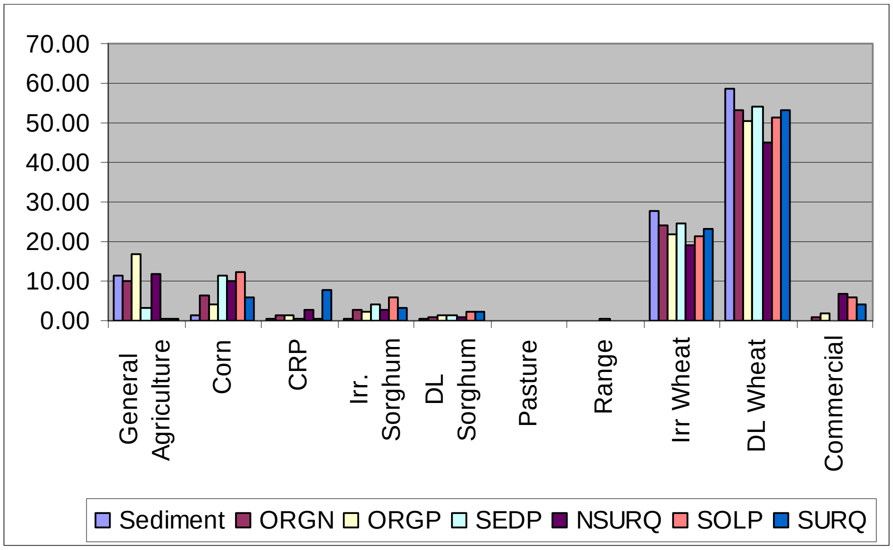

Figure 3.46: SWAT predicted land cover sediment and nutrient comparisons in Texas County within the Beaver River watershed derived from 40-year simulation.

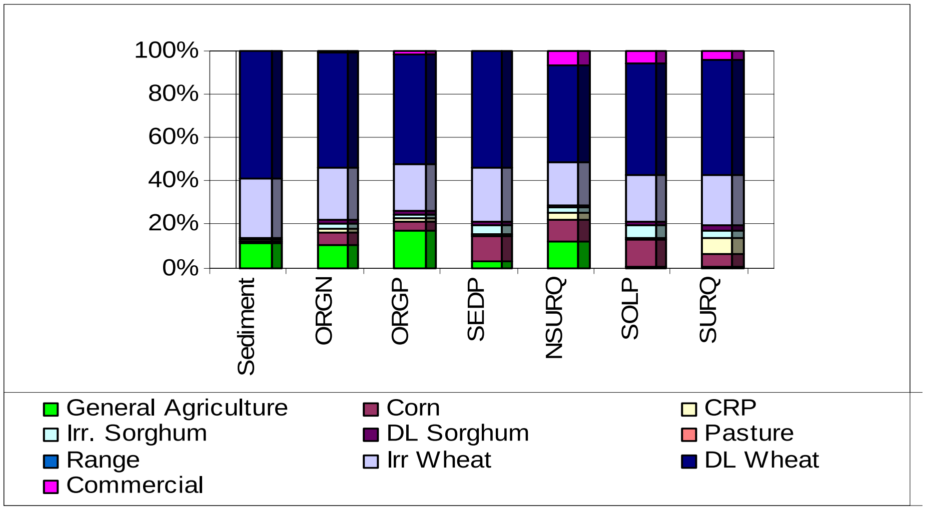

Figure 3.47: Relative contribution of each land cover to the total county load in Texas County within the Beaver River watershed derived from a 40-year simulation.

## 3.7 CRP AND LANDSCAPE STRUCTURE

The CRP was initiated to reduce soil loss on highly erodible agricultural land. However, there are other secondary environmental benefits to the program such as ecological benefits that deserve evaluation. These benefits include decreasing landscape fragmentation, enhancing biodiversity, and establishing wildlife habitat. These benefits must be accounted for before renewal of the program. The purpose here is to quantify these secondary ecological benefits of the CRP that were not a primary goal of this research. Land use change within a region has not only an impact on various hydrologic landscape functions but also affects the habitat quality and thus the biodiversity of a landscape (Fohrer et al. 2002).

Plowing of large areas in the US Great Plains in historic times has caused reduction and fragmentation of the natural habitats (grasslands, wetlands and woodlands) for wildlife species (Peterson et al. 2001). Fragmentation is defined as the breaking up of the larger habitat or land areas into smaller parcels (Forman 1997) by either natural or anthropogenic agents. Fragmentation reduces biodiversity, increases the local extinction of flora and fauna, increases the vulnerability of patches to external disturbances including windstorms and drought (Nilsson and Grelsson 1995), increases the number of edge species, and reduces the number of interior birds present (McIntyre 1995). If regional landscape fragmentation continues, fewer and smaller grasslands would result. Small grasslands are unsuitable for large wide-range dwelling wildlife species. Forys and Humphrey (1999) found that patch isolation and patch area were positively correlated with patch occupancy. Fragmentation of grassland on the Great Plains has caused the reduction in the number of breeding bird species. Minimum acceptable patch size varies by species, ranging from 5 to 55 ha (Egbert et al. 2002). Helzer and Jelinski (1999) examined species richness for grassland birds and found that the species richness is maximum when the patch size is large (>50 ha) and free from the impacts of edges.

Landscape structure is an important element in wildlife habitat. For example, some species require minimum patch area, others prefer short distances between patches to facilitate species colonization (Egbert et al. 2002). The grasslands of the CRP are new land covers that constitute a major increase in potential wildlife habitat. Kantrud (1993) found that CRP fields provided more secure nesting areas of upland-nesting ducks in the Prairie Pothole region in North Dakota. Isolated grasslands are brought close together, in the sense that some landscape connectivity would be established (Dunn et al. 1993). CRP resulted in both more edge and more interior habitat (Dunn et al. 1993). Many other studies proved the benefits of the CRP grasslands to the wildlife habitat (Berthelsen and Smith 1995, Howell and Issacs 1988). Dunn et al. (1993) studied the changes in landscape structure of woodlots in Cadiz Township, Wisconsin. They reported an increase in total forest area, number of woodlots, average woodlot size, total edge and average distance between woodlots due to CRP.

CRP lands constitute an important habitat for wildlife species because most CRP fields consist of large unbroken tracts-often 36 ha or more (Egbert et al. 2002). In this section the effect of CRP on spatial patterns is examined by analyzing changes in landscape metrics within the boundaries of Texas County. To examine landscape structure statistical measures of the characteristics of patches that make up the landscape were calculated. The extension Patch Analyst (grid version) was used to calculate landscape metrics for the pre-CRP and post-CRP grassland. Patch analyst is an extension to the ArcView GIS system that facilitates the spatial analysis of landscape patches, and modeling of attributes associated with patches. The extension includes patch analysis functions developed using Avenue code, and interface to the FRAGSTATS spatial pattern analysis program developed by McGarigal and Marks (1994).

Table 3.23 summarizes the results of the landscape metrics analysis. The area of grassland has increased from 315,000 ha in the pre-CRP scenario to 349,000 ha in the post-CRP scenario. The increase in the area of grassland by 7% from pre-CRP to post-CRP scenario indicates that grassland was not converted to cropland during the course of CRP enrollment. The mean patch size increased from 24.7 to 36.68 ha. The total number of patches has declined by 24% from 12,750 to 9,650. This could be explained by the role of CRP in coalescing the small grassland parcels into single large parcels. Upon this decrease in the number of patches the perimeter of grassland is expected to decrease too. Large patches are essential to many area-sensitive biota (Bender et al. 1998). Many species of grassland birds, for example, are area sensitive and most species require large grass-dominated patches without trees and with low perimeter-area ratios for breeding territories (Helzer and Jelinski 1999; Herkert 1994). Grassland enchroachment by woody vegetation compounds the effects of habitat losses from agriculture alone because many species are intolerant of even small amounts of woody vegetation (Herkert 1994). The mean shape index (MSI), measure of shape complexity with lower numbers, representing simple compact shapes such as circles and squares. The mean shape index and area-weighted MSI decreased from 1.28 to 1.26 and from 51.46 to 47.41 respectively. This decrease reflects the occupation of CRP to large square or rectangular blocks of land (Egbert et al. 2002). The mean shape index values for both scenarios are greater than 1, indicating that the average vegetation patch shape in all landscapes is non-square (Apan et al. 2000). However, there is no significant change in the shape index values. The metric nearest neighbor distance measures the mean distance between patches of the same type. The value of this metric decreased from 55.04 to 52.2 between pre-CRP and post-CRP, indicating the increased clustering of patches in the study area and that the inter-patch connectivity has increased (Apan et al. 2000). This is supported by the mean proximity index values (increased from 874,700 to 1,176,176). It is also evidenced by the decrease in edge density from 37.43 to 33.68.

Table 3.23: Grassland landscape metrics pre- and post-CRP in Texas County.

| Metric | Pre-CRP | Post-CRP |
|---|---|---|
| Grassland area (ha) | 315000 | 349000 |
| Percent area in grassland | 62% | 69% |
| Number of patches | 12754 | 9666 |
| Mean patch size (ha) | 24.7 | 36.11 |
| Total edge (km) | 18900 | 17000 |
| Edge density (m/ha) | 37.43 | 33.68 |
| Mean shape index | 1.28 | 1.26 |
| Area-weighted MSI | 51.64 | 47.41 |
| Mean nearest neighbor distance (m) | 55.04 | 52.2 |
| Mean proximity index (m) | 874700 | 1176176 |

Previous studies have shown that many bird species benefit from grassland habitats established by the CRP (Patterson 1994; Kantrud 1993; King 1991). Johnson et al (1995) found that CRP fields are especially important for grassland birds during the breeding season, including Sedge Wrens, Grasshopper Sparrows, Savannah Sparrows, Dickcissels, Lark Buntings, Red-winged Blackbirds, Common Yellowthroats, Clay-colored Sparrows, and Bobolinks.

Recent analysis of breeding bird survey data (BBS) (USGS Patuxent Wildlife Research Center. 2004) indicates that some species that were declining in North Dakota before the CRP began such as the Grasshopper Sparrow and the Lark Bunting, have shown population increases coincident with the establishment of perennial grasslands after the CRP began (Reynolds et al. 1994).

Recent evidence suggests that CRP also benefits grassland bird populations in other areas of intensive agriculture such as the Midwest. In Nebraska, King (1991) found 16 species of birds in CRP fields and 13 species in native prairie during the breeding season, compared with only two species, Horned Lark and Killdeer, in cropland. Likewise, in Iowa, Patterson (1994) found 16 species of birds nesting in CRP fields compared with only two species, Horned Lark and Vesper Sparrow, in similar areas of cropland.

In Texas county two sets of data were derived from the BBS database (North American Breeding Bird Survey 2004). Data for two BBS routes in Texas County were analyzed. Figure 3.48 shows the changes in population of birds pre- (1974-1984) and post-CRP (1990-2000). In general, the figure shows the about 58% increase in the population of birds with a mean value of 1500 birds for the post-CRP compared to about 950 birds for the pre-CRP.

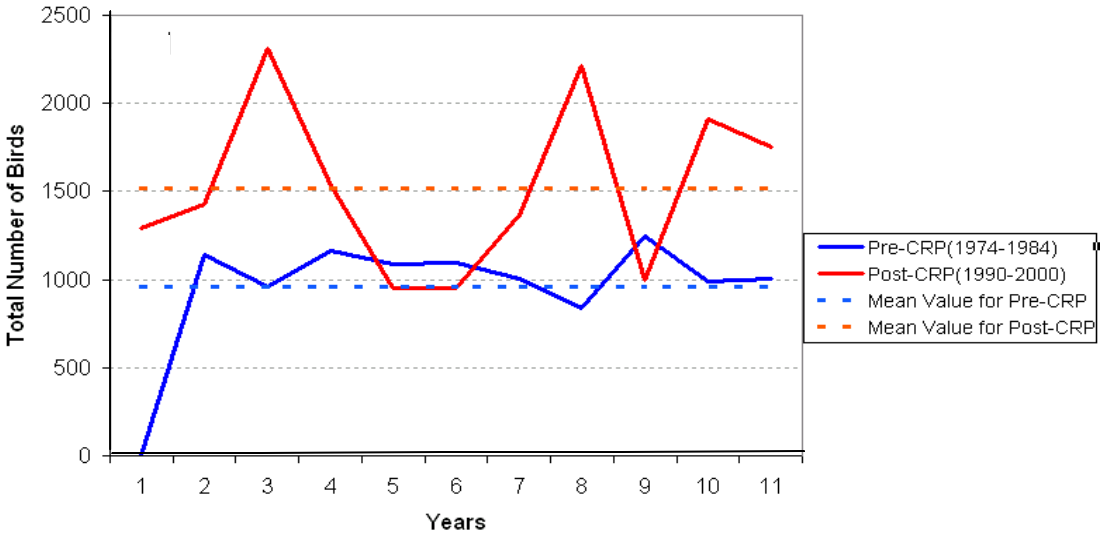

Figure 3.48: Variation in bird population during pre- and post-CRP in Texas County, Oklahoma

Table 3.24 lists the correlation coefficients between sediment yield and landscape metrics of grassland. As we can see, the mean patch size shows the highest inverse correlation with sediment yield (*r* = -0.27). Mean patch edge also shows high correlation with *r* -0.25. Edge density is the only variable showing positive correlation with sediment yield. However, the correlations between all landscape metrics and sediment yield are non-significant. Figure 4.48 and 4.49 are scatter diagrams showing the negative trendline of sediment yield with mean patch size and mean patch edge.

Table 3.24: Correlation coefficients of sediment yield with landscape metrics of grassland.

| *Variable* | *Correlation Coefficient* | *Significant value* |
|---|---|---|
| Total landscape area | -0.179 | 0.414 |
| Number of patches | -0.103 | 0.640 |
| Mean patch size | -0.270 | 0.213 |
| Median patch size | -0.142 | 0.517 |
| Total edge | -0.144 | 0.511 |
| Edge density | 0.174 | 0.428 |
| Mean patch edge | -0.256 | 0.238 |
| Mean shape index (MSI) | -0.214 | 0.327 |
| Area-weighted MSI | -0.156 | 0.477 |

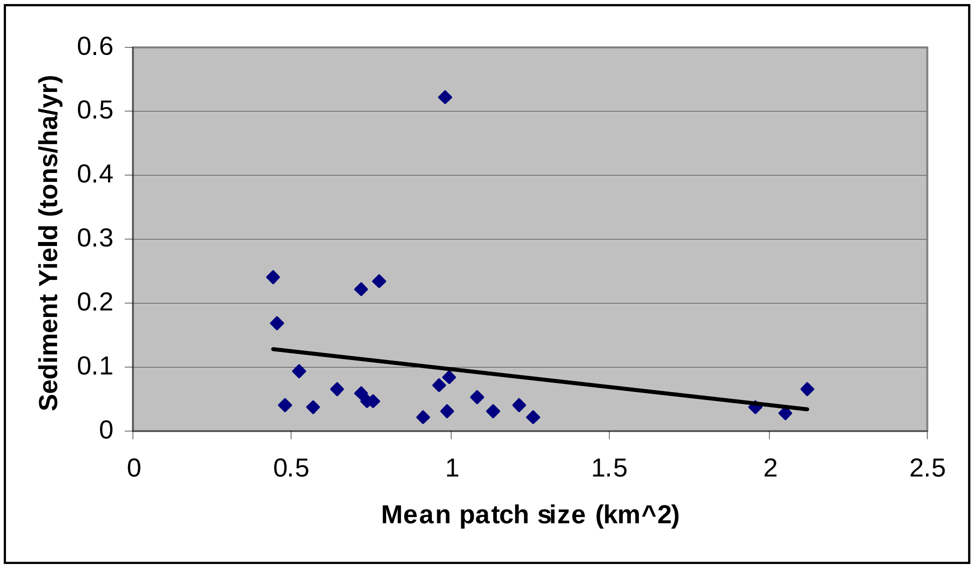

Figure 3.48: Scatter diagram of CRP mean patch size vs sediment yield in Texas County within the Beaver River watershed.

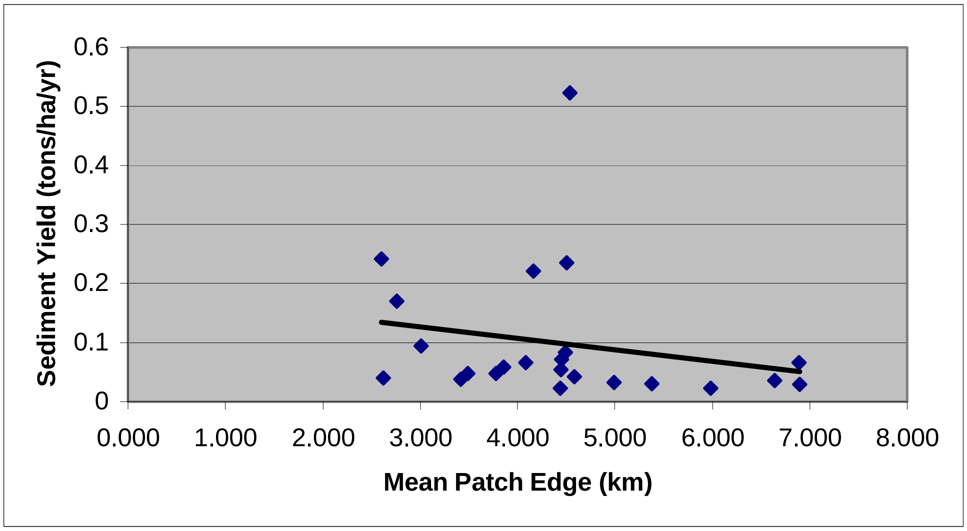

Figure 3.49: Scatter diagram of CRP mean patch index vs sediment yield in Texas County within the Beaver River watershed.

# Chapter 4 SUMMARY, CONCLUSIONS and FUTURE WORK

## 4.1 SUMMARY

With soil conservation as the principal environmental problem, the Conservation Reserve Program (CRP) was initiated in 1985 with the passage of the Food Securities Act. The CRP is a voluntary program in which landowners are encouraged to remove highly erodible land from production and plant native grasses or other protective vegetation for 10-15 years. Farmers are paid an annual per-acre rent, plus one-half of the costs of establishing permanent land cover (Young and Osborn 1990, USDA Farm Service Agency 2003a). The CRP was established primarily to bring crop production more in line with demand and to conserve and improve soil and water quality. The emphasis was on reduction of soil erosion and stream sedimentation and on improvement of water quality on erodible or eroding lands and tilled wetlands (Hughes et al. 1995).

The primary goal of this research was to evaluate the environmental benefits of the Conservation Reserve Program (CRP) in Texas County, Oklahoma. Another goal was to identify priority areas for future CRP enrollment. This study tried to address the following objectives:

1. Evaluating changes in soil erosion potential due to CRP.
2. Evaluating the effect of CRP enrollment on water quality.
3. Determining the relative sources of sediments, nitrogen and phosphorus.
4. Delineating suitable zones for future CRP enrollment, in particular identifying critical erosion areas within the Texas County.
5. Evaluating the benefits of CRP for wildlife habitat.

Texas County, the study area of the project, ranks first in the state in terms of CRP enrollments. The GIS-integrated hydrologic model AVSWAT (ArcView–Soil and Water Assessment Tool) was used to evaluate the potential environmental benefits of the CRP in terms of soil and water quality. AV-SWAT is a public domain hydrologic model developed by the USDA-ARS, Temple, Texas. SWAT simulates the effect of management decisions on water, sediment, nutrient and pesticide yields with reasonable accuracy on large, ungaged river basins. SWAT is a physically based model capable of simulating long periods of management operations. It is a distributed hydrologic model (Arnold et al. 1998) that allows a watershed to be subdivided into smaller subbasins to incorporate spatial detail. SWAT uses a two-level disagregation scheme; a preliminary subbasin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. The physical properties inside each subbasin are then aggregated with no spatial significance. Available NRCS databases and the ArcView GIS provided input into SWAT.

Some of the input data for Texas County include DEM (30m), soils (STATSGO), LULC (CRP and other cover types), management practices (acquired from County Extension Offices) and weather (Cooperative Observer Program, COOP). The Beaver River Watershed was subdivided into 53 sub-basins using the DEM as the base data source. The CRP tracts in Oklahoma were evaluated in terms of soil loss, phosphorus and nitrogen loadings. The CRP was also evaluated for changes in landscape structure and its benefits to the wildlife habitat. The SWAT model was calibrated using two USGS stream gage stations (Guymon and Beaver River), and then the average sediment yield was estimated from 40 years of simulation.

A large amount of data is involved in modeling a natural landscape. The management, manipulation, and analysis of large volumes of data can be an impediment. GIS technology has improved the ability of scientists to use and manage large amounts of spatially distributed modeling data. By using GIS the large amounts of model input can be efficiently manipulated and spatially organized. Therefore, a detailed model can become more accurate and inexpensive to implement (Liao and Tim 1994). GIS is ideally suited for input data management and output visualization purposes. AVSWAT provides a user-friendly interface to easily pre-process the input data and post process the output data of SWAT.

Several findings and important conclusions can be drawn from this work:

1. Introducing the CRP has reduced soil erosion in Texas County.
2. Wheat growing areas is the largest source of sediment in Texas County. Wheat fields account for 75% of all sediment leaving the county although wheat covers only about 24% of the county area. Wheat land cover also accounts for about 71% of total phosphorus leaving the county and about 77% of total nitrogen leaving the topsoil. These large contributions of wheat to sediment yield, phosphorus and nitrogen are explained by management operations required to grow wheat.
3. The hotspots map of sediment yield will facilitate the decision making process by the Farm Service Agency. Based on such information CRP enrollment can be evaluated easier and simpler. The farm under consideration for CRP enrollment is located on the hot spots map, and it is determined whether or not

it falls within the desired category of soil loss. This map will also facilitate digital mapping of tracts enrolled in the program.

4. Analysis of changes in landscape structure indicates that CRP can potentially improve the quality and quantity of wildlife habitat.
5. There was negative association between wind erodibility index and area under CRP. Areas of high wind erodibility index were poor in CRP. The Farm Service Agency must focus on areas with high wind erodibility index for CRP enrollments.
6. Statistically, sediment yield is negatively and inversely related to area under CRP.
7. Coefficient of areal correspondence indicated a positive relationship between sediment yield and area under CRP.

The data collection and preparation process was the most time-consuming part of this project. ArcView GIS proved to be a valuable tool that it significantly reduced the amount of time for processing input data for the SWAT model. GIS and agricultural watershed models are important analysis tools in watershed management. Such tools can be used by management agencies to identify critical areas within a watershed and promote appropriate agricultural management practices in the targeted areas to control soil erosion and nutrient runoff.

## 4.2 RECOMMENDATIONS AND FUTURE WORK

1. Since the highest amount of sediment yield came from wheat fields, decision makers are encouraged to prioritize lands of wheat for CRP enrollment.
2. Since this study focused on one county in the State of Oklahoma, similar studies are recommended for other areas with high CRP enrollment.
3. More detailed data (land use and SSURGO) may improve the accuracy of simulation in the area of study.
4. Higher resolution of the watershed data (more subbasins) may improve the accuracy of simulation. However, there is a level beyond which the accuracy can't be improved, suggesting that more detailed simulation may not always lead to better results. Trade-offs exist between the number of subbasins in the watershed and the hardware and software limitations.
5. Confined animal feeding operations (CAFO) and other livestock operations are key agricultural sources of nonpoint source pollution, via nutrient losses from land-applied manure. Animal wastes form feedlots and hog farms is contained in shallow depressions called lagoons. The lagoons function as ephemeral lakes and can recharge shallow aquifers. Soil cracks formed in the depression floor during dry periods allow downward movement of surface water. The pollutants from these playas might contaminate the groundwater. The number of CAFO has increased drastically in Texas County within the last decade. And because livestock production has been implicated as a major source of pollution to streams and water bodies it is recommended to assess the effect of livestock production on water quality in Texas County.

6. Since soil loss in Texas County is primarily a result of wind erosion, it is recommended to evaluate the role of the CRP on reducing soil erosion due to wind.
7. The Farm Service Agency needs a decision support system (DSS) that is available to users and decision makers. This DSS will facilitate the evaluation of CRP and can assist in future CRP enrollments. The availability of this system on the web would make it accessible for both public and government agencies.
8. It is extremely important to have SWAT developed to a higher level so that outputs are mapped on a cell level.

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# APPENDIX

## I. Management operations for agricultural land uses used in SWAT 2000 model for Beaver River watershed.

| | Irrigated Wheat | |
|---|---|---|
| yr 1 | disk | march 15 |
| | disk (or moldboard) | March 30 |
| | Fertilizer 260 lb/acre N<br>= 290 kg/ha | march 30 |
| | Fertilizer 50 lb/acre P<br>= 56 kg/ha | march 30 |
| | Irrigation | April 30 |
| | Plant corn | May 1 |
| | Irrigation | May 15 |
| | Harvest corn | Sep 1 |
| | Disking | Oct 1 |
| | Fertilizer 75 lb/acre N<br>84 kg/ha | Oct 1 |
| | Fertilizer 30 lb/acre P<br>34 kg/ha | Oct.1 |
| | Plant wheat | Oct 15 |
| Yr 2 | Fertilizer 75 lb/acre N | March 1 |
| | Harvest wheat | June 1 |
| | Graze out 150 days | June 30 |

| | Dryland Wheat | |
|---|---|---|
| yr 1 | disc | July 15 |
| | moldboard | August 20 |
| | Fertilize<br>85 lb /acre N 95 kg/ha | August 20 |
| | Fertilize<br>40 lb/acre P 45 kg/ha | August 20 |
| | Plant wheat | Sep. 30 |
| Yr 2 | Fertilizer | March 30 |
| | 100 lb/acre N | 112 kg/ha |
| | Harvest wheat | Jun |

| | Irrigated corn | |
|---|---|---|
| yr 1 | Disk | March 1 |
| | Chisel | March 15 |
| | Fertilizer 260lb/acre N<br>290 kg/ha anhydrous ammonia | March 30 |
| | Fertilizer 50 lb/acre P<br>56 kg/ha Elem. p | March 30 |
| | Field cultivator | April 15 |
| | Pre-watering | May 15 |
| | Plant corn | June 1 |
| | Fertilizer 260lb/acre N | June 1 |
| | Auto irrigation | June 15 |
| | Harvest corn | Oct.1 |

| Irrigated sorghum | |
|---|---|
| Disk plow | March 1 |
| Chisel plow | March 15 |
| Fertilizer 110 lb/acre N<br>123 kg/ha | March 30 |
| Fertilizer 40 lb/acre P<br>45 kg/ha | March 30 |
| Plant sorghum | April 30 |
| Fertilizer 110 lb/acre N | June 15 |
| Auto irrigation | August 1 |
| Harvest sorghum | Oct.15 |

| Dryland Grain Sorghum | |
|---|---|
| Disk | May 1 |
| Disk | May 1 |
| Fertilizer 55 lb/acre N<br>62 kg/ha | May 15 |
| Fertilizer<br>20 lb/acre P<br>23 kg/ha | May 15 |
| Plant sorghum | June 7 |
| Harvest sorghum | Oct.7 |

| Pasture | |
|---|---|
| Plant | April 1 |
| Graze out 150 days | May 15 |
| Harvest/kill | Sep 1 |

| Range | |
|---|---|
| Plant | April 1 |
| Graze out 150 days | May 30 |
| Harvest/Kill | Sep 1 |

## II. Macro for calculating missing values in climate stations.

```
Sub Macro1()
'
' Macro1 Macro
' Macro recorded 3/18/2003 by Mahesh Rao
'
' Keyboard Shortcut: Ctrl+x
'
j = 1
a = 3
With ActiveSheet
For i = 3 To .UsedRange.Rows.Count Step 3

Rows(i & ":" & i + 2).Select
    Selection.Copy
    Sheets("Sheet2").Select
    With ActiveSheet
    .Cells(j, 2).Select
        Selection.PasteSpecial Paste:=xlAll, Operation:=xlNone, SkipBlanks:=False _
        , Transpose:=True
    l = j
    dy = 1
    For k = a To .UsedRange.Rows.Count

                Yr = .Cells(j + 1, 2).Value
                 If dy < 10 Then
                 .Cells(k, 1).Value = Yr & 0 & dy
                 ElseIf dy > 9 Then
                 .Cells(k, 1).Value = Yr & dy
                 End If

                 dy = dy + 1
    Next k

    j = .UsedRange.Rows.Count + 1
    a = j + 2
    End With
    Sheets("Sheet1").Select

Next i

Sheets("sheet2").Select
With ActiveSheet
For m = 3 To .UsedRange.Rows.Count
    If .Cells(m, 2).Value = "-99999" Or .Cells(m, 2).Value = ",-99999" Then
```

```
        Rows(m).Delete
        m = m - 1
    'ElseIf .Cells(m, 2).Value = "-99999" Or .Cells(m, 2).Value = ",-99999" Then
        'Rows(m).Delete
    ElseIf .Cells(m, 2).Value = "-99999" Or .Cells(m, 2).Value = ",-99999" Then
        Rows(m).Delete
    ElseIf .Cells(m, 1).Value = "" Then
        Rows(m).Delete
       ' m = m - 1
        'Rows(m).Delete
    End If
Next m

For n = 3 To .UsedRange.Rows.Count
    If .Cells(n, 1).Value = "" Then
        Rows(n).Delete
    End If
Next n


.Cells(1, 1).Select
End With




End With

End Sub

Public Sub rm()

With ActiveSheet
rcount = .UsedRange.Rows.Count
For i = 2 To rcount
      If .Cells(i, 2).Value = "-99999" Then
              respbefore = .Cells(i - 1, 2).Value + .Cells(i - 2, 2).Value
              k = 0
              'j = i
              Do While .Cells(i, 2).Value = "-99999" ' count the error rows
                      k = k + 1
                      i = i + 1
              Loop
            If k > 4 Then
                MsgBox ("Too Many -99999s at " & i - k)
            End If
```

```
            If k < 4 Then
                respafter = .Cells(i, 2).Value + .Cells(i + 1, 2).Value
                Average = (respbefore + respafter) / 4
                .Cells(i - k, 2).Value = Average
                i = i - k
            End If
        End If
Next i

For i = 2 To .UsedRange.Rows.Count
      If .Cells(i, 3).Value = "-99999" Then
              respbefore = .Cells(i - 1, 3).Value + .Cells(i - 2, 3).Value
              k = 0
              'j = i
              Do While .Cells(i, 3).Value = "-99999" ' count the error rows
                      k = k + 1
                      i = i + 1
              Loop

        'If (.Cells(i + 1, 2).Value <> "-99999") And (.Cells(i + 2, 2).Value <> "-99999")
Then
            respafter = .Cells(i, 3).Value + .Cells(i + 1, 3).Value
            Average = (respbefore + respafter) / 4
            .Cells(i - k, 3).Value = Average
            i = i - k

        End If
Next i
End With

End Sub
```

# VITA

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Candidate for the Degree of Doctor of Philosophy

Dissertation “GIS-Based Modeling to Evaluating the Conservation Reserve Program in Texas County, Oklahoma”

## PERSONAL INOFRMATION

Date and place of birth: 3 December, 1966, Irbid-Jordan

## EDUCATION

M.Sc. in Quaternary Paleoenvironments, Yarmouk University, 1998.
M.Sc. in Industrial Mineralogy, University of Leciseter, U.K, 1991.
B.Sc. in Earth and Environmental Sciences, Yarmouk University, 1989.
Completed the Requirements for the Degree of Doctor of Philosophy with a major in Environmental Science at Oklahoma State University in March 2004.

## RESEARCH INTERESTS

Geographic Information Systems, Soil Erosion Modeling, Remote Sensing, Industrial Mineralogy.

## EXPERIENCE

Research Assitant, March 2003-present, Geography Department, Oklahoma state University. Project “Toward an Integrated Web-GIS Decision Support System for Evaluating USDA’s Conservation Reserve Program”.
Full-time teaching and research assistant, April 1993 – September 1999, Dept. of Earth and Environmental Sciences, Yarmouk University, Jordan.
Part-time teaching and research assistant, Sep. 1989-June 1990, Feb. 1992-June 1992, Department of Earth and Environmental Sciences.

## AWARDS

Outstanding Graduate Student Research Award 2004, Oklahoma State University.
First place university competition, 14th Annual South Central Arc Users Group, Dallas.
The best informative poster, The 6th Annual Oklahoma Chapter of the South Central Arc Users Group (SCAUG) (SCAUG) Oct 9, 3003. Moore Norman Technology Center, Oklahoma, “Evaluation USDA's Conservation Reserve Program in Texas County, Oklahoma".
Yarmouk University Scholarship, 1999-2003.
ICSC-World Laboratory Grant, 1999-2000.
ICSC-World Laboratory Grant, 1990-1991.

## CERTIFICATES

Certificate in Geographic Information Systems, Oklahoma State University, May 2001.

Certificate in Laboratory Methods of Soil, Plant, and Environmental Analysis, Oklahoma State University, December 2000.

## ACTIVITIES

The 14th Annual South Central Arc Users Group, 7-8 April 2004, Irving Dallas.
Graduate College Symposium, Oklahoma State University, March 2004.
Southwest Association of American Geographers (SWAAG) Annual Meeting, Oklahoma State University Oct. 23-25, 2003. Poster “Evaluating USDA’s Conservation Reserve Program (CRP) in Texas County, Oklahoma
The 6th Annual Oklahoma Chapter of the South Central Arc Users Group (SCAUG) (SCAUG) Oct 9, 3003. Moore Norman Technology Center, Oklahoma.
Spatial Analysis Workshop June 13, 2003, University of Oklahoma, Norman. Poster "Toward an Integrated Web-GIS Decision Support System for Evaluating USDA’s Conservation Reserve Program".
The Sixth Jordanian Geological Conference “Earth resources are the basis of sustainable economic development”. Amman 5-8 October 1998.
The fifth Jordanian Geological Conference and Third Geological Conference on the Middle East (GEOCOM III). Amman 3-5 October 1994.
Symposium on Limestone Quarries. University of Leicester, UK, May 1991.

## MEMBRSHIPS

The Jordanian Geologists Association.
The Environmental Society of Jordan.